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Elected FRS 1998

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Ronald Charles (Ron) Newman was one of the most versatile semiconductor physicists of his generation and is distinguished for his work in several different areas, most notably epitaxial growth and the behaviour of impurities and dopants in a range of device-related materials, mainly silicon and gallium arsenide. His most significant contributions came from the application of local vibrational-mode spectroscopy to studies of the segregation and diffusion of oxygen and hydrogen in silicon. The results were of fundamental importance in the fabrication of integrated circuits.

EARLY YEARS

Ronald Charles Newman (Ron to family, friends and colleagues) was born on 10 December 1931 in Edmonton, north London. He was the only son of Charles and Margaret Newman but had a younger sister, Rita May. Like many of that generation, his father was unable, for financial reasons, to take up a scholarship, but nevertheless had a successful career in the Post Office and took a keen, if non-professional, interest in science and mathematics. As a result he strongly encouraged Ron during his early education.

Ron’s schooling started at the Bruce Grove Infant School in Edmonton, from where he moved on to the Junior School. Despite the Blitz, his family decided to stay together in London, so Ron was not evacuated and he believed this meant that his education was less impaired than those of his peer group who were evacuated. His final school move was to the Tottenham Grammar School in White Hart Lane, where in 1949 he passed the ‘standard four’ Higher School Certificate subjects for potential physical science degree students (pure mathematics, applied mathematics, chemistry and physics), but was disappointed not to be awarded a State Scholarship.

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He was also disappointed that his applications to several universities to study physics, based on these results, were unsuccessful and he was told he should remain at school for a further year. However, Imperial College, which had its own entrance examination, offered him a place provided that he passed their examination, which he duly did and he started his undergraduate studies in September 1949. He enjoyed his course and fulfilled his early promise when he was awarded a first-class honours BSc degree in physics in 1952.

POSTGRADUATE RESEARCH AT IMPERIAL COLLEGE

After graduation, Ron was offered a research studentship to work in the group of the then Head of Department, Sir George Thomson FRS, on electron diffraction, although he had expressed a strong preference to study high-energy nuclear reactions and cosmic rays. These were, however, the days when research students did not choose their own topic but instead followed the requirements of the Head of Department or Group. So Ron worked on electron diffraction with a grant of £220 per year provided by the Department of Scientific and Industrial Research, one of the precursors of the present Engineering and Physical Sciences Research Council (EPSRC). This was the start of Ron’s work on thin films, one of the two main areas he pursued during his research career. The other was local vibrational-mode (LVM) spectroscopy (see below). His thin-film work in the modern idiom would be characterized as ‘nanoscience’, but it took almost another 50 years for this ‘new’ subject to be ‘invented’ and to spawn a plethora of books, papers, conferences and popular articles.

Sir George, known as GP, soon moved to become Master of Corpus Christi College, Cambridge; Ron’s new supervisor was Professor Morris Blackman (FRS 1962) and he also collaborated with the late Don Pashley, who was then a postdoctoral research assistant and subsequently Professor D. W. Pashley (FRS 1968). This relationship was to be resumed at Imperial College, London, many years later (see below).

