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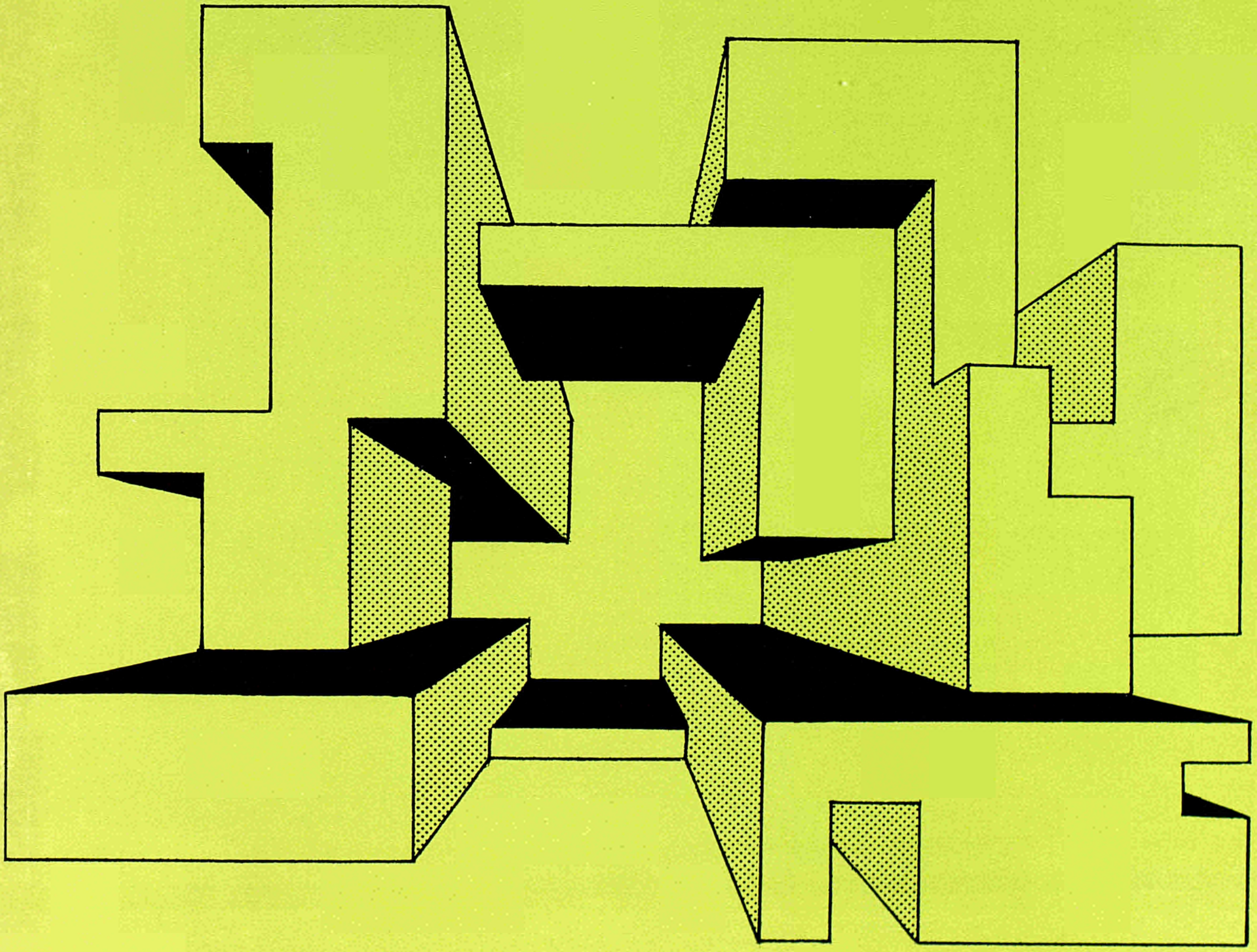

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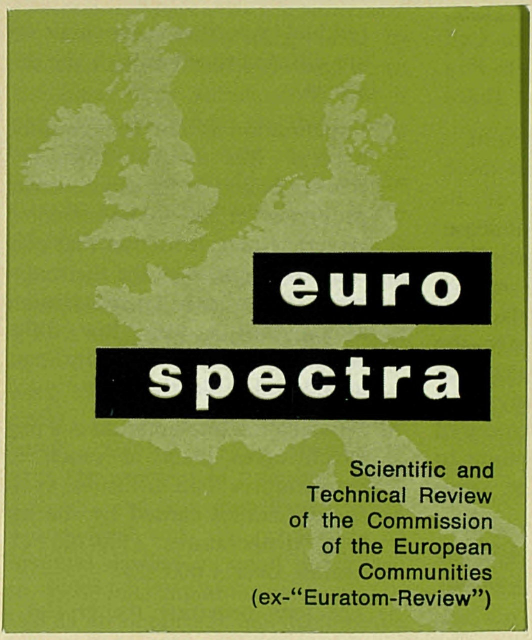

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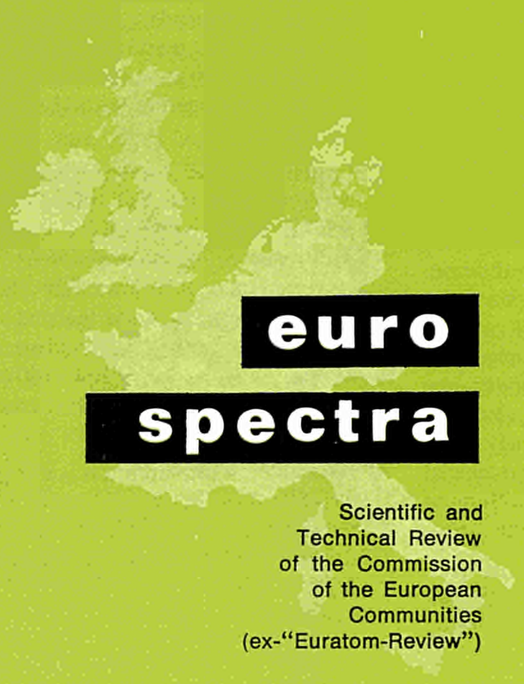

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On the vast construction site of the European Community, where ideally every one brings his own brick to contribute to the structure, work does not always proceed with the desired speed and organization. Difficulties and problems arise both with the architects who design and supervise the building work and with the labour force which harbours a persistent nucleus of anti-Europeans.

There has been no lack of noisy demonstrations of opinion from these people both recently and in the past. The typical anti-European, who has his own Euro-brick like everyone else, does not bring it to the common site to contribute to the construction but feels only the irresistible urge to hurl it at the heads of those he thinks are responsible for the project.

The irate anti-Europeans with itchy hands flourish equally in the newly-acceded countries of the Community and in those which helped create it. The former would have preferred not to have to work on the site, being staunch upholders of the old adage that foretells endless trouble for those who abandon the old ways for the new, whilst the latter identify the success, or even more simply, the raison d'être of the Europe of the nine either with the total abolition of customs formalities and frontier control or with the levelling of potato prices down to the last halfpenny in all the tiny outlying markets in Italy, Belgium, Denmark, Holland, and so on.

Like all large-scale and complicated undertakings, the Community of Europe has its convinced detractors who are often in the dark as regards what has been done, what is being done, what it is proposed to do and why, and who are stubbornly determined not to know. Obviously having to help carry the bricks on the site is not as easy or as pleasant as going to live in a soundly constructed building but it is equally true that without labourers no one has ever managed to build anything.

We should like to ask the typical anti-Europeans to devote to the construction of Europe just one tenth of the interest and attention which they lavish on their house plans for themselves and their children. This would undoubtedly help them to proceed to a profitable examination of their conscience.

Ion implantation in semiconductors

GIANCARLO BERTOLINI, FRANCESCO CAPPELLANI,
GIAMBATTISTA RESTELLI

ENERGIZED IONS can be used to change the properties of materials: this new technique is known as "ion implantation". The required atomic species ionized and accelerated in an electrostatic field is fired at the material which is to be treated. The ions penetrate the target and lose their energy in collisions with the atoms and electrons in the solid until the rest energy is reached (thermal energy). This, briefly, is the process.

In 1954 Shockley, who with Brattain and Bardeen shared the Nobel prize in 1956 for invention of the transistor, patented the use of an accelerated ion beam as a means - in conjunction with traditional processes - of producing electronic devices, outlining the potential advantages of a technology which was only effectively developed at the industrial level at the end of the sixties. As is known, the manufacture of solid state electronic devices involves the introduction of a specified quantity of electrically active impurities into a semiconductor (e.g., silicon). The semiconductors undergo a change in their original electrical properties which depends on the type of impurity. This is what is meant by the term "doping", which is the key process for all solid state electronics.

With this system, combined with the creation of insulating layers and various types of connections, it is possible to produce devices ranging from simple diodes to complex integrated circuits which incorporate many thousands of devices.

The two basic characteristics of the "doping" process are, firstly, that transformation by the introduction of impurities takes place on the surface of the semiconductors and extends to only a very small depth below the surface (of the order of μm or less); secondly, the alteration of the original electrical properties is useful when extremely small amounts of impurities are introduced (from one atom per hundred million to one per hundred atoms of the semiconductor).

In the present state of the art, the methods which can be used for "doping" are, in order of importance:

- thermal diffusion;
- introduction during the growth of the crystal or the formation of an epitaxial layer;
- alloying with a metal.

The first method is by far the most used and it is mainly as an alternative to this method that ion implantation has been introduced, even in industrial production. It may seem rather extraordinary that such a recent technique should be able to replace thermal diffusion, which is braked by a vast amount of development work and technological research.

In fact ion implantation is not a complete alternative but is only a substitute technique used in the production of some devices or in certain phases of the manufacturing process.

The advantages of ion implantation compared with thermal diffusion can be itemized as follows:

1) The quantity of impurities introduced, the depth of penetration and therefore the concentration in the crystal are parameters which can be controlled precisely and independently through the intensity of the ion beam and the energy of the ions. By contrast, in diffusion it is possible to act on the diffusion time and the temperature, but not independently.
2) The purity of the material which is introduced does not depend on the original material and is very closely controllable. In thermal diffusion everything depends on the degree of purity of the materials used: e.g., residual impurities in the single crystal are diffused together with the doping atoms.
3) Implantation is not an "equilibrium process" like thermal diffusion and it is not bound by the physicochemical properties of the solute/solvent (ion/target) system. It follows that concentrations in excess of the thermal solubility limits can be obtained and atoms with a very low diffusion velocity or zero solubility can be introduced in depth.
4) Basically ion implantation is a process which takes place at much lower temperatures than diffusion, avoiding the difficulties caused by the use of high temperatures (500-700 °C as against over 1 000 °C).
5) The ions penetrate the crystal as a directional beam; in this way the doped region is defined with remarkable precision, contrary to what happens in diffusion where the isotropy of the process causes leakage at the edges of the mask which delimits the doping zone (Fig. 1).

On the other hand, the main disadvantage of ion implantation must be attributed to the slowing down of the ions during their penetration into the semiconductor. The single crystal originally has an ordered periodic structure which determines its electrical properties. The energized ion penetrating this collides with the atoms of the solid, which may receive enough energy to be displaced from their lattice position so that the bonds are broken and as a result the characteristic regularity of the structure is lost. In extreme cases, if a sufficiently large number of atoms are displaced, the solid changes from crystalline to amorphous. Fortunately this disadvantage can be largely remedied by carefully heating the bombarded sample; this annealing restores the crystal structure and makes it possible to retain the typical electrical properties of the chemical species of the introduced ions. This is still one of the main problems, however, as it may raise difficulties with some materials.

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The theoretical studies on the influence of ion bombardment in solids go back to the fifties. The first experimental studies followed about ten years later. Originally it was thought that the physical properties of materials subjected to ion bombardment were substantially determined by the damage caused by the slowing down of the ions. Only subsequently did it become clear that under suitable experimental conditions it was possible to obtain a predominant effect due to the physicochemical properties of the introduced ions.

The first device obtained by ion implantation was a p-n junction in silicon used as a nuclear particle detector and made in 1962 by Alväger and Hansen. Between 1962 and 1964 the studies were generally of a fundamental nature. Research, slanted more specifically towards the problem of "doping" semiconductors, gradually intensified between 1964 and 1969 with the production of commercial devices in small quantities. From 1970 ion implantation began to emerge as an important new technology of especial interest in the microelectronics field. In 1972 it became obvious from technical papers published or presented at conferences and from industrial production that this technology had acquired its own niche in the semiconductor devices industry.

The potential advantages of industrial-scale ion implantation had originally attracted the interest of firms producing ion accelerators. This resulted, between 1968 and 1970, in the development of commercial accelerators for implantation and subsequently in complete ion implantation systems for industrial use.

The physical process

When the ion penetrates the interior of the solid it loses energy through two main processes:

(*a*) collisions with the free or bound electrons in the solid;

(*b*) elastic collisions with the atoms which form the lattice.

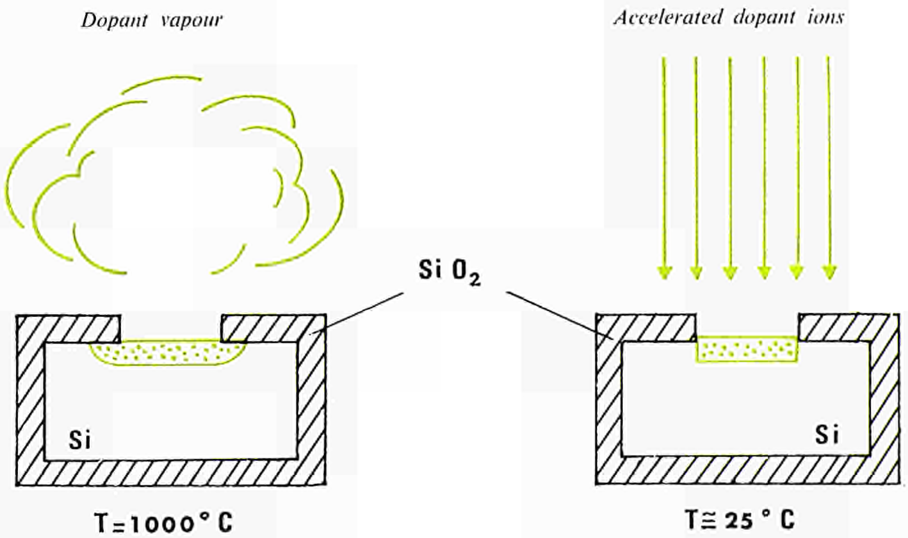
In (*a*), because of the tremendous difference between the masses, the ion loses a small part of its energy at each collision with virtually no change in its original trajectory. This process, termed "electronic stopping", is characterized by a low "specific energy loss" (i.e., per unit of length travelled by the ion in the solid).

In (*b*), the collision of the ion with an atom in the lattice may, depending on its severity, draw off a considerable amount of energy and sharply deflect the trajectory from its original direction. The process is called "nuclear stopping" and is characterized by a specific energy loss which is much greater than that occurring in electronic stopping. The atom, in the collision, can be displaced from its equilibrium position in the lattice and in turn causes chain collisions with the other atoms. This mechanism is responsible for the ion bombardment damage, with the formation of highly disordered regions around the path of the ion through the solid. It should be noted here that in crystalline structures the defects generated in this manner produce a marked change in the properties (optical, electrical, mechanical, etc.) of the solid. Ultimately the original energy of the ion is exhausted by nuclear and electronic stopping. The fraction of energy lost in one or other of the processes depends on the initial energy and on the atomic numbers of the projectile and the stopping medium.

Electronic stopping increases linearly with the velocity of the projectile, whilst nuclear stopping has a bell-shaped curve with a maximum at low velocity values of the ion. It follows that the two curves intersect at an energy value which depends on the atomic numbers of the projectile and the medium (Fig. 2).

Two parameters are used to characterize the ion penetration process: the "range" and the "penetration distribution". When the ion has reduced its initial energy to a value of about 10 eV, it stops moving freely in the crystal and is captured by the cohesive forces of the medium. The route followed from the impact on the surface of the solid to this point is defined as the "range" which we will call R; Rp will be the "projected range" which corresponds to the projection of R along the extension of the direction of incidence of the ion (Fig. 3).

The projected range Rp expresses the effective depth of penetration of the ion inside the medium and is therefore more commonly used for practical purposes. The penetration distribution is determined by the fact that, since the slowing follows a random pattern, the ranges of the ions will not all be equal but will be distributed over a certain curve around a most probable value. If we plot the individual R or Rp versus their probability, given a large number of ions all having the same energy, their distribution approximates pretty closely to a Gaussian curve characterized by an average value



Thermal diffusion

Ion implantation

Fig. 1: *Owing to the directional precision of the ion beam, in implantation the doped area is exactly defined by the mask* (*SiO₂*).

