Departments of the Research School

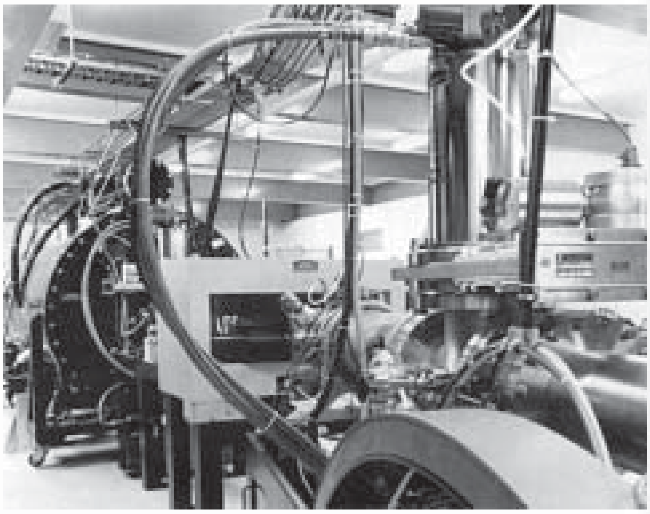
Electronic Materials Engineering

From its small foundation staff of seven people in 1988, the Department of Electronic Materials Engineering has grown to about 50 in 1995, including several visiting scientists and a number of PhD students.

The department traces its origins back to the ANU Strategic Plan and the Wilkinson review of the Research School in 1987, which identified electronic materials engineering as a field of high national promise and need. Begun as a collaborative venture with the Royal Melbourne Institute of Technology and led by Professor Jim Williams, it was the ANU's largest new venture in a decade; it is now wholly located within the ANU. Its programs, however, have a very strong national and international collaborative flavour, involving strong links with other school departments, university groups, government laboratories and industries.

In its 1994 annual report, the department noted that research, whilst covering a broad spectrum of topics, concentrated on the physics of processed materials, especially semiconductors and materials of importance to rapidly advancing communications and information technology systems. There were three main themes evolving: the emerging area of photonic materials and devices, covering processing of group III-V semiconductors as well as a range of 'optical' materials; ion beam processing of semiconductors as a major tool for studying defects and their stability, impurity diffusion, alloy and compound formation and crystallization mechanisms; and materials development and processing, in particular, using novel ball-milling methods to induce and study the formation of hard nitrides and composites and to mechanochemically enhance reduction and other solid state reactions in minerals. The department's cutting-edge research in these areas owes much to the progressive acquisition of a frontline suite of facilities for producing, processing and characterising materials. In addition to university start-up and major equipment funds, the department's rapid development of state-of-the-art experimental facilities was also facilitated by three Syndicated R&D projects in the areas of germanium-silicon materials, ultrasonic structures and devices, and hard materials.

Andrew Clark, Jim Williams, Hoe Tan, Fouad Karouta and C. Jagadish pictured in front of the MOCVD reactor.



Part of EME's "arsenal", the tandem ion implanter.

Some highlights from the recent history of the department follow.