The basic equipment that Ron used for his research was an electron diffraction camera that had been built in the department in the prewar years but which had a few deficiencies in its vacuum system that had to be resolved. His initial topic concerned the growth and characterization by reflection high-energy electron diffraction of electrodeposited Ni films on single-crystal Cu substrates. Earlier work by Dr W. Cochrane at Imperial College had proved to be ambiguous because it involved the concept of pseudomorphism, a very contentious issue at the time among those groups working on epitaxy. The basic idea is very simple: the growing film takes up the lattice parameter of the substrate and so becomes distorted. Blackman was very reluctant to accept this, but F. C. (later Sir Charles) Frank (FRS 1954) and J. H. (later Professor) van der Merwe published a theory of epitaxy in which the initial stage of film growth was a pseudomorphic monolayer (Frank & van der Merwe 1949a,b, 1950). As the thickness of the growing film increased, a transition occurred to give a strain-free oriented deposit. Ron therefore had to solve what at the time was the very difficult problem of measuring the thickness of very thin films, down to sub-monolayer dimensions. He used a method based on radioactive deposits and chose electrodeposited $^{60}$Co on Cu, but he found that there was dissolution and then redeposition of the Cu substrate atoms, which confused the effect of the Co. As a result it was concluded that pseudomorphic growth had not occurred; however, subsequent work showed that it could happen and the use of radioactive materials could provide thickness measurement for monolayer films.
Following a suggestion by Blackman, Ron’s PhD studies moved to the deposition of thin films by evaporation *in situ* in a new diffraction camera, which was built very successfully in the department’s workshop. It even had a facility for automatic photographic recording of the diffraction pattern as a function of time, and the machine drawings were subsequently used by Surrey and Queen’s (Belfast) universities, as well as the Atomic Weapons Research Establishment and the Atomic Energy Research Establishment, Harwell. The only problem was that vacuum pumps available at the time could not produce a low enough base pressure to avoid surface contamination. Nevertheless Ron was able to study thin epitaxial films of several different metals on single-crystal Ag substrates, that were able in large part to resist contamination. The comparatively poor vacuum did, however, result in some surface contamination, which explained the absence of pseudomorphic growth in these experiments.

Ron was awarded a PhD in September 1955 for a thesis entitled ‘The deposition and orientation of thin metallic films on single crystal substrates’. Armed with this PhD he quickly secured an appointment at the Central Research Laboratories of AEI at Aldermaston Court in Berkshire, and as a result was not called up for National Service by virtue of certain government contracts having been awarded to that establishment.

**ASSOCIATED ELECTRIC INDUSTRIES (AEI) CENTRAL RESEARCH LABORATORIES, ALDERMaston COURT, BERTHSHIRE, 1955–63**

Having accepted this offer from the director, Professor T. E. Allibone FRS, to join the laboratory, Ron commenced work on single-crystal silicon, the ‘wonder material’ of the time. Support came from Ministry of Defence contracts and, as was common then, Ron was able to choose his own research topic from within the scope of the contract, which came as something of a surprise. It did, however, give him the opportunity to pursue several rather different areas. His first project was to study the surface morphology of silicon after the high-temperature treatment used in dopant diffusion experiments. For this, he developed the technique of reflection electron microscopy at a Bragg angle to reduce inelastic scattering (1)*, but although the results were encouraging the subject was not pursued further until work at the Nippon Telegraph and Telephone Laboratories in Japan in 1988, when the same technique was used to study step growth on silicon and gallium arsenide layers grown by molecular beam epitaxy.

The most important work Ron undertook at this stage of his career was in collaboration with Dr (later Professor) Ron Bullough (FRS 1985). They joined the AEI Laboratories on the same day, and became lifelong family friends. Their joint study at this time concerned investigations of impurity diffusion in metals and semiconductors and combined theory with experiment, with Ron (Newman) being largely responsible for the experimental work (2–6). This was carried out principally on silicon using infrared microscopy and absorption measurements and enabled impurity precipitation of oxygen and carbon on dislocations and grain boundaries to be directly observed in thin silicon wafers. Ron found this combination of theory and experiment to be an ideal way of working, and throughout the rest of his career he collaborated with several other theorists, including Dr Mike Sangster and Dr Roy Leigh at Reading University and Professor Bob Jones at Exeter University.

* Numbers in this form refer to the bibliography at the end of the text.
The identification and quantification of various spurious impurities in silicon ingots was an important outcome of this project, and included silicon carbide particles and isotopes of carbon. These analyses were carried out by measuring the integrated carbon LVMs, and this technique probably became the most important of Ron’s contributions to the basic science of semiconductor materials. Certainly, the work on carbon in silicon (7) proved to be of fundamental importance in the fabrication of silicon integrated circuits, which were developed some years after these studies.

During this period of his career he also had a brief involvement with the homoepitaxial growth of silicon and germanium films, but AEI showed little or no interest in the subject and it was dropped. When AEI moved its semiconductor activities to Rugby in 1963 Ron moved there briefly, but it was not a happy experience and in the following year he moved to the Physics Department at Reading University.