In thermal diffusion the isotropy of the process causes the dopant to diffuse under the edges of the mask.

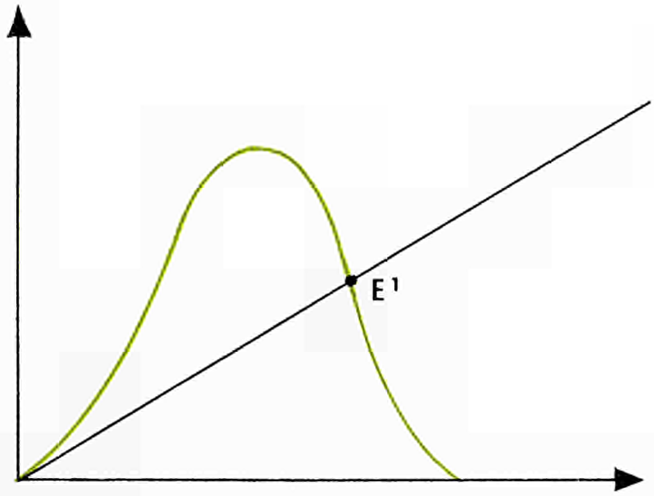


Fig. 2: *E^1 represents the energy at which the initial energy of the ion is equally distributed between the two processes (nuclear stopping in colour; electronic stopping in black). Some values of E^1 in the case of silicon and germanium and for some types of ion are in keV:*

	boron	*phosphorus*	*arsenic*	*antimony*
Si	*17*	*140*	*800*	*2 000*
Ge	*13*	*140*	*800*	*2 000*

Obviously ions with a mass equal to or greater than phosphorus and implantation energies of the order of 100 keV lose their energy almost entirely in nuclear collisions. (Abscissa: energy of the incident ion; ordinate: loss of energy per unit of path).

Table I: *Ions impinging on silicon with an energy of 100 keV; values in Ångström units (1 Ångström = 10^{-8} cm).*

Ion	Atomic number	Rp calculated	Rp observed	ΔRp calculated	ΔRp observed
Boron	5	3 275	3 700	726	508
Phosphorus	15	1 228	1 200	350	380
Gallium	31	602	610	133	195
Arsenic	33	574	580	122	178
Antimony	51	448	450	71	123

The ion penetration decreases as the atomic number increases. The correlation between the values of the average "projected ranges" $\overline{\text{Rp}}$ calculated on the basis of the Lindhard theory and the values observed in experiment is good; some discrepancies occur for the variance ΔRp.

Values of the average "projected range" calculated in Ångströms for ions of different energies impinging on silicon

	40 keV	80 keV	120 keV	200 keV	500 keV
Boron	1 413	2 695	3 802	5 588	13 000
Phosphorus	488	976	1 483	2 514	6 000
Arsenic	263	471	677	1 097	2 800
Antimony	221	376	519	797	1 800

The penetration of the ions increases with the increase in energy.

$\overline{\mathrm{Rp}}$ and a variance which we shall show as ΔRp (Fig. 4).

Implantation makes it possible, in principle, to create any type of profile because one can continually vary the energy, whereas thermal diffusion is always characterized by a monotonic pattern of concentration versus depth. The two parameters $\overline{\mathrm{Rp}}$ and ΔRp are sufficient to characterize fairly approximately the penetration of any ion into any substrate.

A detailed theory of the phenomenon was originally drawn up by a group of Danish theorists headed by Prof. J. Lindhard; subsequent theories follow the lines of the original work done by these scientists.

A vast collection of experimental data was only later obtained with the development of extremely refined techniques for the removal of thin layers of a specified thickness (of the order of 1/100 000 mm) from the implanted sample, together with the use of radioactive tracers. There is a good correlation between the calculated and experimental values of $\overline{\mathrm{Rp}}$ but there are still some discrepancies between the calculated and experimental values of ΔRp (Table I).

Until 1963 the phenomena of ion penetration in a solid were thought to be independent of its allotropic form (amorphous or crystalline), even though as early as 1912 J. Stark had foreseen an

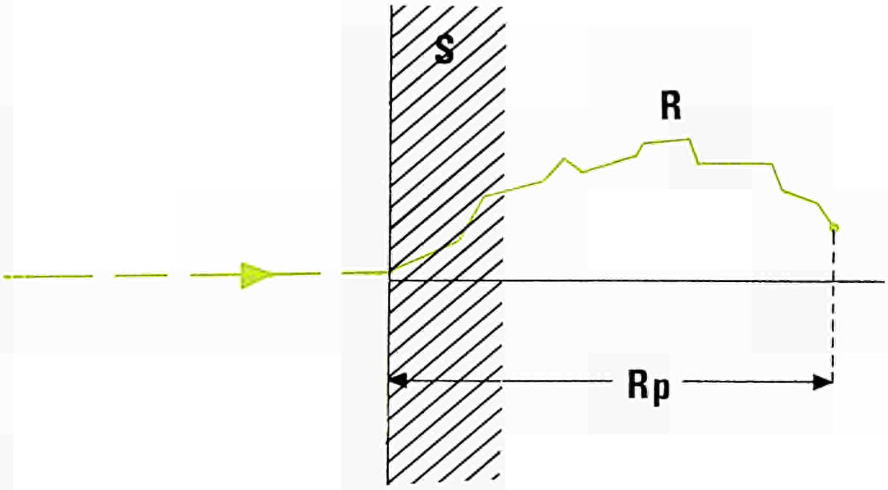


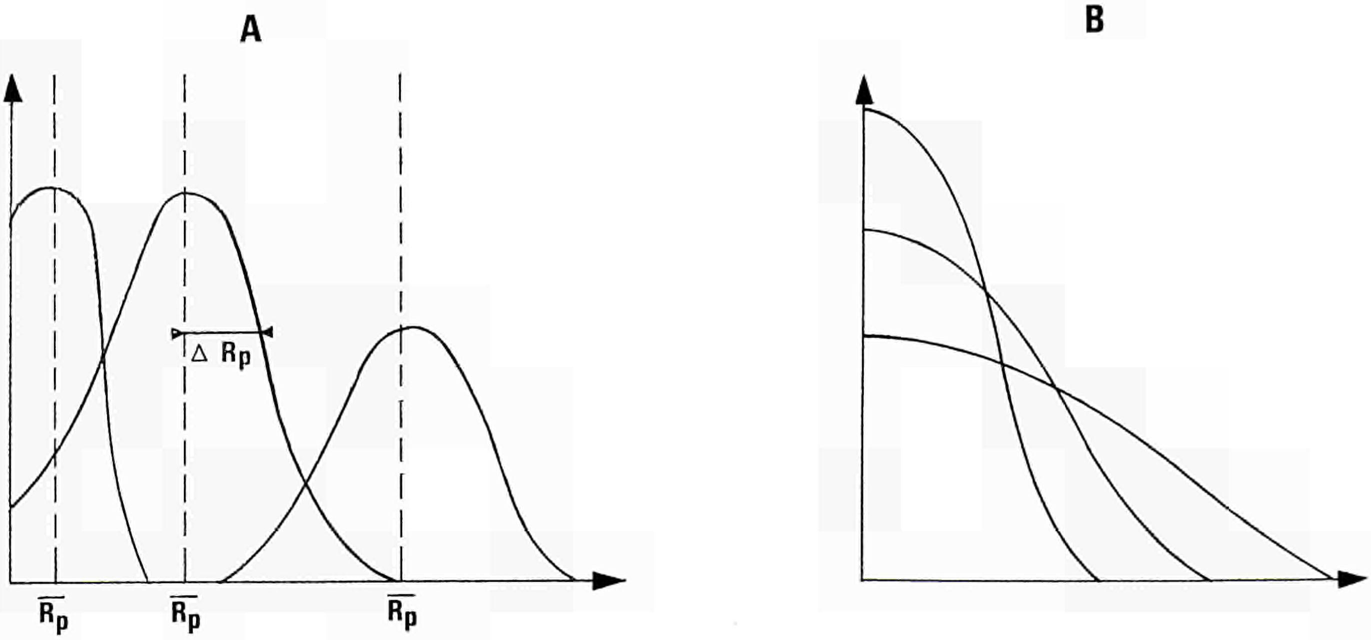
Fig. 3: *The path from the point of impact on the surface of the solid (S) to the point where the ions stop (continuous coloured line) is the "range" R; its projection along the extension of the direction of incidence is the "projected range" Rp. The coloured dotted line shows the trajectory of the incident ion.*

Fig. 4: *Figure A shows some typical penetration curves for ions of various mass and energy (abscissa: depth of penetration Rp; ordinate: number of ions with range Rp).*

Figure B shows atom penetration curves obtained through thermal diffusion with various temperatures or times (abscissa: depth of penetration; ordinate: number of atoms per cm^3*).*

The implanted ions are distributed according to a penetration curve which is roughly Gaussian.

The curves also represent the concentration of the ions as a function of the depth and can be compared with typical thermal diffusion profiles which always show a monotonically decreasing concentration depth. The variance ΔRp is obtained from the halfwidth of the curve at $\frac{1}{\sqrt{e}}$ *of the maximum concentration.*



effect of the interatomic fields on the motion of charged particles in solids.

It was in 1963 that computer simulation of the phenomena enabled two American scientists, Oen and Robinson, to show that the ion penetration process was substantially different in crystalline solids, for these permitted a new phenomenon termed "channelling". Experimental confirmation was obtained almost at the same time by a group of scientists at Chalk River with implantation in single-crystal aluminium and tungsten. Channelling in single-crystal germanium had been observed, but not identified, years before by two Russian scientists.

The explanation of channelling is based on two considerations, the first of which is the degree of anisotropy of the crystalline solids. If we observe a crystalline lattice from different crystallographic directions it can be seen that some directions are more open than others, forming a system of free channels for the passage of the ions (Fig. 5). This is especially true of lattices in which the atom has a higher coordination index and which are therefore more densely populated, for example, the diamond and zinc blende type lattices, into which the most important semiconductor materials crystallize.

The second consideration is that the repulsion potential (coulomb) which exists between the ion and the lattice atoms keeps the ion at some distance from the atoms when the energy component perpendicular to the direction of motion of the projectile, and therefore to the row of atoms forming the channel, is less than the repulsion potential supplied by the row itself (Fig. 6). This occurs at suitable values of lattice spacing and ion direction and velocity. In such cases the ion encounters no break, in the repulsion potential between the atoms in the row, and the channel will look like an open tube inside which the ion will be contained through successive correlated interactions at small angles. There will therefore be minimal loss of energy through nuclear interaction and the electronic type of slowing down will predominate. The range taken by the ion will therefore be considerably longer (up to two orders of magnitude greater) than those observed in the same solid where there is no channelling (Table II).

The fact that the transversal energy component is less than the repulsion potential obviously keeps the angle of incidence of the ion low in relation to the axis of the channel. This angle, called the critical angle, is in inverse proportion to the energy of the ion and directly proportional to the product of the atomic numbers of the ion and of the atoms of the crystal (Table III).

By changing the direction of the ion beam one can, roughly speaking, make the crystal behave like an amorphous solid as regards the ion-stopping effects. This occurs, in the case of crystals with a diamond-type lattice, when the beam is set 8° out of line with one of the main crystallographic axes.

Alterations of the crystal order, for example, interstitial atoms which obstruct the channels, reduce the magnitude of the phenomenon ("dechannelling"). The surface of the crystal causes dechannelling either because inevitably some of the incident ions impinge directly on the atoms of the lattice or because the surface itself easily accommodates dishomogeneities and impurities. These initial collisions give rise, moreover, to structural defects which in their turn generate dechannelling of the ions. The probability of dechannelling increases with the integrated dose (number of ions which have struck the crystal).

The distribution of the ions which penetrate a single crystal under channelling conditions differs substantially from that obtained in an amorphous solid or disoriented crystal.

The atoms which remain channelled until they have completely lost their energy correspond to the maximum penetration of the crystal and, depending on the extent of the dechannelling processes, may or may not form a peak. The parameter used to characterize the channelling peak is the maximum range R_{max} (Fig. 7). The dependency of R_{max} on the square root of the energy confirms that for a well-channelled ion the predominant mechanism consists in collisions with the electrons of the solid. Considerable difficulties are encountered, however, when we try to find the value of R_{max} with variation of the atomic number of the projectile and of the different

Table II: *Depth of penetration of the ions in the solid. Slower channelled ions (such as* Sb^+*, compared with* As^+*) have a lower specific energy loss and penetrate deeper into the crystal.*

Ion	Energy keV	$\overline{Rp}$ μm	Rmax μm	Direction of channelling
Boron	60	0.21	0.92	(110)
Arsenic	200	0.11	2.8	(110)
Antimony	200	0.08	4.3	(110)

Table III: *Critical angle in silicon calculated on the basis of the Lindhard theory for different crystallographic directions. The maximum angle of entry, in relation to the channel axis, at which the incident ion is still channelled increases with the atomic number and the decrease in ion energy. Some crystallographic directions are more "open" than others, which means that the incident ions channel with greater or less ease.*

Ion	Energy (keV)	⟨ 110 ⟩	⟨ 111 ⟩	⟨ 100 ⟩
Boron	50	3.7°	3.2°	2.9°
	100	2.6°	2.3°	2.0°
	500	1.2°	1.0°	0.9°
Arsenic	50	5.2°	4.4°	4.0°
	100	3.7°	3.1°	2.8°
	500	1.6°	1.4°	1.3°

crystallographic directions in a particular solid. Up to now no method has been devised to calculate R_{max} with reasonable accuracy, but the problem is being actively studied.

From what has been said so far, the reader can see which parameters influence the distribution of ion penetration plotted against the depth within the solid (concentration profile or "physical profile").

A particular physical profile can be made by acting on the following variables:

- energy of the implanted ion;
- atomic number of the ion;
- direction of incidence of the beam on the crystal;
- temperature of the sample, and dose which in addition makes it possible to regulate the absolute value of the concentration of the introduced ions.

In such applications as the manufacture of electronic devices, however, it is important to know the distribution versus depth of concentration of the electrically active atoms: this is known as the "electrical profile". This does not necessarily correspond to the "physical profile", since the introduced ions may be associated in complexes with the structural defects (which also have electrical activity) caused by the implantation, or may not find themselves in a suitable lattice position (Fig. 8).

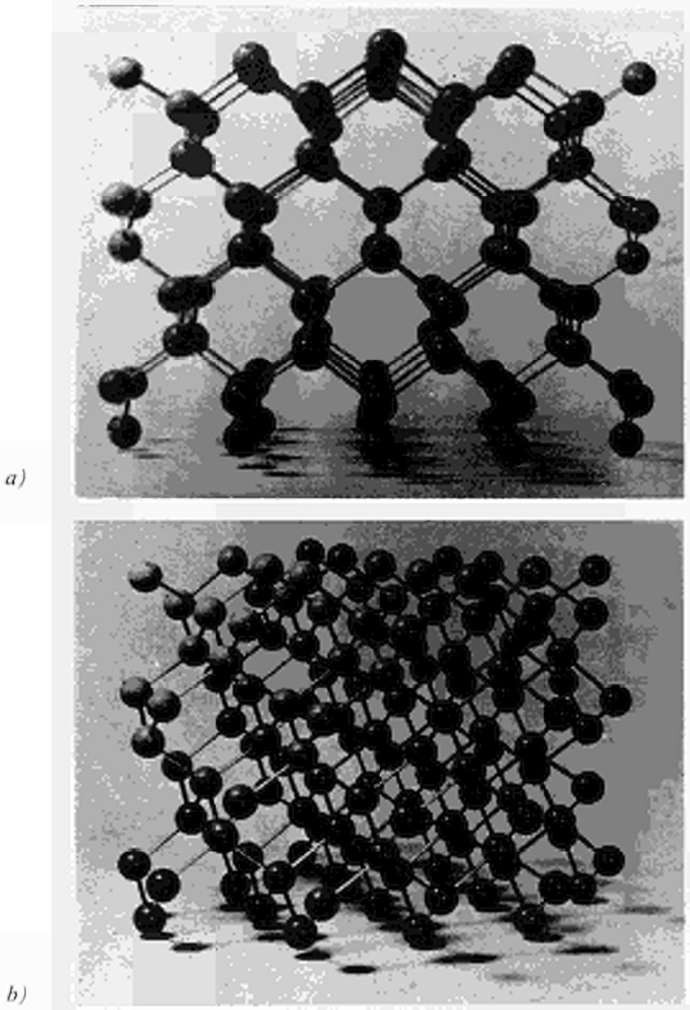


Fig. 5: *A diamond type lattice (typical of such semiconductors as silicon, germanium, gallium arsenide) displays obvious channels when it is oriented in a main crystallographic direction. In a) direction* $\langle 111 \rangle$*; in b), the direction rotated by an angle of 7° to the* $\langle 111 \rangle$ *axis.*

It is known that the introduction of atoms which have an outer electron shell, and therefore a valence, differing from that of the atoms constituting a semiconductor induces well-defined electrical properties in the semiconductor. Thus in the lattice of a silicon or germanium single-crystal (group IV in the periodic table) the presence of atoms of group III, which tend to capture an electron, gives rise to predominant conductivity for the transfer of holes (type p) and conversely the presence of elements of group V, which tend to lose an electron, gives rise to predominant conductivity for the transfer of electrons (type n). These impurities are usually termed "dopants"; common n-type dopants (or donors) are P, As, Sb; p-type dopants (or acceptors) are B, In, Ga. In order to produce the desired effect the dopant atoms must form a solid solution in the semiconductor, occupying well-defined lattice positions (mostly substitutional positions, i.e., sites normally occupied by an atom of the semiconductor) in a crystal with almost no structural defects. The presence of impurities in other forms, e.g., in the form of precipitations, strongly affects the electronic processes in the semiconductor but not in the way desired. The traditional "doping" methods are based on processes which take place while heterogeneous equilibria are being established at the interface. Thus in thermal diffusion, at the high temperatures used for the process, the introduced ions are able to reach the lattice position which is thermodynamically correct and has the appropriate electrical activity for them. This does not occur in the case of ion implantation for two reasons. First, at the moment when the introduced ion reaches thermal energy it may be in any lattice position. Secondly, the structural defects resulting from bombardment, besides being themselves electrically active, act in combination with the introduced ions or with the impurities present in the semiconductor, modifying the effect due to the chemical species of the implanted ions.

