Circuits & the paintbrush

A new way of printing with semiconductors promises ease and flexibility. s anthanarayanan **elaborates**

THE early *printed circuit*, decades old, was just a pattern of connections made of strips of copper where components like transistors, resistors, etc, could be soldered in. Then came the *integrated circuit*, which is a whole circuit built on a slice of silicon crystal. The IC soon grew complex, with hundreds, thousands and millions of components on the crystal slice, but the limitation is the need for the silicon crystal, which is difficult to build and needs to be carefully encased.

Hiromi Minemawari, Toshikazu Yamada, Hiroyuki Matsui, Jun'ya Tsutsumi, Simon Haas, Ryosuke Chiba, Reiji Kumai and Tatsuo Hasegawa of the National Institute of Advanced Industrial S&T and the Institute of Materials Structure Science, High Energy Accelerator Research Organisation, Tsukuba, Japan, and the University of Tokyo report in *Nature* their discovery of an alternative — a method to spray on the crystalline material on which circuits could be built. This would sidestep the need to grow large silicon single crystals and also allow electronic circuits to exist in rolled sheets or other convenient shapes and spaces.

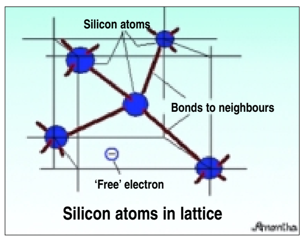
The transistor

This marvel of electronics, introduced in the 1950s, depends on the properties of semiconductor materials for its action. Materials conduct electricity because the electrons — tiny, negatively charged particles in the atoms of conducting materials — can move within the mass of the material somewhat freely. Metals, which have just a few electrons in their "loosely bound" outer shell of electrons, are the best conductors.

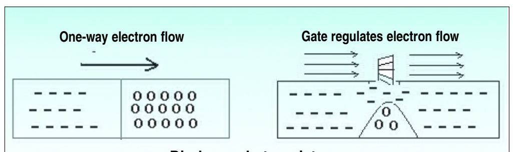
In non-metals, on the other hand, which are usually insulators, the electrons in their outer shells are just short of the ideal number of eight, and atoms of these materials need to borrow electrons and not let go of what they have. Silicon is half way, with four electrons in the outer shell. It is thus neither a conductor nor an insulator. But it can be made into a pretty good conductor if atoms of an impurity, of atoms that have exactly five or three outer shell electrons, are added to the crystal structure. The "extra", or "one short" electron (which is called a "hole") in the lattice is not bound within the structure and can move, just like a "free" electron in a conductor!

Now when one part of a crystal of silicon is "doped" with an "extra electron" impurity and the adjoining part with the "electron short" impurity, the junction stays a conductor but allows current to pass only in one direction – it becomes a "one-way" street. And again, if a part of doped silicon has oppositely doped silicon on either side, the part in the middle can act as a "gate" that can be opened or closed by controlling the voltage applied at the gate.

Such a three-way bit of silicon, where the middle terminal controls the current that flows between the other two, is the transistor. As the transistor is small, light, inexpensive and versatile, it set off a revolution in electronics – pocket radios, cheap TV sets, a host of control mechanisms and, best of all, the modern digital computer.



Silicon atoms in lattice



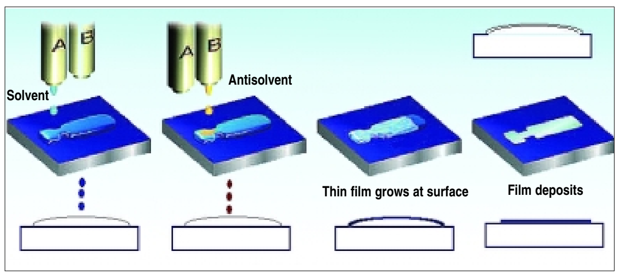
Diode and transistor

Integrated circuits

A step beyond the transistors was when a number of these and other junctions were built on a single chip of silicon crystal, with connections created by depositing layers of metal, etc. The first of such devices had five transistors built on the same silicon chip. The technology soon grew and with a deposit of material on the silicon chip in layers it was possible to build in other components, like resistors, and the number of transistors also increased. Further development enabled hundreds of transistors (Large Scale Integration and Very Large Scale Integration) and the current technology of Ultra Large Scale Integration combines millions of components on a single, albeit large, slice of silicon crystal. The growth of the personal computer and now super computers is entirely thanks to whole computer processors now being built on single silicon chips with this technology.