MOCVD Growth and Photonics

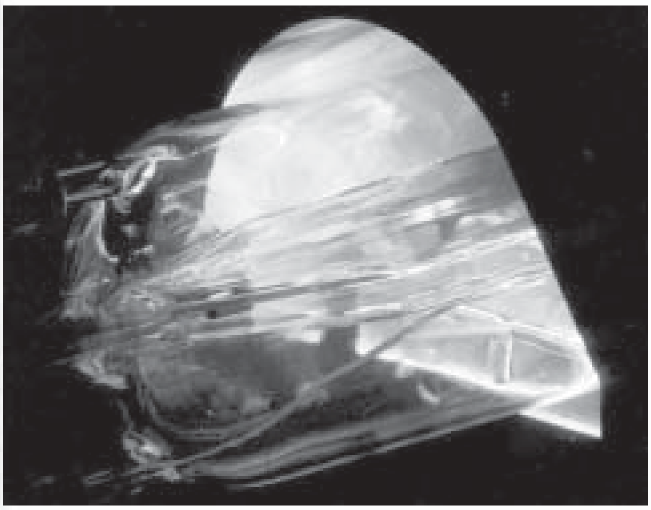
The ANU's metal-organic chemical vapour deposition (MOCVD) apparatus was installed in the EME Department in 1991. The MOCVD apparatus was chosen because of its flexibility in growing layers for special applications. It uses the MOCVD process to lay down thin layers of semi-conducting materials on a variety of substrates. This method can grow high quality semiconductor layers (as thin as a millionth of a millimetre), and the crystal structure of these layers is perfectly aligned with that of the substrate. The growth is accomplished by passing a stream of hydrogen mixed with high purity gases such as arsine and metalorganic vapours such as trimethyl gallium over a heated wafer.

The first project using this technology investigated the growth and characterisation of semiconductor layers such as gallium arsenide (GaAs) and aluminium galium arsenide (AlGaAs) crystal layers (epigrowths) suitable for a range of applications in advanced communications systems.

There were two objectives at the start, to provide a major new initiative and contribution to the science and technology of optra-electronic materials and devices, and to contribute to the establishment of a commercially viable industry based on this research.

Dr Jagadish has led the MOCVD group since early 1992. There have been several research highlights, including world records for the highest concentration and most abrupt atomic layer doping, so-called delta doping, for carbon, silicon and zinc in GaAs and AlGaAs layers. The group has also grown narrow multilayers, so-called quantum-well structures, with very interesting optical and phonon (vibrational) properties. Most recently, the group has taken giant steps towards the fabrication of practical devices based on this front line research. For example, the group has fabricated laser sources, light reflectors and modulators of the types used in CD players to record and read digital information stored on disk. Novel operating modulators at wavelengths of 550-630 nm have been produced.

Semi-conducting lasers are able to convert electrical impulses to light, and they have many uses in advanced optical communications. Indeed, EME researchers have made a range of so-called GRINSCH (Graded Index Confinement Heterostructure) lasers which have about 40 different layers of varying thickness, compositions and dopings. Some of the quantum-well layers are only seven nanometers thick. Novel growth and processing methods have been developed to tune the wavelength of the lasers by tuning the width or composition of the quantum well. Recently, EME has taken the next step to commercialising its growth and devices research by establishing a company, Australian Epitaxy, through which it hopes to market its ‘products’.



The MOCVD reactor.

Ion Beams and Materials

In 1991, the EME Department commissioned a 1.7 Megavolt tandem ion implanter for the study of controlled damaging of semiconductors, deep electrical doping, isolation of semiconductors, formation of buried compounds and phase transformations in materials. The ion beam activities are led by Dr Elliman.

With regard to defects in semiconductors, despite more than three decades of research effort, defect formation during ion bombardment of semiconductors and the evolution of secondary defects during subsequent thermal annealing is still not well understood. EME’s MeV ion implanter has been used to controllably introduce damage into Si, Si-Ge and III-V materials to study the formation and evolution of defects. New defect levels and defect-impurity complexes have been observed and the annealing behaviour has been studied to provide insight into defect complexing and the stability of defects. The crucial role of the Si interstitial in silicon, in controlling the evolution of defect structures during thermal annealing has been identified and studied. Such interstitials can decidedly influence the transient diffusion of dopants, for example. Defects can also trap impurities that diffuse through silicon. The ability of dislocations and cavities to trap metal impurities has been studied by Professor Williams and coworkers and novel diffusion and precipitation processes, particularly at cavities, have been discovered. These studies are of considerable relevance to advanced silicon device processing, where a knowledge of the processes of defect evolution during annealing, impurity diffusion and trapping is vital for predicting device performance.