The structural defects are moreover extremely critical by reason of the modifications they produce in the salient characteristics of the semiconductor such as mobility, average carrier lifetimes, etc., which contribute vitally to the performance of the devices.

Every incident ion is, directly and through a series of chain collisions between the atoms of the lattice, responsible for knocking a large number of

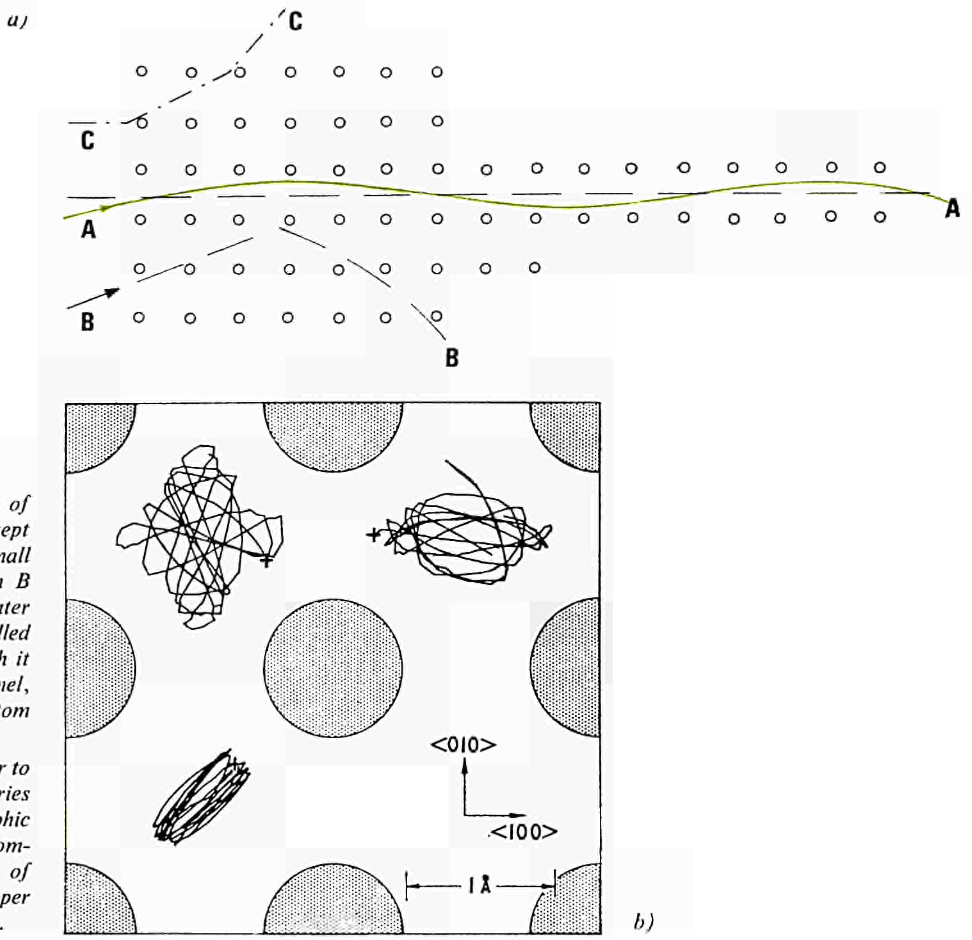


Fig. 6: *a) Ion A penetrating at an angle of incidence smaller than the critical angle is kept on course by a series of successive small angle interactions within the channel. Ion B penetrating at an angle of incidence greater than the critical angle is rapidly dechannelled through nuclear collisions. Ion C, although it impinges in a direction parallel to the channel, is not channelled as it directly strikes an atom on the surface.*

b) The projection, on a plane perpendicular to the direction of incidence, of the trajectories of ions directed parallel to a crystallographic axis clearly illustrates the channelling phenomenon. The figure refers to the results of calculations by Robinson and Oen for copper ions impinging on single-crystal copper.

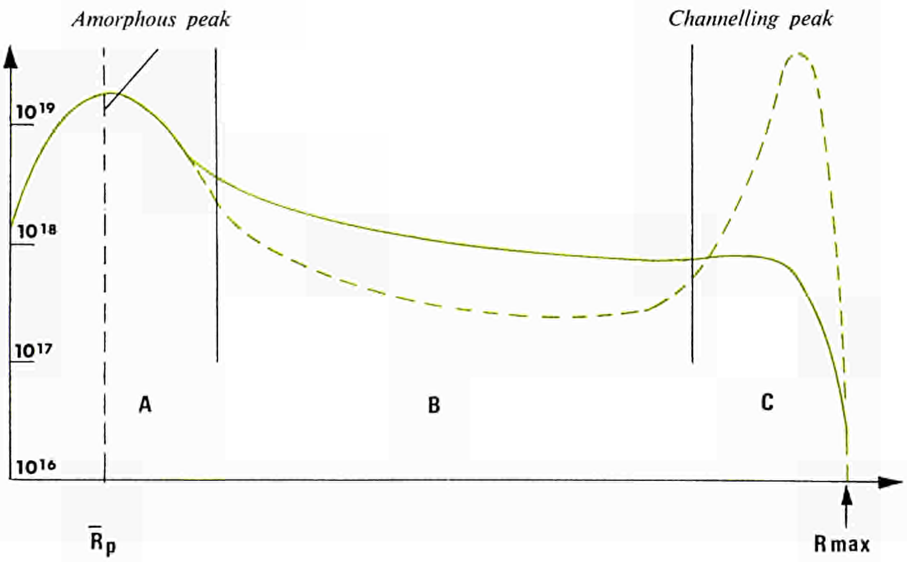


Fig. 7: *The penetration curve of channelled ions in a crystal has three zones. The first (A) shows the atoms immediately dechannelled at the surface and corresponds to the curve of distribution in amorphous material. The second (B) corresponds to the ions dechannelled along the path. The third (C) represents the ions which remain channelled until they have lost all their own energy.*

The dotted curve represents an almost ideal case; the continuous curve represents a typical real case, for example of single-crystal silicon.

Abscissa: depth of penetration; ordinate: ions per cm^3.

atoms of the bombarded material out of their lattice position, thus forming vacancies and interstitials (Fig. 9).

The minimum energy required to form a Frenkel defect, that is a vacancy-interstitial pair, varies from one type of crystal to another but is of the order of 10-20 eV. Consequently, an ion with an initial energy of a few tens of keV generates some thousands of defects of this type, for example, a 40 keV Sb^+ ion displaces on average some 2 000 silicon atoms. The number of atoms displaced varies with the energy of the particle, with the nuclear collision cross-section and above all with the degree of channelling of the ion beam in the crystal. The damage increases with the dose until the originally crystalline substrate becomes amourphous. Where the amorphous state extends to the surface and modifies the optical reflectivity of the material (Fig. 10) this change actually becomes visible.

The number and spatial distribution of the atoms displaced from the ions have been extensively studied both theoretically and experimentally. The experimental studies have used various techniques ranging from the study of the optical properties to the diffraction of low energy electrons, from electron microscopy to X-ray diffraction and to recent techniques based on the channelling of H^+ or He^+ particles with energies of 1-2 MeV.

According to the theoretical calculations, the defects will be non-uniformly distributed along the path of the ion. The curve which expresses their distribution versus depth in the crystal is analogous to the ion concentration profile but lies appreciably nearer to the surface.

Ideally, in order to use the electrical properties of the implanted layer the atoms would be implanted in the correct lattice positions in an almost defect-free crystal. This condition can be more or less completely achieved through an annealing process in which the sample is heated in a vacuum furnace or in an inert atmosphere at a given temperature for a given time (typically, for semiconductors 300-900 °C for 10-60 minutes).

The characteristic annealing temperatures vary considerably depending on the degree of disorder. For low doses where the damaged zones around the

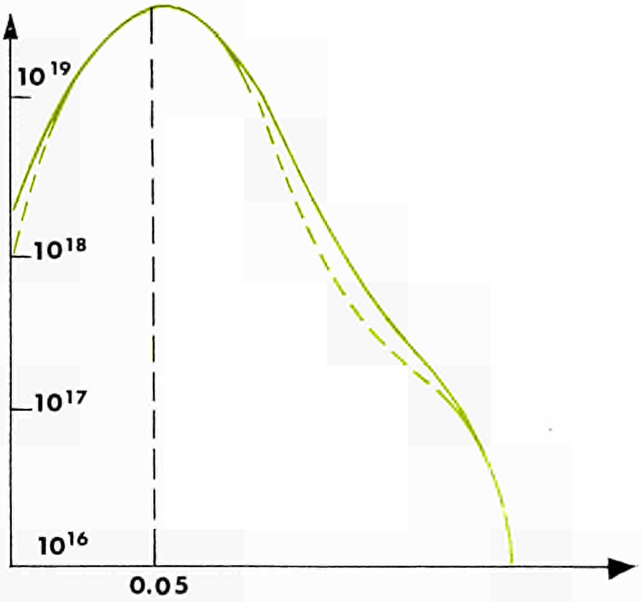


Fig. 8: *Physical and electrical penetration profile of 80 keV arsenic ions in silicon. The physical profile was obtained by tracing the As by radioactivation:* $As^{75}(n, \gamma)As^{76}$*. The radioactive tracer was then assayed in the silicon layers (140 Ångström per volt), and removed through anodic oxidation and selective dissolution using an automatic apparatus. The electrical profiles were obtained by measurement of resistivity and differential surface Hall effect and sectioning by anodic oxidation. The continuous line shows As atoms per cm³, the dotted line the number of electrons per cm³. The depth of penetration (in μm) is plotted on the abscissa.*

Table IV: *Possible reactions which determine the lattice position of an ion X implanted in silicon. At the end of the implantation the ion X is in a particular position surrounded by substitutional silicon atoms* Si_S*, interstitial silicon atoms* Si_I*, vacancies V, general defects D.*

Substitutional reactions	
1. The ion (free or interstitial) reacts with a vacancy becoming substitutional	X or $X_I + V \rightarrow X_S$
2. The ion becomes substitutional during the reordering of the lattice disorder	
3. The ion becomes substitutional through collision during the final stage of the range	$X + Si_S \rightarrow X_S + Si_I$
Interstitial reactions	
4. The ion migrates into an interstitial position	$X_S \rightarrow X_I + V$
5. The ion becomes interstitial during the reordering of the lattice disorder	
6. Watkins displacement reaction	$X_S + Si_I \rightarrow X_I + Si_S$
Other reactions	
7. The ion moves into an irregular lattice position (precipitates from the solid solution)	X_S or $X_I \rightarrow X$
8. The ions interact with one another to form pairs	$X_S + X_I \rightarrow X_S X_I$
9. The ion interacts with defects to form complexes (ion-vacancy pairs)	$X_S + D \rightarrow X_S D$ $X_I + D \rightarrow X_I D$

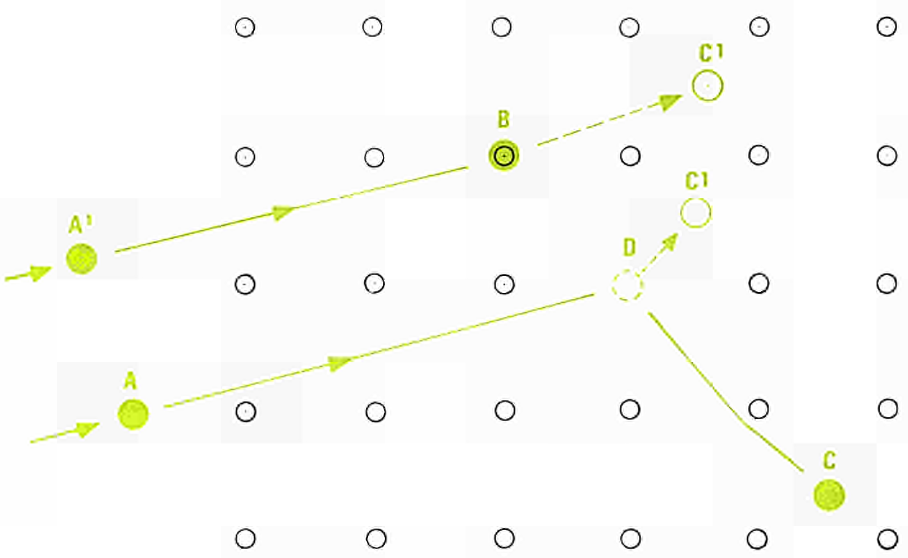


Fig. 9: *During its journey through the crystal lattice the incident ion may collide with a lattice ion and displace it into an interstitial position, thus creating a vacancy; in this way a Frenkel defect or pair (vacancy + interstitial) is formed. At the end of its trajectory, the incident ion may either be in an interstitial position (case A) or in a substitional position, having projected a lattice atom into an interstitial position (case B).*

A, A¹ = incident ions;
B = ion in substitutional position;
C, C¹ = ions in interstitial position;
D = vacancy;
D-C¹ = Frenkel defect.

various ion paths are not superimposed, the reordering takes place at relatively low temperatures: in germanium and silicon at about 200° and 300 °C respectively. For doses sufficient to cause the formation of an amorphous layer higher temperatures are needed — in the above case about 400° and 600 °C respectively.

The reconstitution of the single-crystal phase is most probably due to a process of epitaxial reordering starting from the crystal under the amorphous zone.

The transition of the material from the amorphous to the crystalline state may be not enough to dispel the more complex defects caused by the evolution of primary defects (vacancies-interstitials) which associate to form dislocations, dislocation loops, etc. In view of the disproportion between the number of defects and the number of ions introduced, it is obvious that even a small residual fraction (e.g., 0.1 %) can decisively alter the electrical properties of the implanted layer. Hence it is sometimes necessary to use annealing temperatures higher than those required to reorder the lattice.

During the annealing, the implanted ions move into well-defined lattice

Fig. 10: *Photograph of a silicon single crystal implanted at higher doses than the amorphization dose. Note different surface reflectivity. The doses (ions/cm²) required to render single-crystal silicon amorphous with various ions of 40 keV energy are: boron $2 \cdot 10^{16}$; phosphorus $5 \cdot 10^{14}$; arsenic $2 \cdot 10^{14}$; bismuth $5 \cdot 10^{13}$.*

positions through complex interactions with the crystalline solid.

The group V donor elements tend (as to about 90 % of the total number) to occupy substitutional positions, whilst the group III acceptors have an appreciable substitution fraction (30 %); the remainder are partly in interstitial positions (30 %) and partly in irregular lattice positions. It seems to be proved, however, that the final position of the implanted atom is determined by the treatments applied after the ion has been slowed down by thermal energy, and not by the events which take place during its slowing-down in the crystal.

On the basis of experimental data a generalized model has been formulated which examines various types of reaction which can take place between the introduced atoms, lattice atoms and defects, and which finally determine the lattice position (Table IV). As a general rule it has been observed that a higher electrically active fraction is obtained when the degree of damage to the implanted zone is such as to make the crystal amorphous. In the reordering of the lattice there is the strong possibility of a substitution reaction between a doping atom and a vacancy. For example, in implanting ions which produce a low degree of damage, e.g., boron, it has been found useful to make the silicon amorphous before annealing, by bombarding it with ions which do not confer electrical activity on the semiconductor. After implantation and annealing only 10 % of the introduced boron atoms are electrically active; the value leaps to 80 % after rendering amorphous with argon or neon ions.