The trouble with and limitation of integrated circuits is they need large single crystals of silicon to be built upon. If components like transistors, or "diodes" — the "one-way gates" — are built on separate crystals, the interface does not allow the circuit to function. The entire lot of components then needs to be built on a sliver of a single crystal. Now growing large diameter single crystals, to create such slivers, or "chips", is difficult and expensive.

Crystals almost 30 cm across that are now being grown, but at astronomical cost. The processors of personal computers, for instance, need to be on slivers not more than two or three inches across to be useful and competitive. Apart from larger sizes not being available, small crystal dimensions also drive the need to miniaturise the electronics. The high currents to be handled then create great heat and the need for heat sinks and cooling arrangements arise. The effect, overall, is that the need for single crystals is a major roadblock in the way of integrated circuits.



Alternative

An alternative that has been dreamt of is creating a silicon substrate not by growing it from the ground up but by spraying it on – which should allow larger sizes and also flexibility in shape. The regular printing technologies, of depositing material on a surface, have not made much progress because semiconductor material, when deposited, rapidly forms islands of micro-crystals with interfaces that do no allow the electron or "electron hole" carriers of charge to move freely. In effect, using inks that have semiconductor material in solution or in dispersed form, or even spraying molten semiconductors to condense on a surface, have not been successful in creating the thin films with the required crystal properties.

The team of scientists in Tsukoba and Tokyo appears to have found a way out. What they have used is not semiconductor material that crystalises out of solution by evaporation of the solvent, for instance, but material that is apidly thrown out of solution using an outside agent. A supersaturated solution, which is one that has more of the solute than normal, is first prepared and sputtered on the surface. Next, specks of a complementary, *anti-solvent* are added. An anti-solvent is a liquid in which the material does not dissolve. The addition of the anti-solvent brings about the immediate and largescale release of the solute and this finally settles on the surface in crystal form.

The growth of the material by evaporation of a solvent has features like "crater formation", which is the result of more material in the solution being at the periphery of a drop than in the centre. But in the case of a deposit by anti-solvents, the thin solute is seen to be released at the surface of the solvent that is in contact with air, where the solute spreads out as an orderly crystalline layer. The film settles and fixes to the substrate as the solute evaporates and the film formed is uniform, well smoothed out as the evaporation of the solute is slow. X-ray studies, which reveal fine physical features of the order of the wavelength of X-rays, show that the films are in the form of single crystals, over long distances.

The work was done with an organic semiconductor called BTBT, using solvent and anti-solvent that easily mix and evaporate together. The technique is quite generic and shows the way for creating thin, crystalline films of many useful semiconductor materials. The work, the authors say, is "in principle a useful new way of producing transistor arrays on top of plastic substrates, which is indispensable for realizing large-area, light-weight and high-speed electronic products".

The writer can be contacted at simple-science@gmail.com

Pesticides & their uses

tapan kumar maitra **unlocks the latent chemistry**

CHEMICAL compounds used to control pests and diseases of plants, to eradicate weeds, to kill pests and microorganisms that spoil agricultural products, materials and articles and to control parasites and vectors of dangerous diseases of man and animals are called pesticides. These are classified according to chemical composition, their targets and also according to the ways they penetrate into an organism and the nature of their action.

With respect to chemical composition, three main groups of pesticides are distinguished: a) inorganic compounds (compounds of mercury, fluorine, barium, sulphur, copper and also chlorates and borates); b) pesticides of a vegetative, bacterial, and fungal origin (pyrethrins, bacterial and fungal preparations, antibiotics and phytocides); and c) organic compounds, the most extensive group including pesticides having a high physiological activity like organochlorine compounds (hexachlorocyclohexane, polychloropinene, toxaphene, heptachlor, endosulfan, dilor), organophosphorus compounds (dichlorvos, letrachlorvinfos, tri-chlorfon, parathion-methyl, fenitrothion, trichloromentafos-3, etc) and derivatives of carbamic, thio- and dithio-carbamic acids as well as nitro-derivatives of phenols, phthalimides, mineral oils and organic mercury compounds.