Crystallization of amorphous semiconductors is the main area where EME staff have a long history of contributions. The understanding of solid phase crystallization of silicon and gallium arsenide and

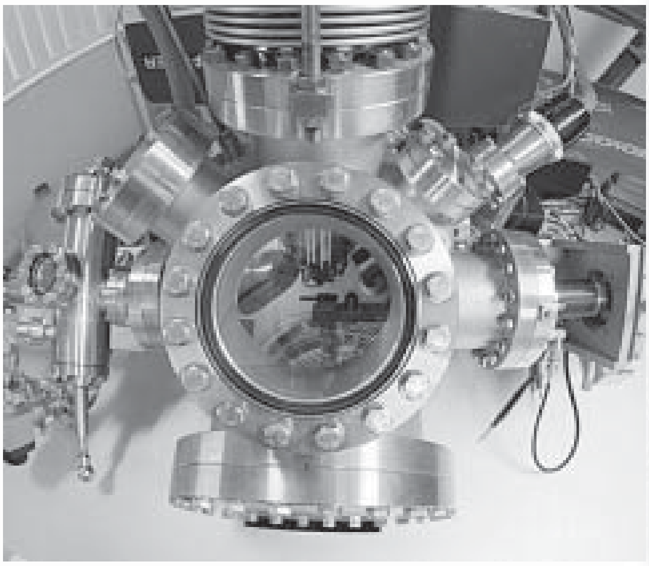
Rob Elliman and Mark Ridgway at the controls of the implanter.

the role of dopant atoms and strain on the kinetics of the process are major contributions. More recently, Dr Ridgway has studied the influence of local stoichiometry differences on crystallization of compound semiconductors, studied with in-situ optical and electron microscopy techniques to evaluate growth mechanisms.

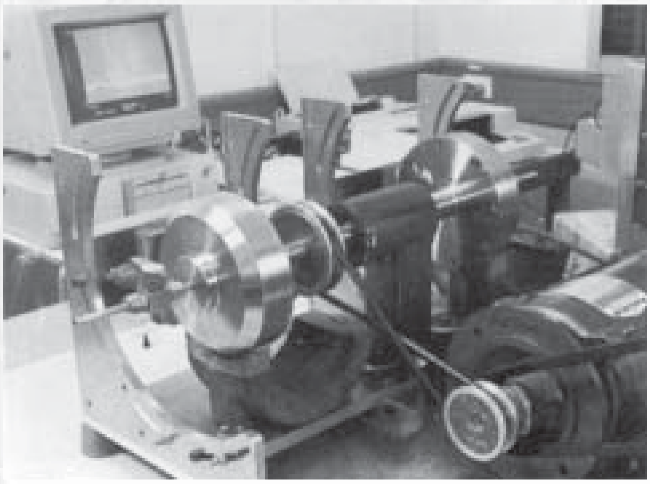
Compound and alloy formation by ion bombardment has been another area of concentration in EME. Novel Ge-Si alloys have been produced directly in Si and these structures used to make transistors which are 45% faster than comparable silicon devices. Improved buried silicon dioxide layers have also been made by implantation of MeV oxygen, and the study of this process has made important contributions to the understanding of silicon-on-insulator structures for advanced electronic circuits.

Low energy ion bombardment, using the department's secondary ion mass spectrometer (SIMS) apparatus, is also an active research area. Led by Dr Petravic, the SIMS machine has been applied to measure the composition and elemental depth profile of a number of materials, thereby contributing in a significant way to much EME materials research. However, the major contribution of the low energy bombardment research has been in understanding the modifications that such bombardment causes to surfaces and the underlying physics of the process. For example, bombardment of solids with oxygen is used to sputter surfaces and enhance positive ion yields for elemental depth profiling, but it is the process of oxide formation and the segregation of many elements at a moving oxide-substrate interface that has been a major focus of SIMS research, particularly for trace metals in silicon. In addition, Dr Petravic and coworkers discovered that electron bombardment of semiconductor and insulator surfaces caused very high positive and negative ion yields of surface contaminants such as H, O, F, etc. These studies uncovered completely new (and efficient) mechanisms for electron stimulated desorption of ions from surfaces.