Particularly in implantations with an intermediate degree of damage, contained in structures of the dislocation type, on annealing, these structures can trap the implanted ions and prevent them from reaching substitutional positions. It is therefore understandable that the electrically active fraction, produced by implantation in semiconductors heated to 250-300 °C in which there is a continuous partial repair of the damage, is decidedly lower than that obtained with low-temperature implantation and heavy damage followed by annealing at about 600 °C.

In the foregoing examples reference has always been made to implantation in silicon, since this material has been by far the most closely studied, but similar phenomena have been observed elsewhere, for example, in germanium.

A discussion of the atomic position is difficult in this context, since it would inevitably turn into a list of cases itemized according to the nature (type of ion) and the conditions (dose, temperature during implantation, annealing temperature) of the implantation. Some patterns have been brought to light, as we have already indicated, but there is still no general theory of the phenomenon.

To conclude, there is still the problem of whether completely channelled ions have a preferential lattice position by comparison with non-channelled ions. The question is still open since the relevant data are extremely sparse.

Ion accelerators

The first studies on ion implantation were carried out with the then existing isotope separators. This limited the range of available energies, because on average these instruments accelerated the ions to an energy of the order of 40 keV.

Later, increasing interest in implantation led to the planning and development of special accelerators.

The energy imparted to the ions usually ranges from 40 to 400 keV. The values most generally used are around 100 keV (Fig. 11); high-energy (MeV) accelerators are rarely used.

The ion currents on the target vary between tenths and tens of microamperes, i.e., from $6 \cdot 10^{11}$ to $6 \cdot 10^{13}$ ions a second.

A typical ion implantation accelerator is composed of an envelope under high vacuum in which we may distinguish the following components:

(a) *ion source:* consists of a chamber into which the substance is introduced in the gaseous state and ionized by various processes. The ions thus formed are extracted from the chamber using a suitable electric field, which, in the simpler types, determines the final energy of the ion.

(b) *analysis system:* the ion beam which leaves the chamber generally contains a certain number of ions from which the desired species will be selected. This is done by means of a magnetic field or an electric field combined with a magnetic field (Fig. 12). In the first case, when a certain path has been defined by means of slits, for a given ion energy and for a given magnetic field, only the ion species with a specific charge/mass ratio will follow the trajectory that passes through the slits. In the second case,

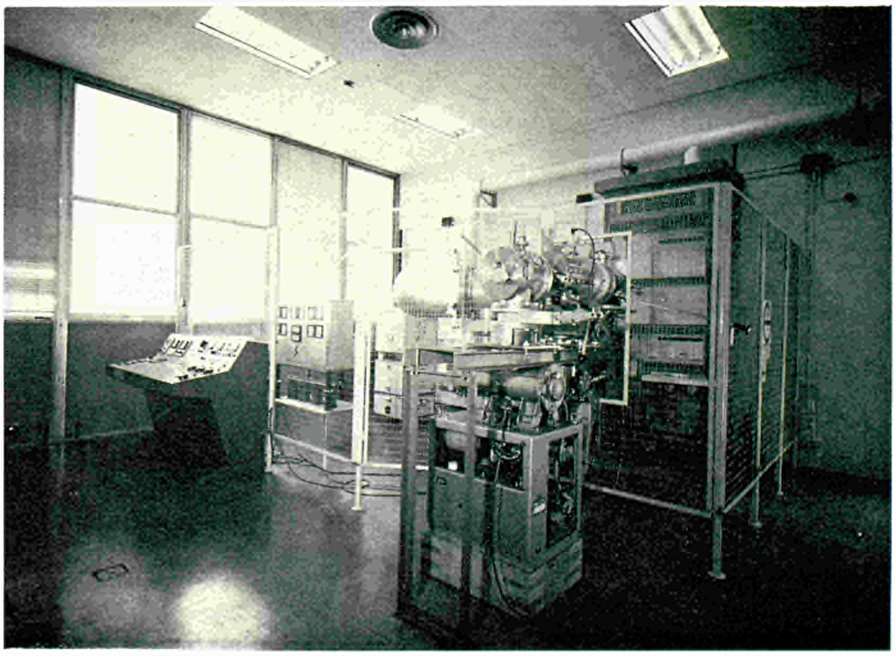


Fig. 11: *100 keV ion accelerator fabricated by the Electronics Division of the* Joint Research Centre, *Ispra.*

mass separation is effected by the antagonistic action of an electric field and a magnetic field set at right angles to one another (velocity filter). The second system is more economical than the first, the magnet in this case being much smaller, and although it operates a less distinct separation of the masses than the first system, in many cases it suffices.

(c) *beam deflection system:* in order to bombard the sample as evenly as possible, the ion beam sweeps an area containing the sample to be implanted. This is done by means of two pairs of flat electrodes set at 90°, to which appropriate potential differences variable in time, will be applied.

(d) *target chamber:* this part of the equipment is designed to contain the implantation sample and the devices which control its orientation in regard to the ion beam, and also its temperature. Owing to the variety of conditions in which implantation can take place, this part of the equipment varies according to the purpose for which it is intended. The basic requirements for a target chamber for research and development work are as follows:

  - high vacuum (10^{-6} torr), "clean", i.e., free from organic or any other vapours that might contaminate the sample surfaces;
  - a means of heating (500 °C) or cooling (−200 °C) the sample during bombardment;
  - a means of treating several samples without having to raise the chamber to atmospheric pressure between the treating of one sample and the next;
  - a means of mounting the sample on a goniometer enabling a crystallographic direction of the sample to be aligned with the ion beam.

The implantation sample is part of a "Faraday cup" type of structure, which enables the number of ions striking the target to be assessed from the current reading. By connecting the Faraday cup to a current integrator, it is possible to stop the implantation automatically when a certain charge, corresponding to a pre-set number of ions, has been reached

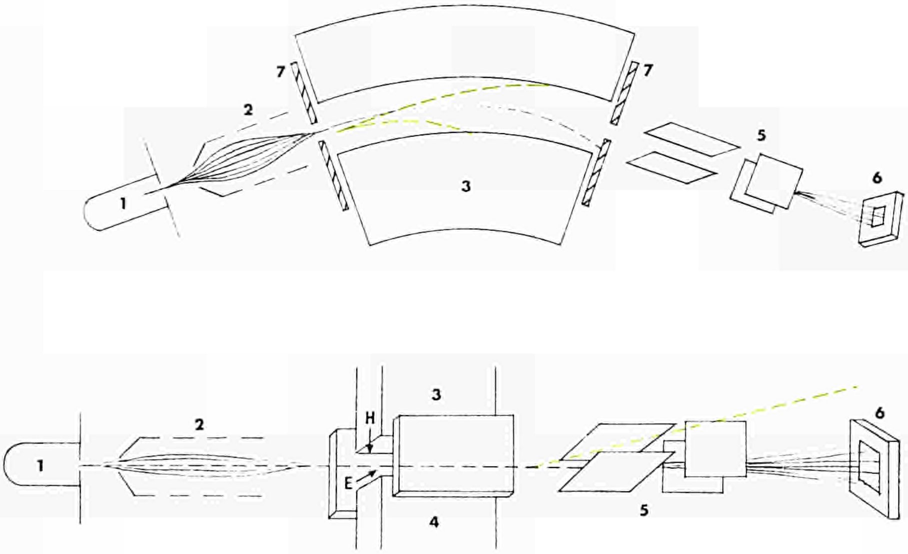


Fig. 12: *In the upper accelerator diagram mass selection is obtained by means of a magnetic field which (with a given energy and a given value of the magnetic field) focuses on to the outlet slit only that ion species with a certain charge/mass ratio which is to be implanted. In the lower diagram, the analysis is done by means of the antagonistic action of an electric field E and an orthogonal magnetic field H. The only trajectory not deflected by the opposing forces due to E and H is that of the ions which have a given velocity (imposed by the values of E and H) and which therefore, since the energy imparted to the ions is constant, possess a certain mass.*

1: ion source;

2: accelerating and focusing system;

3: magnet;

4: velocity filter;

5: beam sweeping system;

6: sample;

7: slit.

Industrial implanters — When fabricating implantation accelerators for research purposes, the tendency is to make them capable of performing as many functions as possible, even at the cost of the machine's simplicity; but the principle is different in implantation systems for industrial uses. In this case, the ion-beam accelerator and analyser are reduced to their basic components in order to optimize reliability and safety and to speed up the operations. For instance, in the case of the target chamber, great importance is attached to the possibility of housing and treating a large number of samples. In a typical implanter for industrial production, the target chamber can hold about 40 silicon wafers of 20-30 mm diameter. The total duration of the operations is shortened, allowing a processing rate of 100-200 samples an hour.

When one has to manufacture a large number of small devices in high-density on a single silicon wafer, or to fabricate integrated circuits, two different technologies may be applied.

The first consists in using mechanical or, preferably, chemical masks (e.g., layers of SiO_2 grown on silicon crystal, the structure of which is determined by photo-engraving processes) which are bombarded uniformly by the ion beam.

The second consists in the possibility of producing one or more ion beams with a diameter of the order of a micron or less. These beams, suitably controlled and directed by means of electronic deflection systems, are able to "write" directly on the semiconductor without the use of masks, structures or complex circuits. The obvious advantage of this system is that it can be directly controlled by a computer, a fact which, if developed to the extreme, would lead to a complete automation of the manufacturing processes in microelectronics.

Application to semiconductor devices

The importance of ion implantation in the technology of electronic semiconductor devices derives from the differences, outlined in the introduction, between this process and thermal diffusion as methods of "doping" semiconductors. It is worth noting that at present the range of applications is expanding rapidly. On one hand devices basically intended to be produced by thermal diffusion are optimized by the introduction of steps obtained by ion implantation; on the other hand, designing draws new potential from the greater degree of freedom that ion implantation allows in the doping of semiconductors, and devices with totally new characteristics become feasible. The greater flexibility of the doping process and better control of the basic parameters of the devices are the two factors which determined the introduction of implantation as an industrial production technology for silicon devices. In the case of compound semiconductors the advantage is still more obvious, since with thermal diffusion it is often impossible to introduce the desired doping impurities without at the same time altering the structure of the semiconductor with consequent deterioration of the electric characteristics. This is due to the decomposition phenomena which occur in the material at the high temperatures required for thermal diffusion.

It should be noted that implantation is compatible with all the technological processes already in use in the manufacture of these devices, and could be introduced either as an integral part of the process or as a process complementing or — in some cases — replacing thermal diffusion.

From a strictly technological point of view, the main advantages of the diffusion process may be summarized as follows:

- a wide choice of doping elements;
- possibility of varying the concentration profile to a wide degree, independently of the temperature;
- high precision control of the doping down to the lowest levels with optimum uniformity even on surfaces several cm^2 in area;
- concentration profile not influenced by the presence of defects (e.g., dislocations) in the semiconductor;
- use of relatively low temperatures, which reduces the risk of introducing unwanted impurities by diffusion and spoiling the characteristics of the initial material (average carrier lifetime);
- absence of lateral spreading of the dopant when introduced through a mask;
- possibility of using one accelerator for several types of dopants.

In terms of performance of conventional devices, the advantages listed above take the form of improvement in three basic characteristics:

- high frequency response;
- ability to withstand high power values;
- reproducibility and production yields.

The high frequency response is limited by the time required for carrier transit through the active region of the device, and by the parasitic capacitances and resistances, which depend on the geometry and the concentration profiles of the doped zones. One example of the advantage achievable is given further on in the detailed comment on the implanted *MOST* (Metal Oxide Semiconductor Transistor).

The ability to withstand high power values (high voltages without rupture, and high amperages) depends on the concentration profile and its uniformity along the surface.

Reproducibility and production yield are higher owing to better control and greater uniformity of the doping.

Some of the devices developed by means of ion implantation are listed in Table V; the list is far from exhaustive, and is only intended to exemplify some of the advantages discussed above.

MOST — A more detailed treatment has been reserved for *MOST* devices, both for historical reasons, because they were the first to be made by implantation on an industrial scale, and because it is this category of device which has hitherto chiefly benefited from the advantages provided by the use of ion implantation (Fig. 13). In the conventional *MOST*, the tolerances in the masking process and the influence of lateral diffusion are such that the overlap

Table V: *Characteristics of the devices obtained through ion implantation.*

Resistors	Possibility of obtaining high resistivity with good reproducibility, uniformity and increased value of discharge voltage to the substrate. Small dimensions with advantages in the case of complex circuits.
Diodes:	
— solar cells — nuclear radiation detectors	Junctions very close to the surface are obtained which minimize the radiation "entry windows". It is possible to obtain uniform doping over an extended area.
— variable capacity (varactor) diodes	The relation between the diode capacity and the applied voltage can be predetermined within very broad limits by varying the concentration profile of the implanted ions.
— *IMPATT* (Impact Avalanche Transit Time) diodes	Junctions are obtained in which the tendency to form microplasmas is reduced by the uniform depth of penetration of the implanted ions. This characteristic is particularly useful because these diodes operate with electric fields close to the discharge level.
— photodiodes	The yields are improved from 10% to 90% owing to the improved uniformity and reproducibility of the doping.
MOST (Metal Oxide Semiconductor Transistor)	Lower parasitic capacitances are obtained and therefore it is possible to operate with higher frequencies; greater compactness and density of devices in complex circuits; lower energy consumption; improved control of characteristics; better reproducibility; higher production yield.

between the gate electrode and the other electrodes is, in most cases, comparable with the width of the gate electrode (a few microns). This gives rise to parasitic interelectrode capacitances which limit the frequency response and therefore the performance of the *MOST*. Using ion implantation, the source and drain regions adjacent to the gate electrode are produced by implanting phosphorous in high doses (~ 10^{15} ions/cm^2); the resulting zone is perfectly aligned with the edges of the gate electrode. The gain thus obtained, in the form of a reduction of the parasitic capacitance by as much as a factor of 20, enables the implanted *MOST* to operate regularly at frequencies of over 10 GHz. In addition, with the precision obtainable in the definition of the implanted zone and in the thickness of the doped zones, it is possible to reduce the overall size of the transistor, thus achieving greater compactness, greater density of the components (up to three times that of the diffused *MOST*) and less energy consumption, and to obtain high reproducibility of the characteristics and hence a higher production yield.

The practical results of the above are applied to the manufacture of integrated circuits of the *MOST* type, used for various devices, e.g., computer memories, pocket computers, clocks, etc.

To conclude this short report, a word must be included on *bipolar transistors*, by far the most commonly used device. Much research is being done in this field, but the results have not yet led to an industrial manufacturing process. For production purposes, however, implantation has already found a place as a method of accurately controlling the quantity of dopant which is subsequently displaced by diffusion, thus obtaining a better production yield.

The use of ion implantation to dope compound semiconductors offers extremely attractive prospects, which result from the following facts:

- compound semiconductors are widely used in the field of microwave devices and optoelectronics as light emitters and detectors;
- there are many obstacles stemming from the characteristics of these materials which cannot be overcome by using the traditional diffusion techniques.