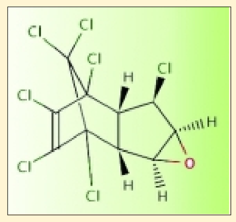
With respect to what they are used to control, all chemical formulations are divided into insecticides, acaricides (acarus-mite), insectoacaricides, ovicides (ovum-egg), larvicides, nematicides, rodenticides (for controlling harmful rodents) fungicides, bactericides, herbicides (for destroying grassy vegetation) arboricides and algicides for destroying algae.

This classification is provisional to a certain extent because many pesticides have universal action and kill larvae and mites in addition to insects. For example, fenitrothion and malathion are both insecticides and acaricides and for this reason the term insectoaca-ricides is applied to them. Many pesticides control fungal diseases as well as harmful insects and mites (for instance, DNOC, dinocap, binapacryl and sulphur formulations) and the term acarofungicides is used for them. Many herbicides when their dose is increased can destroy trees and shrubs, ie belong to arboricides.

With respect to the ways they penetrate into an organism and the nature of their action, pesticides are divided into stomach, contact formulations and fumigants. This classification makes it possible to judge how the poisons penetrate into an organism and, consequently, how they are used.

Stomach insecticides poison harmful insects when they enter their organism together with food and contact insecticides kill insects upon contact with the integument.

Fumigants are chemical substances that penetrate into the organisms of insects and animals through the respiratory tract in the form of a gas or a vapour. They also include insectoacaricides having a fumigant action that poison harmful insects and mites when they enter organisms through the respiratory tract.



Heptachlor has a stomach, contact and fumigant action.

This classification is also provisional to a certain extent because many pesticides have a stomach, contact and fumigant action. Examples are hexachlorocyclohexane and heptachlor.

All pesticides are also divided into two large groups with contact and systemic action. The former include chemical substances that kill or suppress harmful organisms upon contact with them. Pesticides with systemic action include chemical substances capable of penetrating into plants, moving in their tissues, and of causing the harmful organism (a weed, pathogen, pest) to perish as a result of feeding.

Herbicides with respect to the nature of their action are divided into selective and contact ones. At present, investigations are being conducted for studying, separating and using many biologically active substances in the protection of plants. The following groups of substances have been identified:

- **Pheromones are substances produced by insects and excreted into the surrounding medium for acting on other specimens.**
- **Attractants are substances whose odour and taste attract insects and animals.**
- **Repellents are substances whose odour and taste repel insects.**
- **Inhibitors are organic or inorganic substances of a varied chemical nature and also the products of metabolism of a cell that cause the partial or complete suppression of the activity of enzymes or metabolism in a living organism.**
- **Sterilants are various chemical substances that when introduced into an organism deprive it of the ability of reproduction.**
- **Hormones are substances with a very high biological activity that are secreted into the internal medium of an organism and control its most important functions.**
- **Anti-feedants are substances suppressing the feeding of insects.**

Among the pesticides used in the chemical protection of plants, substances having a specific action are earmarked:

- **Defoliants — substances causing the leaves of plants to fall off.**
- **Desiccants — substances accelerating the drying of standing plants.**
- **Retardants — substances retarding the rates of growth of plants, which results in their having shorter stalks and shoots.**

Every year, the State Board for Chemical Means of Controlling Pests, Plant Diseases, and Weeds under the ministry of agriculture considers the results of pesticide tests and their use in production. Subject to approval by the ministry of health, the agriculture ministry approves the "List of Chemical and Biological Means of Controlling Pests, Plant Diseases and Weeds" allowed to be used in agriculture during the forthcoming year.

The writer is associate professor in botany, Anandamohan College, Kolkata

Blessing in disguise

kaushik dey **discovers the benefits and cost-effective advantages of bioceramic implants being manufactured in India**

NO one across the world is getting any younger and millions go in for implants to maintain a quality of life as the years take their toll. The problem is the need for materials with appropriate properties that will survive as long as those who use them. Ceramics used for the repair and reconstruction of diseased or damaged parts of the musculo-skeletal system, such as bones and joints are known as bioceramics. These products are used extensively in developed countries because of their inherent advantages, but in emerging markets — and India is an example — their use has been moderate; both because of a lack of awareness and the notion that these products are priced beyond the reach of most.

That said, the benefits and advantages of bioceramic products over contemporary implants generally made of metals have been established and several research organisations in emerging countries are conducting research. In India, the Central Glass and Ceramic Research Institute in Kolkata, Sree Chitra Tirunal Institute for Medical Sciences and Technology in Trivandrum and many more are working extensively on the development of bioceramic products at affordable prices.