Finally, the technique developed by Drs Ridgway and Elliman at EME involved irradiating an electronic integrated circuit with high energy ions in the ion implanter to isolate individual components electrically from each other to avoid circuit failure. Ion beam induced isolation was a well established technology for standard gallium arsenide integrated circuits. However, many of the latest high speed transistors used in telecommunications systems are much thicker and conventional ion implantation systems have proved ineffective and cumbersome. The unique high energy capability of the EME ion implanter circumvents such problems and results in considerable process simplification for the manufacture of advanced electronic devices. This new method should provide considerable cost savings in the production of electronic devices by reducing the time and complexity of manufacture.



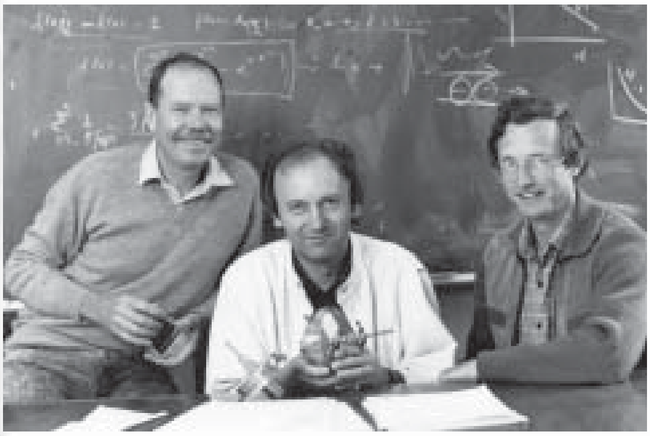
The Secondary Ion Mass Spectrometer.



The prototype Uni-Ball Mill.

Ball milling

Ball milling is a very old technology for crushing ores, mixing powders and particle size reduction, but only recently has the technology been used to synthesise and reduce materials. Around 1990, Dr Calka at EME devised the Uni-Ball Mill, in which the ball movements were very accurately controlled using an external magnet. This elegantly simple idea has opened up many new possibilities, at a time when high technology requires new materials with optimum qualities of toughness, conductivity, durability, etc. In joint projects between EME and the Department of Applied Mathematics, many new types of materials, some never seen before, have been made directly, at room temperature. These include aluminium-based alloys as well as semiconductor and magnetic materials, hard cutting materials, non corrosive steels, many different kinds of nitrides, and zeolites used in catalysis for extracting oil.



∆ *From left, Barry Ninham, head of Applied Mathematics, Andrzei Calka and Jim Williams.*

One of the EME's "workhorse" laboratory mills. ▻

In one project partly funded under a GIRD grant sponsored by Westralian Sands Limited, ball milling of minerals has been studied in an attempt to improve the extraction of desired products. For example, ilmenite (a mixed oxide phase of Ti and Fe) can be activated by controlling ball milling in such a manner that allows efficient leaching of Fe (in acid) and ready extraction of TiO_2. With appropriate additives, a chemical reduction appears to take place during milling. Other complex mineral oxides such as zircon sands can also be reduced by this process, as well as beneficial particle size reduction in magnetic ferrites to enhance magnetic properties.

A particular attempt has also been made to understand the processes which occur during milling at room temperature. For example, the effect of milling conditions on rate of reaction of Ti with NH_3 (ammonia) has been studied by monitoring gas pressure changes in the mill as a function of time. This method has uncovered the individual steps in the milling process that involve particle size reduction, gas absorption and dissociation on new surfaces, reaction and indiffusion of hydrogen to form a brittle hydride, fracturing of the hydride, and finally slow reaction of nitrogen with unreacted Ti and with TiH_2 to form TiN, which is a very hard, industrially attractive material.

Jim Williams