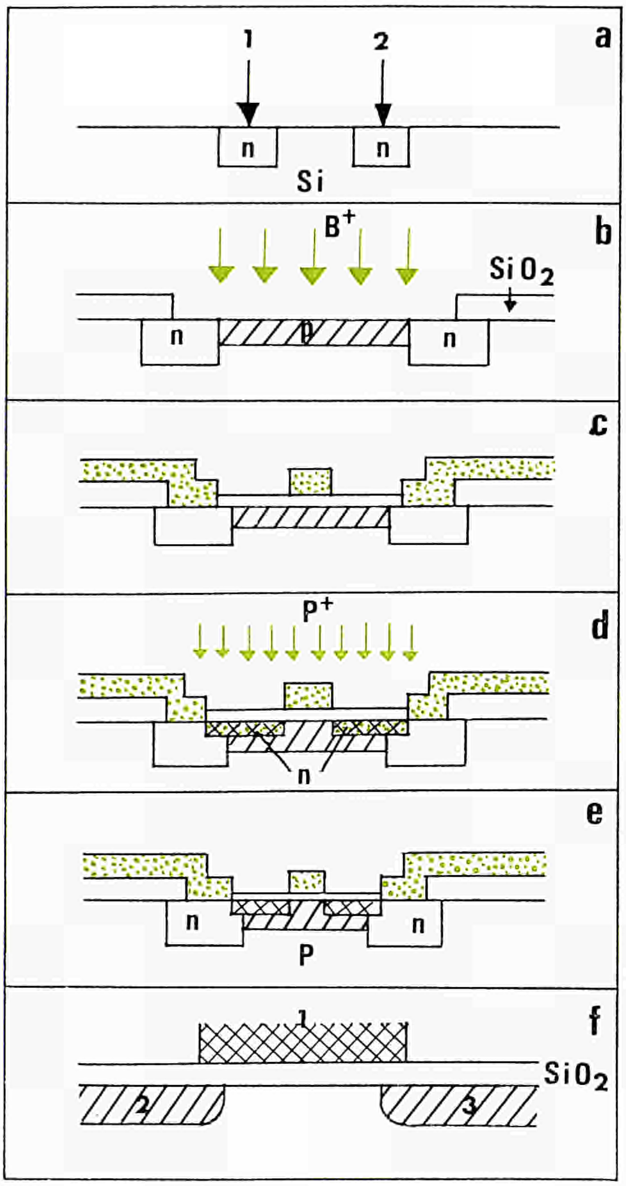


Fig. 13: *Diagram showing fabrication of a* MOST *device (more specifically, a* MOSFET*) with mixed diffusion-implantation technique.*

(*a*) *The source and drain contacts are first prepared by phosphorus diffusion (1: source; 2: drain; Si: high-resistivity p silicon).*

(*b*) *The zone between the source and drain is then implanted with boron in order to obtain a thin layer of type-p material with higher conductivity (channels).*

(*c*) *A new layer of oxide is then grown (thickness of the order of 500 Å) in the gate electrode zone, and the source, drain and gate electrodes are produced by aluminium evaporation.*

(*d*) *The gate electrode is typically 1 μ wide. The device is now complete except for the electric contact between the diffused source and drain zones and the zone directly underlying the gate electrode. This connection is effected by implanting a high dose of phosphorus and then annealing, which produces a highly conductive n zone.*

(*e*) *In the completed device the source and drain zones are cleanly aligned with the gate electrode, with consequent reduction of interelectrode capacitances.*

(*f*) *This is clearly shown by comparing the analogous zone of a diffused* MOST, *where the overlap between the gate electrode and the others is noticeable (1: gate electrode; 2: source; 3: drain).*

Although implantation is not as advanced in this field as in the case of silicon, the principal applications for devices lie in the production of doped layers, the controlled introduction of atomic species which act as luminescent centres, and the creation of zones which are rendered insulating by radiation damage in order to separate different active regions on the same substrate.

There are, furthermore, other aspects of the "planar" technology used on silicon which would be directly applicable to compound semiconductors when ion implantation is used.

Extensive case records exist at the laboratory level on the implantation of luminescent centres in GaP and ZnTe and of dopants in GaAs, InAs, InSb, CdS, CdTe, ZnTe and SiC.

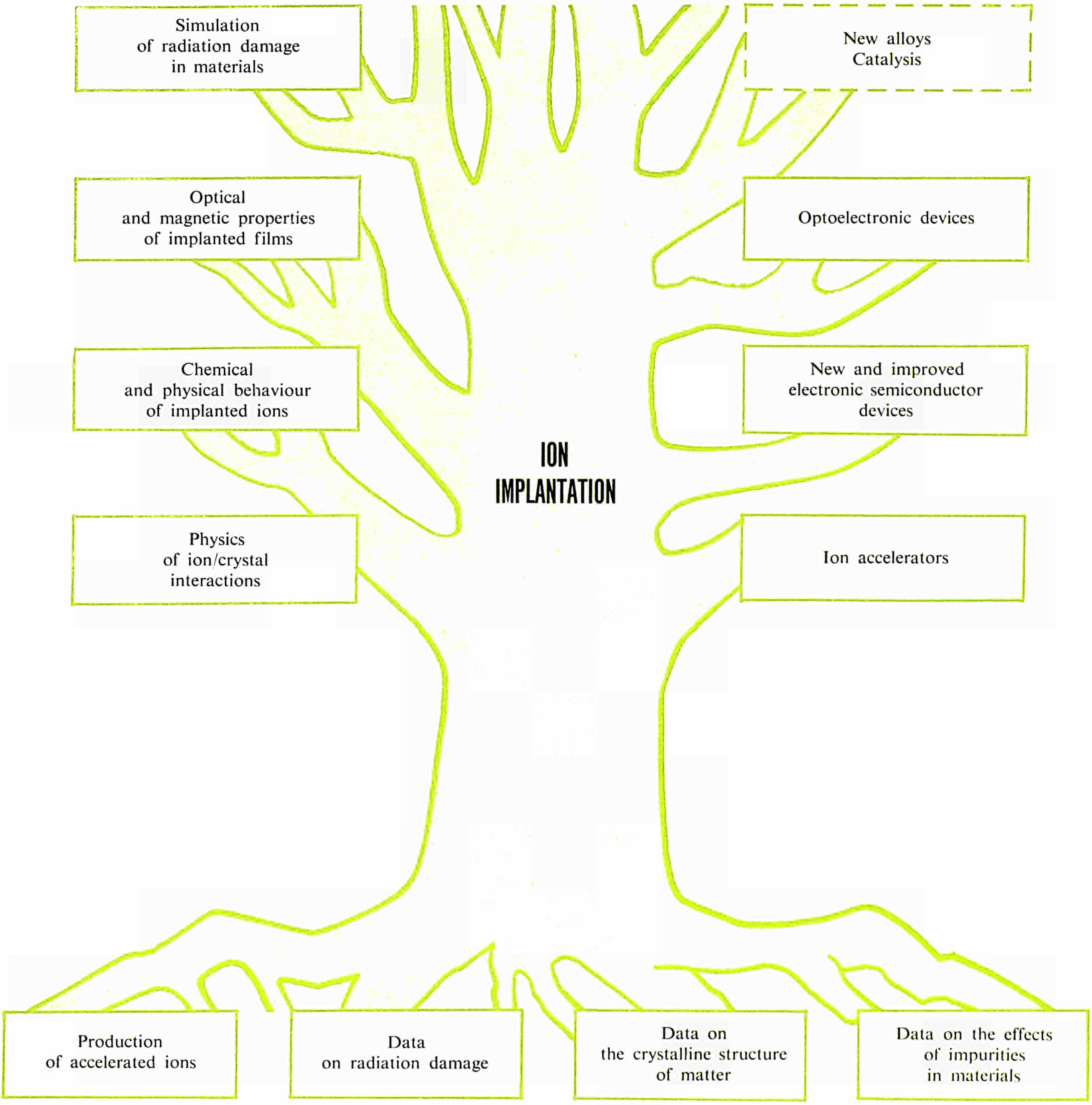


Fig. 14: *Ion implantation is a technology which may be compared to a tree whose roots feed on the existing knowledge in the field of technology and fundamental physics. The branches represent the branches of science and technology to which this process has brought solutions for old problems and has offered fresh developments.*

The advantage of being able to use any type of ion regardless of its solubility in semiconductors is obvious. For example, the conversion of CdS from n type to p type (an important stage in the manufacture of devices based on CdS), not feasible by diffusion, has been achieved by implanting bismuth ions. In addition, because the defects can be annealed at a lower temperature and for a shorter time, the degradation (decomposition with loss of stoichiometry) produced by the high temperatures typical of diffusion is avoided.

One of the problems of compound semiconductors is the complexity of the damage caused by the slowing down of the ions in the solid. The electrical activity of the defects introduced has been utilized to produce, by bombardment with 100 keV protons, donor levels in GaAs and high-resistivity layers in ZnTe. The existence of acceptor or donor levels introduced by bombardment often tends to conceal the effect produced by the chemical species of the implanted ion and to complicate the annealing process. A great deal of work is being carried out to throw more light on the behaviour of these systems.

Summary

In this article, ion implantation has been presented as a complementary and sometimes alternative technique to thermal diffusion for the doping of semiconductors. The explanation of the physical process has shown the reader why it is a highly flexible and potentially valuable method.

As regards fabrication of the devices, we have confined ourselves to those that have already been favourably assessed and have found uses in industry which, after all, is the real test bench for any new technology. The material is continually being developed, and it is foreseeable that in 7-8 years time nearly all the devices will include one or more ion implantation stages in the production process; the prediction is supported by the fact that this new technology pushes components electronics further along the road it has already taken and which it appears bound to follow, towards greater device density, reliability and response velocity and lower energy consumption.

Our primary aim was to illustrate the use of ion implantation in the field of semiconductor devices. It is not certain that it could be as widely applied in other fields, but its potential is equally promising.

Particularly noteworthy are the prospects in the field of the optical and magnetic properties of materials. It has been shown that the refractive index of dielectric materials can be varied very accurately, by means of ion implantation; this is of particular interest in the development of integrated optical circuits. By using a similar technique it is possible to modify thin films so as to control their magnetic properties; such a process could be used in the technology of superconductors and magnetic-bubble memories.

Other interesting applications are being found in the field of materials for nuclear uses. They depend on the possibility of simulating, by ion bombardment, the effect of high neutron fluxes on the properties of the materials; an irradiation with $\sim 10^{15}$ ions/cm^2 is equivalent to an integrated flux of $10^{20} - 10^{21}$ fast neutrons/cm^2. Specific applications concern void formation processes and gas emission from the structural materials of nuclear reactors and, in the field of thermonuclear fusion, simulation of pressure vessel damage done by 14 MeV neutrons.

In the field of fundamental research, the discovery of this technique has led to a far greater understanding of ion/crystal interaction processes and of the chemical and physical behaviour of atoms introduced into different matrices. Another contribution was the discovery of ion channelling in single crystals, which disclosed a new branch of research and created a powerful instrument for diagnosing the position of atoms in a crystalline matrix.

Altogether, ion implantation is an excellent example of how a new technique can help to stimulate studies and applications in various scientific fields (Fig. 14).

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Ecology and environmental hygiene[*]

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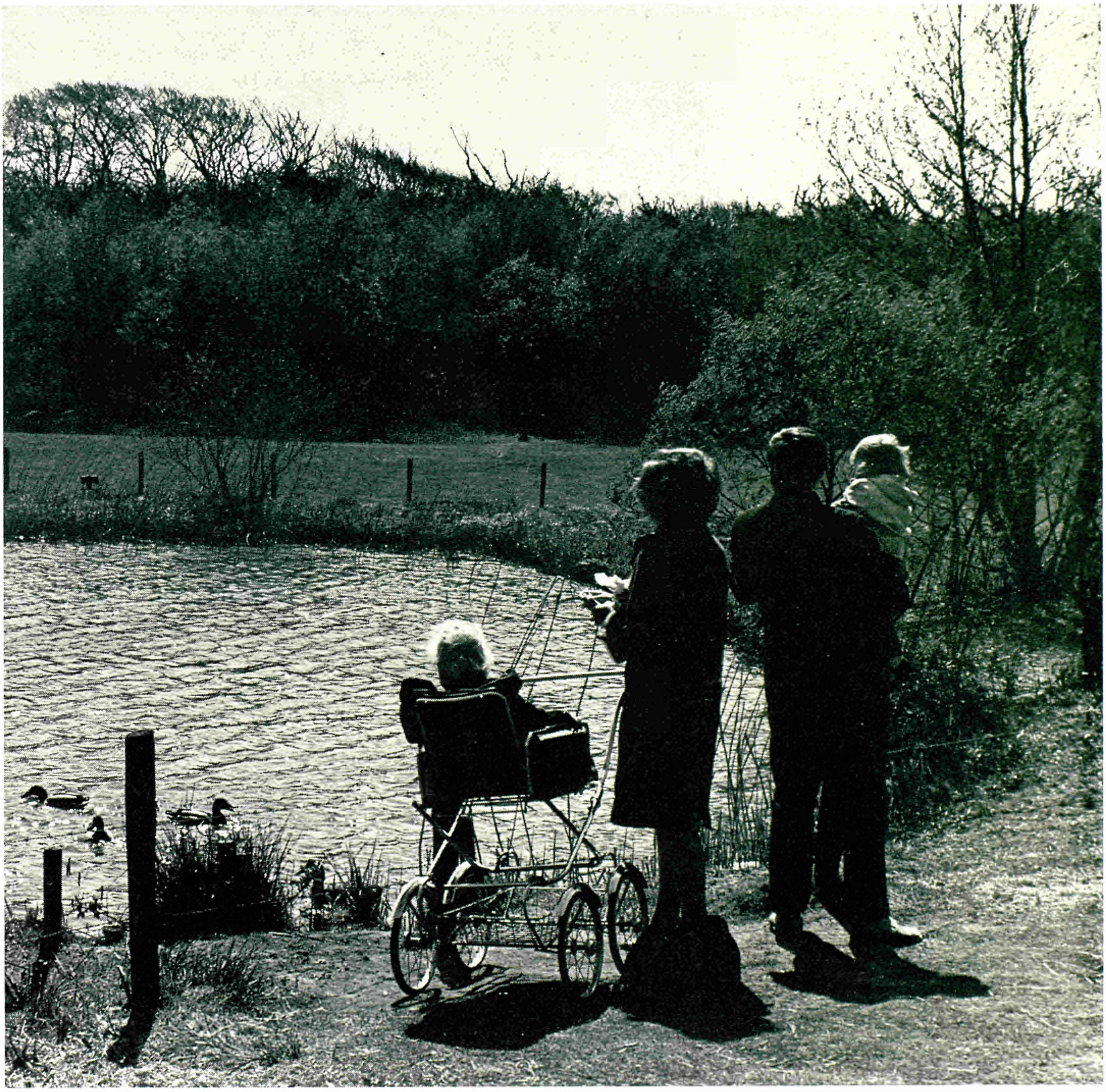

Fig. 1: *Man in an attempt to return to a place in his natural habitat where he is in harmony with his environment.*

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[*] This article appeared in Dutch in *Natuur en Techniek*, *40* (1972), Nr. 9, pp. 441-453.

Ecology and ecosystems

According to the usual definition, the science of *ecology* or synecology[1] means the study of the relationship between living beings and their environment and each other. This term was suggested in 1896 by the German biologist Haeckel (1) in order to distinguish ecology from other biological and allied natural sciences, such as plant and animal physiology, systematics, sociology, agrogeology, etc. Because of its many facets, ecology is a synthetic science, made up of different disciplines. Ecological research is just as old as the research done in the numerous fields which form a part of it.

Ecology is not a new science, but it is a topical one, as result of all the anti-ecological threats and dangers to which the human, plant and animal environment is exposed to nowadays.

Though it is really stretching the term ecology somewhat, further distinctions are currently made between the world of plants (plant ecology), animals (animal ecology) and man (human ecology). A particular aspect of human ecology is further known as health ecology, defined by Zielhuis (2) as "The study of the processes which at the level of biotic and social relations between man and his environment are relevant to the health, diseases and health care of man as a species and as a group". The results of these studies will help public authorities to act with purpose and direction.

Radioecology (also known as radiation ecology) is that branch of ecology which deals both with the transfer of radionuclides in the ecosystems in relation to the protection of man and animals against the direct hazards of radioactive contamination and with the effects of ionizing radiations on the biotic components of ecosystems (3).

In the natural physical habitat, with definite abiotic ecological characteristics, also known as the *biotope*, a natural community will be formed with a population having specific characteristics. In 1877 Möbius gave the name of *biocoenosis* to a community of all types of organisms living permanently in the same biotope. This community is very closely dependent on the physical, abiotic environment in which it lives and with which, under normal circumstances, it forms an indivisible whole. Tansley (4) called this unity of the biocoenose and the biotope — under natural conditions — the *ecosystem (biogeocoenosis)*.

Ecology is therefore a composite science. The consequence of increasing specialization in the sciences, each leading to its own highly specialized research, was that even a century or more ago it was impossible, both literally and figuratively, to see the community of the wood for the trees. Insufficient attention was paid to the interrelation between the biocoenosis and its habitat, the biotope.

This negligence was most in evidence where human intervention led to the introduction into a particular ecosystem, alongside natural cultures, of cultures originating from other ecosystems with different climatological, geographical, edaphic, orological, biotic or sociological conditions. Even a difference in one of the natural characteristics of a given natural ecosystem, e.g., temperature, light, precipitation or altitude, resulted in the failure of non-indigenous cultures, especially when the life form in question had little if any power to adapt itself.

Many instances can be quoted in this connection, such as the consequences of transferring tropical cultures to our temperate zones. Conversely, natural cultures from our parts of the world appear to have difficulty in adapting to tropical areas. The well-known dandelion which flourishes in low-lying polder areas cannot manage, phenotypically, i.e., in its physical form, to be more than a small, stunted plant in mountainous areas.

There are a number of factors which determine the natural (5) ecosystem and which are essential to man, plants and animals, *system-linked environmental factors* such as :

- *climatological factors :* temperature, rainfall, vaporization, light, sunshine, wind;
- *edaphic factors :* physical and chemical composition of soil, air and water; the substrata in and on which man, plants and animals live;
- *orological factors :* altitude; in general a series of complex influences of pri-

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[1] Oikos = literally "dwelling place": the study of homes, habitats or households, a neologism related to classical "economics".