These products have uses in dental, oral and maxillofacial arenas, not to forget eye and orthopaedic segments. They also enjoy several advantages over comparable products presently in use. Some of the products developed by these research organisations are being made available in the market by IFGL Bio Ceramics. One of these products, the CeraEye synthetic hydroxyapatite orbital implant, is moderately priced and is available at several eye speciality hospitals, including Disha Eye Hospital and Research Centre, Barrackpore. Associated with the development of this product and with five years' experience in its implantation, Dr Arnab Biswas — consultant ophthalmic surgeon at Alo Eye Care, Kolkata, and author of "Colar Atlas of Oculoplastic and Orbital Disorder" – says, "the CeraEye implant is highly bio-compatible and porous. Tissue compatibility and integration is excellent. It has been found to be non-toxic and non-allergic in all the cases I have dealt with."

Another product is BioGraft synthetic bone grafts used for treatment/repair of infra-bony defects in the dental, oral, maxillofacial and orthopaedic segments. Periodontists use bone graft granules and blocks for rehabilitating jawbone defects to help retain teeth.

According to Dr Abhijit Chakraborty, periodontist and professor with the Guru Nanak Institute of Dental Sciences and Research — he has been actively involved in the development of the BioGraft bone graft granules and blocks with the Central Glass and Ceramic Research Institute — "The products are excellent and cost-effective. The BioGraft granules or blocks are placed directly on the application area followed by sutures.

Dr Debabrata Basu

Porus structures promote the colonisation of osteogenic cells from the patient's bloods. For large cavities, bigger granutes/pre-forms may be used together with the patient's own bone. It can also be used in conjunction with resorbable or non-resorbable membrane for Guided Tissue Regeneration."

He cautions that this procedure is not to be used for load-bearing bone defects, nor is it recommended for those with an abnormal metabolic condition, those undergoing prolonged drugs treatment or with immune-deficient syndrome.

Then there is the CeraHip, also developed by the CGCRI. Says Professor Indranil Manna, "The Central Glass & Ceramic Research Institute has started a new division for the development of different innovative biomaterials, implant devices, etc. Most of the state-of-the-art prostheses and devices are out of reach because of their exorbitant costs. Further, these items developed in the advanced countries do not suite our purpose because of the anatomical diversity and the differences in lifestyle. In addition, some diseases that commonly occur in Indian patients do not show up in the Western world and therefore the need to develop specific innovative biomaterials/implants/devices for use in our country."

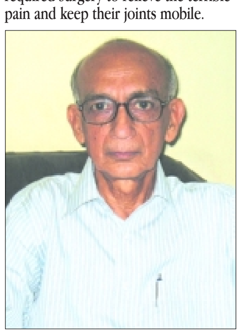
According to Dr Debabrata Basu, scientist, bioceramics and coating division, CGCRI, "It has been found that in advanced countries the need for hip joints is the highest. Due to less weight and difference of lifestyle, the demand is comparatively lower in India. Due to the crippling nature of arthritis, surgeons have been trying for well over a century to successfully treat this debilitating disease. It was clear that many people required surgery to relieve the terrible pain and keep their joints mobile. Scientists manufactured cobalt-chromium alloy in 1936, which was almost immediately applied to orthopaedics. The results remained unpredictable and arthritic destruction of the socket persisted. A large number of patients developed pain because of the loosening of the implant and the results were discouraging due to sudden breakage. The usage of ceramics has been initiated. It is now expected that the life of each ceramic-based joint will survive for at least 20 years — double that of the existing metallic joints. CGCRI has activities related to replacements for eyeballs, hips, knees, teeth, tendons."

Dr G Banerjee, technical advisor, IFGL Refractories, Ltd, says, "About 400,000 patients need hip-replacement every year and they will be greatly benefited by this state-of-the-art prosthesis within an affordable price. Service life will be longer, at least 20 years. The items available are 10 times cheaper than their Western counterparts, which makes them not only cost-effective but they come without side effects and are on a par with foreign products. These products need to be used in government-run hospitals to create awareness."

To highlight the importance of bioceramics in the present context, the CGCRI is organising an international conference, "Biomaterials and Implants – Prospects and Possibilities in the New Millennium", from 21-23 July at its Jadavpur premises. It will be attended by eminent scientists, doctors and industry representatives from India and abroad.

Dr Abhijit Chakraborty

Dr Arnab Biswas



Dr G Banerjee

Professor Indranil Manna