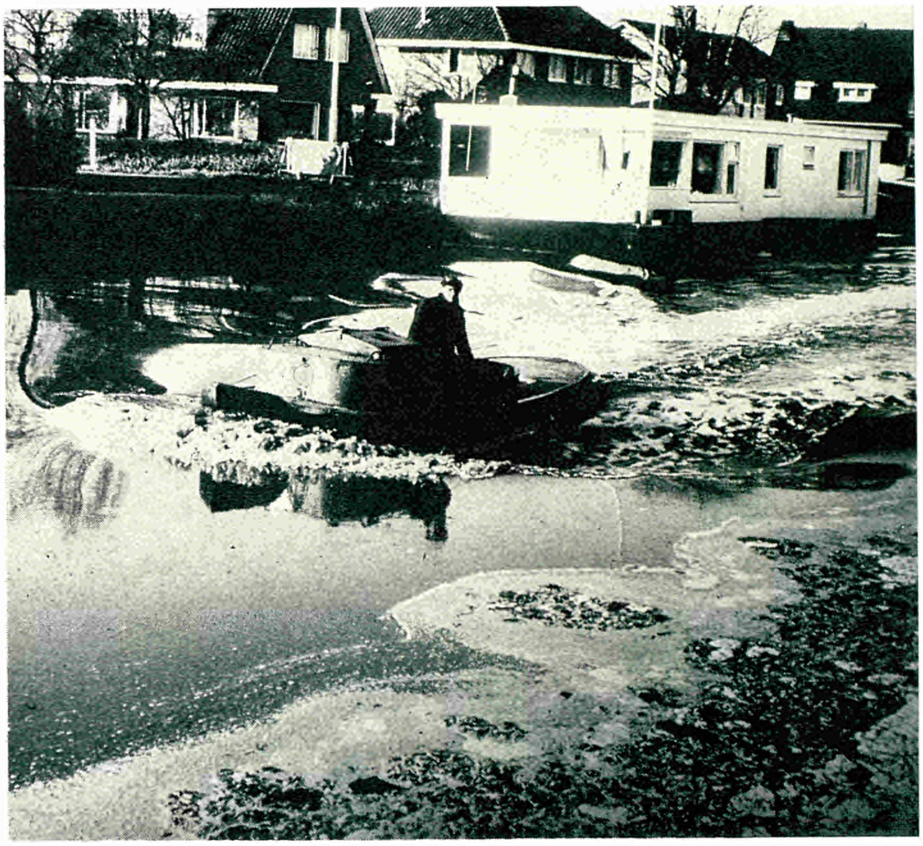


Fig. 2: *A watercourse is regarded as polluted if the water in it is unsuitable for all the purposes for which it could be used in its natural state.*

marily a climatological but also partly of an edaphic nature;

- *biotic factors* : the influences of man, plants or animals on the ecosystem;
- *sociological factors* : those determining social cohabitation, the organic community of man, plants or animals.

Environmental hygiene

Environmental hygiene is concerned with the health of man and the safeguarding of that health with respect to the *exogenous* factors affecting man from the human environment or ecosystem. (*Endogenous* health factors determined by heredity or appearing later in life will not be considered here.)

System-linked and foreign environmental factors — The exogenous factors of interest in this connection are in particular those foreign to the ecosystem and furthermore *xenobiotic*, or foreign to the body.

Ecosystem-linked media such as air, water and food are polluted, contaminated or otherwise influenced by materials foreign to the system which are added artificially or involuntarily to the natural ecosystem and can be injurious to the health of man and his environment. In principle all forms of environmental pollution or nuisance are inadmissible and anti-ecological. The Dutch Air Pollution Law states that : "In principle no one is entitled to disturb and spoil the biophysical environment in equilibrium with which man, plants and animals have originated and evolved and to which, as we are increasingly led to realize, they are attuned".

However, the term pollution is hard to define, either qualitatively or quantitatively. The most obvious definition would appear to be that it is caused when chemical, physical or biological materials which are foreign to the system in

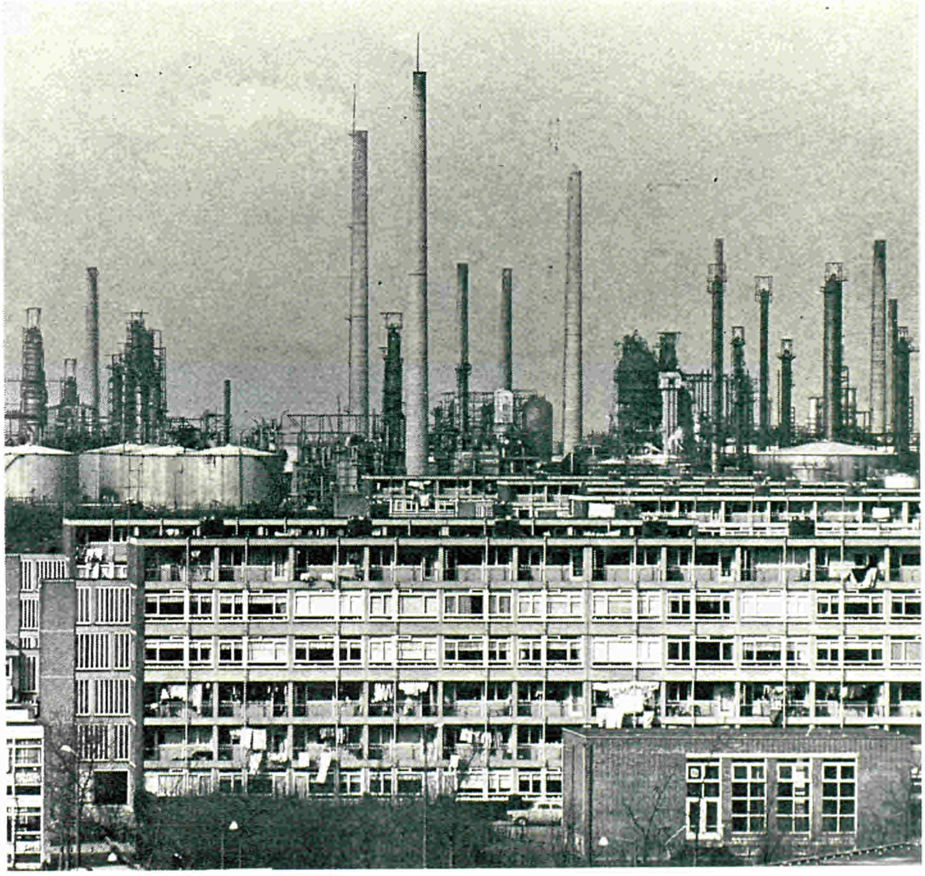
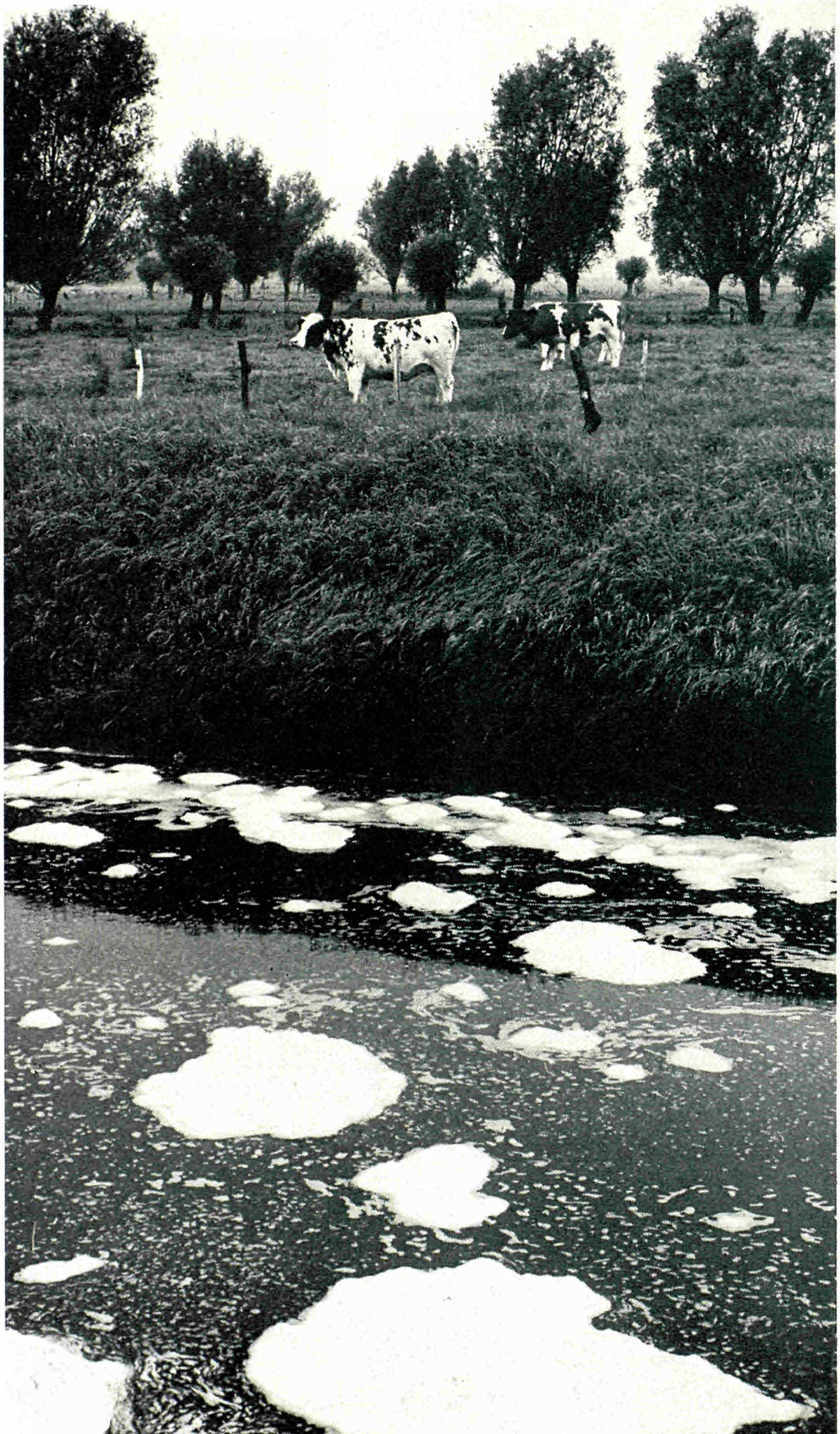


Fig. 3: *A number of developments in modern society, e.g., energy production, have not been accompanied by a corresponding realization that they could have disastrous effects by disrupting the natural balance.*



some way induce changes in the composition of an ecosystem.

In a number of respects, for example, the definition of water pollution formulated at a meeting of European experts in Geneva in 1961 is open to criticism: "A watercourse is considered to be polluted when the composition of the water or condition in which it exists is directly or indirectly changed by man in such a way as to render it less well suited to all, or at least some of the purposes for which it could be used in the natural state".

According to this definition then, the criterion for judging whether water is polluted is whether or not it can be used. Moreover, the only causal agent considered is man, whereas various other circumstances may contribute to pollution, such as floods, animal offal or cadavers, minerals from toxic ore deposits (e.g., deposits containing radium), etc.

Matters or energy foreign to the system may be classified in various ways in the elaboration of measures relative to environmental hygiene. The following categories may be distinguished :

- *waste materials :* as gases, fluids or solids. This heading includes xenobiotica with the most widely differing physical and chemical properties, including radioactive substances;
- *residues* such as pesticides and fertilizers;
- *viruses* such as bacteria and other micro-organisms which may find a good nutrient medium in slaughter houses and municipal garbage disposal plants;
- *additives* used as dyes, preservatives, antioxidants, emulsifiers, stabilizers, antibiotics, hormones, etc., in the manufacture and processing of foodstuffs;
- *thermal loading* of surface or ground water by industrial cooling water;
- *stench and fetid odours:* industry;
- *noise:* industry, means of transport;
- *ionizing radiations:* industry, etc.

◄

Fig. 4: *Harmful substances can enter living organisms by a large variety of ways, e.g., through drinking water, as in the case of these cows.*

Dose-effect relationship — The task of the environmental hygienist is to study harmful exogenous influences and either restrict them to a minimum or eliminate their causes in order to protect human health and the natural environment. According to the World Health Organization's definition, the term "health" has to be interpreted very broadly : "Health is a condition of perfect physical, mental and social well-being and not merely an absence of illness or infirmity".

Theoretically speaking, it would be easy to exclude from the human environment all factors foreign to the system, if other considerations, e.g., of an economic nature, did not have to be taken into account.

We must note that rapid technological development, industrialization, the increase in traffic, urbanization and energy production have not been accompanied by an awareness that disturbances of the natural equilibrium could lead to disastrous consequences (6).

There is one exception to these negative aspects of industrial progress, namely, the peaceful use of atomic energy. Development in this field is surrounded by the strictest of provisions on health protection and environmental hygiene. These standards are so severe that it has taken a long time to get this source of energy developed on a commercial and competitive basis.

One of the great problems confronting environmental hygienists is to determine the maximum admissible levels of matter foreign to the environment. Russian hygienists set their standards in accordance with the following principle : "Any stimulus, whether pleasant or unpleasant, and of whatever kind, becomes unpleasant, intolerable and even pathogenic once it is inescapable".

It is well-known that for system-linked environmental factors there is also an optimum dose situated between a given maximum and a given minimum and which, if exceeded in either direction, produces a harmful effect instead of a useful one. For even an excessive use of cooking salt is harmful. As early as the sixteenth century the Swiss alchemist Paracelsus observed that "*Sola dosis facit venenum*" (it is only the dose which poisons). The optimum dose for materials foreign to the system is naturally nil. It may also be desirable or necessary for other reasons of an economic nature, for example, to set *tolerance levels* with a dose greater than nil.

There are many aspects to the questions which must be asked and answered in establishing tolerance levels and the like. Which materials are harmful to the system, what is the nature of the damage and at which dose will there be harm? It is necessary to have information on the dose-effect relationship. But here, too, there are considerable gaps in our scientific knowledge.

Effects may become apparent in the short term but also in the long term, e.g., in the case of exposure to relatively low doses; they may also have a clinical or a subclinical character. To what extent does man's adaptability play a part here or even immunize him?

People living in mountainous areas are exposed to a considerably larger dose of (cosmic) radiation than those in low-lying areas; people living on the monazite areas of Kerala, India or Terra Rossa in Brazil, which contain highly radioactive minerals, are similarly placed. This radiation dose does not seem to have any influence on the health or life expectation of the local population.

Must tolerance levels be based on the weakest link in the chain or should the population average be taken as the reference level [2]?

In terms of environmental hygiene the following objectives must be pursued in order to protect man and his environment :

- *a reduction in the concentration of pollutants* and particularly of the most dangerous;
- *the improvement of knowledge* about the dissemination and effects of pollutants;
- *the establishing of criteria* giving the dose/effect relationships;
- *the translation of selected criteria into legal provisions* or regulations.

The criteria to be established could take into account the following:

- *for man*
  - increased mortality rate
  - increase in number of hospital cases

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[2] A much-used unit in animal experiments in this context is LD_{50}, i.e., the lethal dose for 50% of the animals tested.

  - increased number of cases involving diseases of the respiratory organs and lungs (e.g., bronchitis)
  - absences from work
  - irritation of certain sensory organs (ears, nose, eyes, etc.)
- *for his environment*
  - damage to flora and fauna
  - reduced sunlight
  - reduced clearness of surface water
  - damaging effect on materials and buildings (corrosion)
  - degree of eutrophication of surface water.

Ecological research

The character of ecological research is determined in the first instance by the point of view from which it is to be conducted, e.g., that of man, plants or animals, and then by defining the research objectives within the appropriate category. The choice of the parameters to be studied and relevant to the ecosystem depends first and foremost on this. However, it should not be forgotten in the analysis of the system that the ecosystem forms an absolute unity. Furthermore one should not forget the interaction of the biocoenose with the physical habitat and the state of its delicate natural balance.

Ecological research concerned with man has many aspects, e.g., with regard to his behaviour as a living species in the midst of other living organisms in a given ecosystem; as a causality factor in the changing and planning of the biosphere and not least with regard to the consequences of such changes for man as a species.

In view of the nature and extent of the problems in this field, and our relatively recent realization of them, it goes almost without saying that our knowledge is far from complete and that a lot more research is needed.

Many questions need to be answered in the short run, such as the dose-effect relation of a very large number of pollutants and nuisances, the short and long term effects of exposure to often relatively low concentrations or doses, the results of the interaction or synergisms of environmental nuisances, the behaviour of pollutants in the environment, the transfer mechanisms, etc.

In order to provide this information it is necessary first of all, in analysing a system, to define the relevant health, ecological and epidemiological parameters, to observe, measure and examine at fixed recurring intervals over long periods of time, to collect and analyse information and then to establish appropriate actions. The problems having very many aspects require a multidisciplinary approach. The research must have at the same time a fundamental, an applied scientific and an operational character.

Transfer pathways (7) — In assessing the degree of risk of waste disposal for human health, the following factors have in general to be examined:

- the processes whereby the *final link in food chains*, *air* or *water* is polluted;
- the processes of *transfer* or agents *to* and *within* man, including metabolic behaviour;
- the epidemiological aspects of the nuisance.

The transfer to man of system-foreign agents may occur *directly*, via air and drinking water. In this case the *number* of factors and transfer processes which influence physicochemical changes in agents and their concentration and dilution is relatively small. They are restricted chiefly to dilution or diffusion by air currents or by water discharge. Air and drinking water are thus the last link.

The food chain, however, is an *indirect* pathway with numerous links. For once system-foreign agents (see Fig. 5) are introduced into the food chain through the air (by atmospheric precipitation) or through water (by irrigation, for example), the transfer is influenced — at the various links or trophical levels — by a number of factors and processes before the agents reach the final link in the food chain (vegetable or animal consumption products). Physiological, metabolic and other processes in plants, animals and hydrobiotics can cause concentration, dilution and change in the physicochemical characteristics of agents. Rainfall can cause erosion of the upper soil stratum.

Food chains can again be divided into *short* and *long* chains. In the former case soil and cattle are not included as intermediate stages and contamination of plants for consumption, e.g., greenstuffs, occurs directly. In the case of the so-

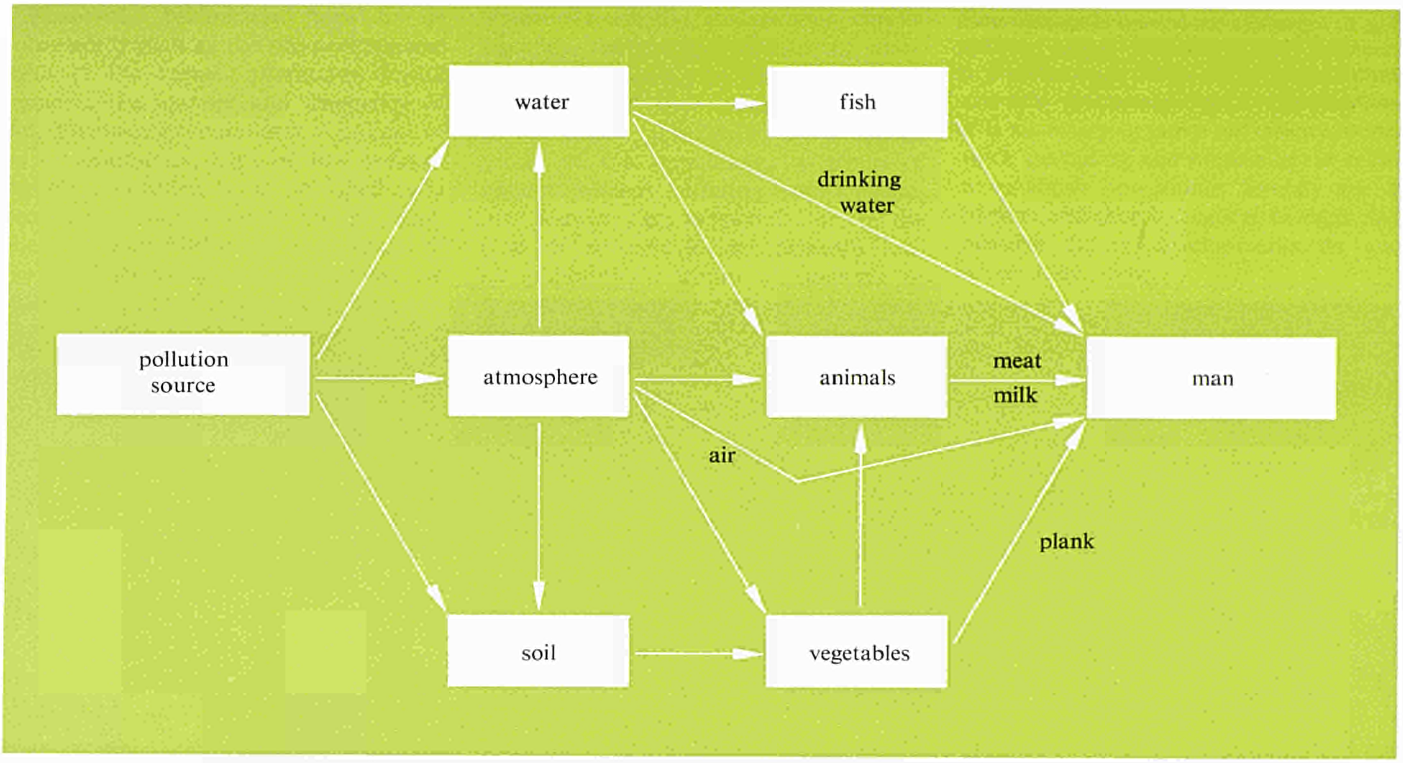


Fig. 5: *System-foreign agents can enter the human organism directly (via air and water), but also indirectly (via one of the food chains).*

called long food chains the stages soil and cattle *are* present.

From the practical viewpoint of health protection this difference between direct and indirect pathways and short and long food chains is of great significance. For this determines not only the method but also the extent of transfer and its importance is thus both qualitative and quantitative. In the case of radioactive contamination, the half-life or radionuclides is of great importance in this connection because of the time lapse of the transfer.

Assessment of the second series of processes, those concerned with the transfer of agents foreign to the system *to* and *within* man, also requires comprehensive, systematic and multidisciplinary examination. The first stage may be said to be the identification of the persons or group of persons most exposed to the potential source of the hazard, the so-called *critical group*. This may be a small population group (e.g., riparians who eat contamined fish from a river), a part of the population (e.g., in the case of drinking water, etc.) or specific groups of the population (children, young people, etc.). In direct relation to this it is necessary to identify the *critical pathways*, namely, air, water or food chain and, in the food chain, the nature and quantity of the products consumed.

The metabolic characteristics of the *critical agent* must be determined, as well as the *critical organ* in the human body which may be exposed to this agent and thus to the greatest risk.

It should be pointed out that the term "critical" in this connection does not in itself imply any danger; its sole meaning is to qualify terms already defined in such a way that specific decisions on health protection can be taken as a result.

The concepts, analyses, research and other aspects we have mentioned earlier in connection with the transfer and hazards of system-foreign agents as far as the protection of human health is concerned can also be applied *mutatis mutandis* to the protection of the other components of the human and natural environment. The objectives pursued may differ, but the principle of research and supervision is the same.

Uptake capacity — Operational research may be considerably assisted by the use of mathematical models, and in particular by the principle of compartment modelling. A system is analysed and the factors of transfer between two links of the system are determined from which can be derived the concentration ratio of a particular agent in two consecutive compartments of links of the chain. These models also enable us to estimate the *uptake capacity* of a particular ecosystem (hydrological basin, atmospheric region) with regard to system-foreign agents. By estimating this uptake capacity — and account must also be taken of the environment's self-cleaning capacities — we can determine the maximum quantity which can be taken up into the ecosystem without creating an unacceptable hazard for man and his environment. This estimate must as far as possible allow for extra safety margins which may be introduced to deal with new or as yet unknown pollutants, i.e., emission sources and system-foreign agents. Estimates of future developments are essential here, and mathematical and similar models can again be useful aids.

Fig. 6: *Impurities can be more dangerous when combined than in isolation; sulphur dioxide, for instance, is known to be more toxic in conjunction with particulates than alone.*

Numerous parameters have to be considered, such as the physicochemical form of the agents, alterations during transfer, the manner and frequency of the discharge of pollutants (continuous or discontinuous, high or low concentration, controlled or uncontrolled as in accidents, for example), the physical, chemical and biological parameters of the receiving environment such as, for example, flowrate, volume and temperature of surface water, prevailing winds, frequency and quantities of rainfall, soil composition, natural oxygen and salt content of soil and water, nature and composition of local or regional communities, etc.

This is simply a rough summary of the factors confronting the ecological researcher in matters of environmental hygiene.

Epidemiological research

Side by side with this ecological research there is also epidemiological research, concerned in this case with the harmful or disease-inducing consequences of environmental nuisance for the population in general. Progress in this field is considerably less advanced than in that of non-human ecology.

The field of industrial hygiene currently provides a rich source of information, especially in toxicological matters, for the establishing of standards in the field of environmental hygiene in general, although an essential difference must be made between "voluntary" hazards and those to which the population is involuntarily exposed.

Epidemiological studies of fairly large population groups are needed in order to estimate:

- the *long term* effects of environmental nuisance, at both high and low concentrations and doses, and thus the harmful effects of living in a polluted area for many years;
- the *shorter term* effects of exposure to different pollution levels for a number of weeks or months;
- *short term effects*, e.g., of 24 hours exposure to high concentrations or levels.

This research may be designed to determine the lethal or disease-inducing effects of a somatic, mutagenous, carcinogenous, psychic or teratogenetic nature. Account must also be taken here of the nature of the reference group: is it the entire population or a special group of the population, a group of patients already suffering from a particular disease, e.g., bronchitis, or, in the case of epidemiological research into air pollution, a group of smokers or non-smokers?

A particular problem in this field is that of the *synergism*, or the effects of the interaction of specific agents. This is the case, for example, with air pollution by sulphur dioxide and particulates. In general it is acknowledged that air pollution by sulphur dioxide in the presence of heavy concentrations of particulates constitutes a greater danger to public health than it does when no particulates are present. This synergism has to be taken into consideration in evaluating the general pollution of the environment and the attendant hazards.

In establishing protection standards against ionizing radiations we are as it were "fortunate" in that the absorbed radiation dose of the various radionuclides as such can be integrated with respect to the biological effect and can be expressed in one radiation unit known as the "rem". In this way an evaluation of the harm commitment of all radiation sources can be given in a particular unit of time. To date it has not yet been possible to develop a similar integration unit for *all* environmental nuisances or for certain non-nuclear *groups* or *categories.*

It should be pointed out that a lot of research conducted in the interests of health only shows significant and useful results when it is carried out *in vivo* or *in situ.* For this reason large-scale epidemiological research is extremely important, although very costly and time-consuming, if meaningful conclusions are to be reached. The results obtained from experiments on animals or using laboratory aquariums often have only a relative significance for extrapolation to man and natural circumstances. Often they give only rough indications which, in a number of cases, can be used as references for lack of better information. Such research methods may be quite helpful for a time, but they are certainly no panacea.

Surveillance

If a strategy aimed at protecting man and his environment is to be effective, it is necessary to carry out observational work (sampling and measuring) in order to establish how things actually are at present and then to register changes and possible future developments as and where they occur.

This information and knowledge is indispensable if suitable surveillance is to be exercised. Up to now measures were only taken once problems had attained serious and obvious proportions, as was the case with the extensive pollution of surface water, air pollution in heavily industrialized areas and the problems of *DDT*, mercury, lead, etc.

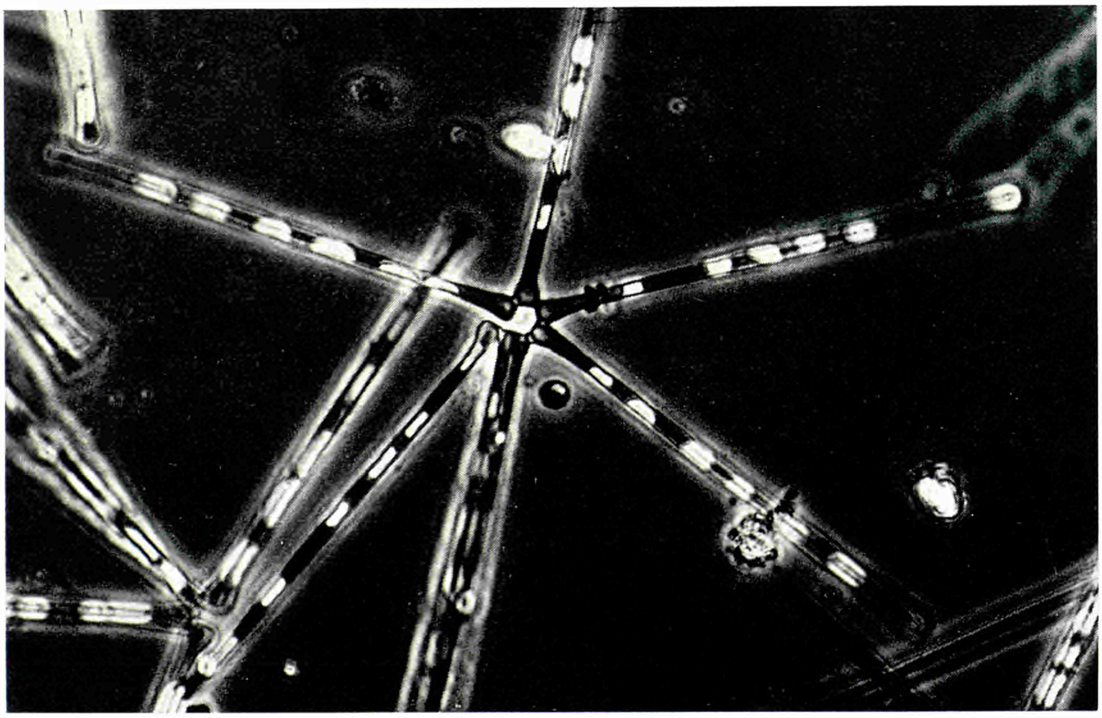
Once parameters and transfer factors have been defined, the necessary means for systematic observation can be established. The required sampling and measuring stations have then to be set up.

In the case of radioactive pollution widespread observation networks have been in existence now for over ten years to measure pollution of air, rainfall, water as well as foodstuffs and soils. Quite a few complications arose, especially with regard to the sampling and measuring of food chains. Supervision and control both of radioactivity in the human environment and in the surroundings of nuclear installation plants has been organized for many years in a satisfactory fashion, so that unexpected situations in the field of radioactive contamination are now kept to a minimum.

With the more conventional nuisances we have a different situation. Although the problems are of longer standing, supervision and therefore observation and measuring are in general still not entirely satisfactory.

The reason for this is not only that interest in these problems is much more recent, but also that the problems themselves are noticeably more complicated because of the greater variety of agents: every substance has its own chemical and physical properties. Whilst the number of specific nuclides examined in the nuclear field is very limited, the variety existing in the non-nuclear field is very

Fig. 7: *It is barely credible that such a polluted piece of water could contain enough oxygen to enable aerobic micro-organisms to exist, but these play an extremely important part in the entire ecology of water.*



great, as is the number of emission sources also. Furthermore, the nature and thus the presence of a certain pollutant are not always known. When the Rhine was polluted by the pesticide endosulfane in 1969, it was more or less only chance and the skill of the investigating analyst which enabled the laboratory in question to identify the pollutant, thereby averting a great disastre.

Each element or chemical compound requires an analytical technique of its own which, particularly in the case of trace elements, is often difficult. No less problematical is the question of sampling, because of the large number of emission sources. In this case a number of points have to be established: the place where the sample is taken (altitude and distance from the source), the density of the network, frequency of sampling, alarm levels if appropriate, the evaluation of the pollution of the background, etc.

This field also affords a wide range of research topics which in turn entails very considerable investment of manpower and capital (personnel, equipment, laboratories, etc.) for the research described earlier.

Conclusion

The ideal situation, where all environmental nuisances are eliminated, is, of course, only wishful thinking. This would at the moment be too demanding, barely rational and in economic terms impossible. One criterion, or rather at this stage an indication, has been suggested in this connection, namely the cost/benefit ratio; increasing efforts are being made to analyse and balance the two elements of this ratio. The difficulties involved in calculating the elements of this ratio, and expecially in determining the benefit factor, are numerous. How high should we put the benefit of a number of values which are hard to estimate? It is easier to express absence from work for the working population in economic terms than it is, for example, to express the incidence of sickness among the non-working population. In the latter case, for example, hospitalization could be used as a standard of reference. But this is only relatively realistic. The number of "invisible references" which cannot easily be measured or not measured at all is very high.

In view of the nature of the problems as a whole and the research, etc., involved, it is quite evident that multidisciplinary cooperation on a large scale and above all at international level is of great importance in the battle against environmental pollution to all parties who can, among other things, keep the costs involved to a minimum by exchanging information. Economic factors involved in the trade within the Common Market also play an extremely important part here.

In many fields cooperation of this kind already exists, but the actual needs and the possibilities too are very much greater.

This international cooperation at the same time places us under an obligation to harmonize our international terminology. In this field there is still a lot of work to be done. Only too often it is apparent that experts of different nationalities fail to understand or actually misunderstand each other over a familiar technical idiom. Standardization of linguistic usage and techniques is indispensable to international cooperation in applied science.

EUSPA 12-10

Since this article was written, the Commission of the European Communities has submitted an action programme for environmental protection to the Council of Ministers, which was approved in its great lines in July 1973 (ed.).

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Technical Notes

The Commission's *technical notes* give descriptions of original results obtained under the Euratom research programmes. Their purpose is to enable firms to decide whether they should consider industrialising these results.

On the basis of article 12 of the Euratom Treaty, a non-exclusive licence may be granted on the results covered by patents, in so far as the licensee is in a position to make effective use of these results. The conditions of the licence, as well as the royalties for technical assistance, will, for each individual case, be fixed after joint consultation.

Requests for additional information should be sent to: Commission of the European Communities, D.G. XIII-A, 29, rue Aldringen, Luxembourg.

— 2001 : Remote control tongs for operations under vacuum conditions

These tongs are designed for relatively complex handling operations inside vacuum chambers with a leak rate of less than $1 \cdot 10^{-7}$ torr. 1/sec.

Vacuum tightness between the guide tube and the push-pull rod, i.e., the system transmitting the gripping motion to the tongs is assured by a removable unit located on the part of the tongs outside the vacuum chamber.

Leak-tightness between the guide tube, ball-joint and the wall of the vacuum chamber is ensured by using a ball-joint penetration of the vacuum-retaining Retzloff joint type.

Applications

Handling operations inside leak-tight vacuum chambers or pressure chambers are extremely difficult. The use of tongs of this type, which are very robust, provides a simple solution to a large number of problems. They can be used in connection with metallurgy, electron-beam welding, in metalplating and heat treatment, in space simulation, etc.

Performance characteristics

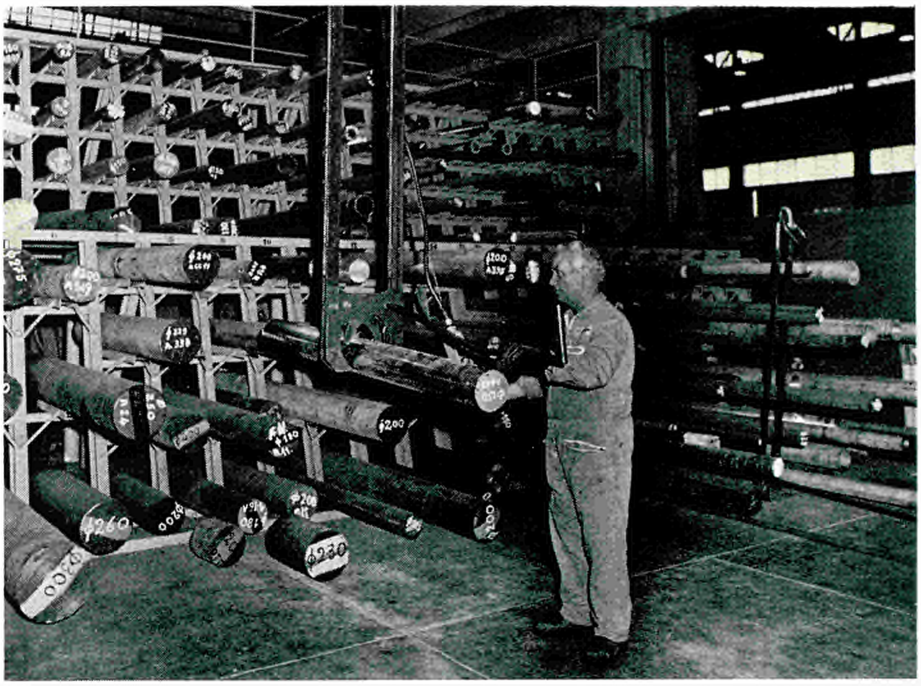
Angle of travel 22°30
Load capacity 3 kg
Clear opening 80 mm

— 2002 : Storage and handling apparatus for material in rod form

Storage premises and labour for materials handling are generally considered as a debit in the operating balance sheet of an enterprise, as are production delays caused by the difficulties of finding, identifying and handling the required goods.

This proposed storage and handling system reduces the disadvantages mentioned above to a minimum.

1. A rack enables different types and sizes of rods to be stored in several horizontal layers; this arrangement makes for :
   - a great reduction in the floor area necessary for storage,
   - easy identification of goods,
   - very easy handling.
2. The design of this machine, which is a grab which can place goods on



this type of rack and take them off again, and also perform all everyday handling operations (placing on and lifting from conveyors, vehicles, etc.) ensures maximum safety in handling operations.

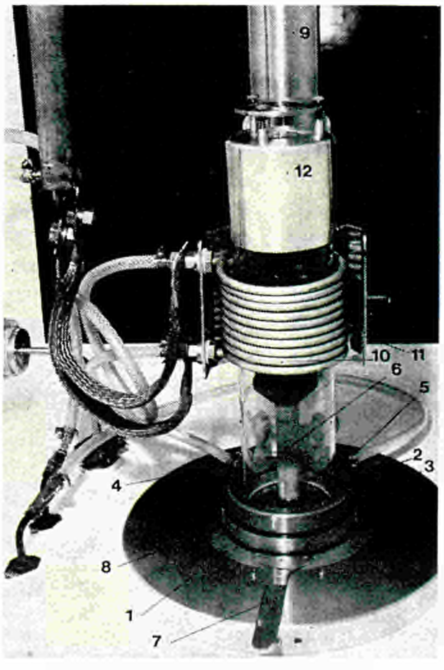
The unit enables an unskilled operator to store or remove the required material quickly and correctly. In addition, the intrinsic features of this storage system allow storage and removal operations to be completely automated.

— 2003 : An easily operated, all-purpose induction furnace for laboratory use

This laboratory induction furnace was designed for the extraction of fission gas from nuclear fuels, a process carried out at a temperature of approximately 1400 °C. In view of the original necessity for that process to be carried out in a lead cell, using a single pair of ball-jointed tongs, the entire handling procedure was simplified as much as possible; potential operators can now take advantage of this for all metal-working processes, such as melting, sintering, annealing, metal-plating, or operations in special atmospheres.

This furnace is made up of:

A. *The fixed base plate* (1). This has a central passage (2) for connection to the vacuum. A mounting, with a central hole (3) and offset holes (4) and (5) can be used to set up a gas circulation system inside the quartz chamber. Thermocouples can also be routed through the central hole to monitor the temperature at the centre of the crucible. A crucible-holder (6) in the form of a ceramic tube is placed in this central hole. A circular groove allows for the cooling of the base-plate. An O-ring housed in the base plate to provide a seal between it and the mounting (8) of the quartz tube. The chamber can be locked down by means of a lever (7) to permit operation with a slight over-pressure.



B. *The mobile chamber mounting* (8) *and its guide pillar*. This mounting is water-cooled to prevent overheating of the seals, and is attached to a carriage with a vertical travel along a pillar (9). The field coil (10) is also fixed onto the mounting. A heat shield (11) protects the pillar against the heat radiated by the crucible. The assembly is counterweighted for easier opening of the furnace, which can be done with a finger.

C. *The quartz chamber*. Set on the above mentioned mounting, it consists of a transparent quartz tube with a hemispherical upper end. No grinding is necessary, as the sealing surface is on the cylindrical portion of the tube. A jacket (12) in sheet aluminium is provided on the upper section in order to reduce losses due to radiation and also serves as a mounting for a prism to deflect infra-red rays emitted by the crucible, thus enabling the temperature to be measured by an optical pyrometer.

Advantages:

The advantages of this furnace lie in its simplicity of construction and the ease with which it can be adapted to other sizes of furnace. Simple design solutions were found:

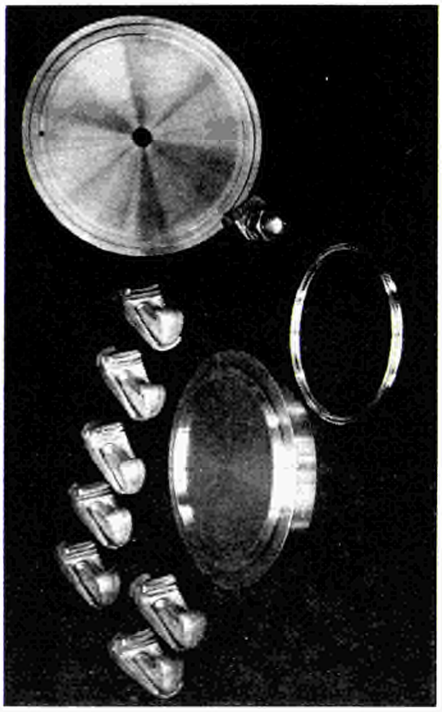
1. For leak-tightness; using the cylindrical portion of the tube with no need for grinding.
2. For the pillar and the locating system, of which there are two versions according to the weight of the furnace. The locating system is free from play and offers very low resistance to movement.
3. Since the furnace is counter-weighted, it can easily be worked manually (without lifting apparatus), even in the case of large units. The furnace can be operated with just one finger.

— 2004: Metal gasket

Few gaskets can withstand temperatures higher than 300 °C.

The Ispra Euratom Research Centre has studied this problem and has now produced a metal gasket *MET X* with very good sealing properties.

The Joint Research Centre, Ispra Establishment, of the Commission of the European Communities has patented it and licenced two companies, *Dilo* and *Le Joint Français* to mass produce and market this product.



Some characteristics of the MET X

Solid, circular metal gasket, quadrilobal in section.

Made of Inconel 600 or any other steel considered adequate for the proposed use.

Temperature range:
minimum: cryogenic temperatures
maximum: 850 °C.

Operating pressure range: ultra-high vacuum to 400 bars

Liquids: all liquids

Requires 3 to 4 times less compression than any other known metal gasket.

— 2005: EUROTRONIK — Self-powered neutron flux detector for in-pile continuous neutron measurement, at temperatures up to 500 °C

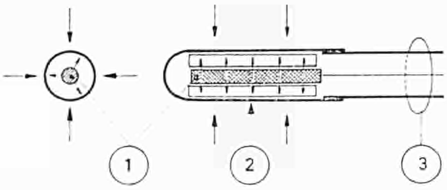
Eurotroniks work on the following principle: if two electrodes (1 and 2), insulated from each other, are exposed to a thermal neutron flux an activating effect β will be generated mainly in the central electrode (the emitter). The resultant electron flux between the two electrodes gives, at equilibrium, a direct measurement of the neutron flux intensity.

Neutron flux measurement is thus reduced to a simple and normal measurement of electron current by measuring the difference in potential at the contacts of a load resistor.

The emitter (central electrode) is generally made of rhodium silver or vanadium of known nuclear properties. A feature of the *Eurotronik* is that they can be manufactured in any length up to several metres (3).

They can be supplied in rigid or flexible form. Quality control is carried out on the product by means of the following tests: continuity, insulation size, sealing and X-rays. Other special tests can be carried out on request.

Eurotroniks were developed at the *Ispra Joint Research Centre* (Varese).



They are sold by the firm Franco CORRADI, Casella Postale 98, 20017 RHO, Milano (Italy), Tel. 930.29.55.

Agent in the United States: LEICO INDUSTRIES, Inc., 250 West 57th Street, New York, N.Y. 10019 - Tel. (212) 765-5290.

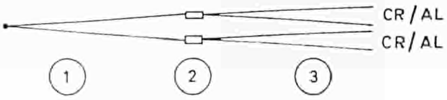
— 2006: Composite thermocouple

These thermocouples, which have been specially designed for measuring high temperatures even where ionizing radiation is present, have been developed at the *Ispra Joint Research Centre*. They consist of a well insulated junction box (cold joint) (2) between the high temperature section (1) and the low temperature section (3).

The low temperature section is made of the following materials:
Sheath: stainless steel, Inconel
Wires: 2 in Chromel, 2 in Alumel
Insulation: MgO

The high temperature section is made of the following materials:
Sheath: Ta, Nb, WRe, Mo
Wires: Pt-Pt/Rh, Pt/0.1 Mo, Pt/0.5 Mo, W-WRe, Mo-Nb
Insulation: Al_2O_3, BeO

These high temperature thermocouples can be made in lengths of up to several metres, and can be either rigid or flexible. Manufacture, assembly and full technical service are offered, including the following tests: physical measurements insulation resistance measurements, helium leakage test, X-Rays. Other special tests can be carried out on request.



This product is sold by the firm Franco CORRADI, Casella Postale 98, 20017 RHO, Milano (Italy) - Tel: 930.29.55.

Agent for the United States: LEICO INDUSTRIES Inc., 250 West 57th Street, New York, N.Y. 10019 - Tel (212) 765-5290.

— 2007: Viscosimeter

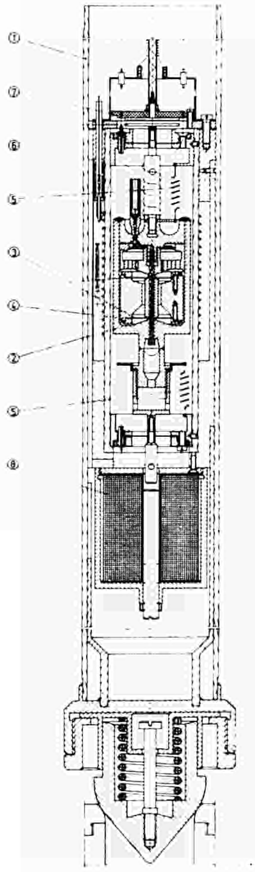
The instrument shown, as an example of the type, was developed for the purpose of measuring viscosity under neutron irradiation in a reactor. It is suitable for general use, however, in particular to measure the viscosity of fluids under high pressure, and of substances that for safety reasons must be kept in closed containers.

The temperature range goes up to 300 °C. The model shown covers a viscosity range of 0.09-2 centipoise. The range can be extended upwards or downwards by 1 minor modification.

The apparatus makes use of the power transmitted by a liquid film of fluid between two concentric cylinders oscillating in opposite directions. Design Features are illustrated in the accompanying section and block diagram. The receptacle (2) is suspended on two sets of springs (3) and from the outer casing (1). The receptacle is free to oscillate along the axis of the outer casing. A combination of coil springs (5) and flat springs (3) ensures that only axial oscillations can occur.

Oscillations are induced by the electromagnet (8). The plate capacitors (6) and (7) serve as transducers, modulating the frequency of a high-frequency oscillator circuit. Demodulation produces a signal proportional to the amplitude of oscillation which is recorded.

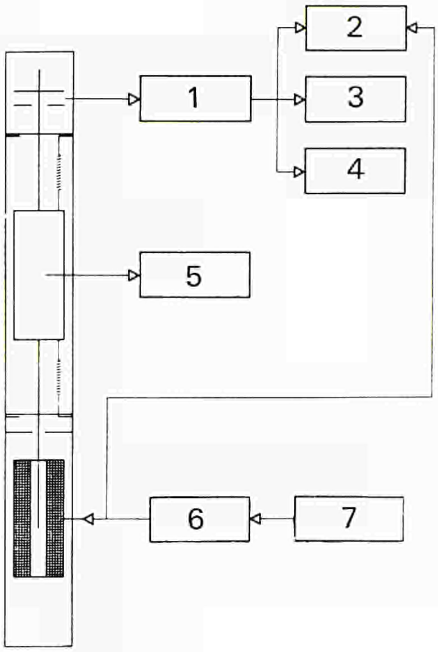
A float (4) is suspended in the receptacle by another set of flat springs. Here again the type of suspension used ensures that the relative motion of receptacle (2) and float (4) is purely axial. The fluid under investigation is poured into the receptacle (2) until the float (4) is completely covered while leaving room for thermal expansion. The oscillation of the float in opposition to the receptacle exerts a frictional force on the film of fluid between them, which damps the oscillations of the container, and the degree of damping is a measure of the fluid's viscosity.



(Patent No. 58 532 Luxembourg 29.7.1969
Schneiders A. und G. Hollebeck, EUR 4817).

Flat spring

Designed for use in the viscosimeter, the spring permits only movements vertical to its own plane. With the dimensions of the example shown, the restoring force is proportional to the amplitude when the deflections are less than 2 mm.



1. *Vibrometer*
2. *L.F. dual beam oscilloscope*
3. *Level recorder*
4. *Frequency counter*
5. *Temperature recorder*
6. *L.F. amplifier*
7. *L.F. oscillator*

(Patent No. 59 527 Luxembourg)

— 2008: Quartz glass shield windows

Shield windows of quartz glass (e.g. *Suprasil*) display the excellent optical properties of that material. They also exhibit extreme leaktightness and resistance to prolonged exposure to high temperatures owing to a glass-to-metal bonding process developed at the *Joint Research Centre*, Ispra. Their leak rate is generally less than 10^{-9} atm. cm^3/s. in a helium atmosphere at 20 °C with an external pressure of 26 bars. They retain the same leak-tightness during prolonged exposures to a temperature of 450 °C. Shield windows of this type are now in production on an industrial scale and can be supplied in several diameters ranging up to 150 mm.

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