**Physics Department, University of Reading, 1964–88**

Ron took up a lectureship at Reading, offered by William (Bill) (later Sir William) Mitchell (FRS 1986) in 1964, but his early experiences there were inauspicious. He had no laboratory space, no equipment, no research funds, no research students and very little teaching and was not helped by other members of staff ‘doing their own thing’. This was a bleak state of affairs by any reckoning. His first application for funding was to the government’s Defence Committee for Valve Development (DCVD) for work on silicon, but it was rejected on the grounds that ‘they knew all that was necessary to make the devices they needed’. Such a response to a materials physicist from the bureaucrats is not unheard of in today’s world of ‘impact rating’ used by the Research Councils.

However, after a visit to Professor Cyril Hilsum (FRS 1979), then at the Royal Signals and Radar Establishment (RSRE), Malvern, his next application, for the study of optical crystals containing rare-earth and hydrogen (or deuterium) impurities, was much more successful. This activity involved combined LVM and electron paramagnetic resonance measurements and led to the understanding of the structure and symmetries of rare-earth–hydrogen (deuterium) complexes in cadmium fluoride, strontium fluoride and related optical crystals. It marked the beginning of his work on hydrogen pairing with impurities in silicon and several III–V compound semiconductors, including gallium arsenide, aluminium arsenide, indium phosphide and indium gallium arsenide. It was evident from the LVM measurements on Czochralski-grown silicon that considerable improvements in crystal quality were required, a finding that vindicated his original proposal to DCVD on silicon.

Despite a very significant body of work being produced at Reading, including collaboration with several national groups, together with Ron’s promotion to Reader in 1969 and to a personal chair in 1975, it became clear over time that the department was rather rapidly reducing staff numbers and that no finances were available to replace them. He was, however, able to solve a difficult scientific problem during this period, related to the limited intrinsic resolution of infrared measurements of the LVMs of impurities in semiconductors. He was using a grating spectrometer at the time in the study of thin epitaxial films, but the solution was to replace it with a Fourier transform infrared (FTIR) spectrometer that had become commercially available. This greatly improved the resolution and provided the mainstay for much of Ron’s subsequent work.
It was around this time that Bill Mitchell managed to persuade the then Prime Minister, Margaret Thatcher FRS, that it would be a good idea to set up so-called Interdisciplinary Research Centres (IRCs) within universities because existing departments were too concerned with their own subjects rather than looking at the broader aspects of research topics. The decision to go ahead with these centres was almost certainly inspired by the award of the Nobel Prize in Physics to Alex Müller and Georg Bednorz in 1987 for their discovery of high-temperature superconductors. Mrs Thatcher saw the commercial potential (never fully realized) of these materials, but learned that there was no related work in the UK; the first IRC was set up in Cambridge soon afterwards for the study of this topic. It involved a number of departments of the university, including Physics, Materials Science and Electrical Engineering, working under a single director with generous Research Council backing. Bill Mitchell was a keen proponent of such centres and several more soon followed, including one for Semiconductor Materials based at Imperial College, London (then Imperial College of Science, Technology and Medicine), but University College London and Queen Mary College, London, were also directly involved.

With the gradual demise of physics at Reading, and probably encouraged by his old mentor, Bill Mitchell, who was then at Oxford, Ron was offered and accepted a post as an associate director of the Semiconductor Materials IRC, commencing work there in 1989.

**RETURN TO IMPERIAL COLLEGE AND THE IRC FOR SEMICONDUCTOR MATERIALS, 1989–99**

Along with two colleagues from Reading, Dr (now Professor) Ray Murray and Mr John Tucker, Ron moved back to Imperial College on 1 January 1989 as an associate director of the IRC, but it cannot be said that he was overjoyed with the situation he found there. The promised new accommodation did not materialize, because Imperial College was rather more concerned with the establishment of a new School of Business Studies at the time, and the allocation of space was less than ideal. In the event, however, Ron was provided with a large refurbished laboratory very close to the IRC administrative offices and he relocated four infrared spectrometers, including the FTIR machine and other equipment from Reading, with the help of Ray Murray and John Tucker. He was also very pleased to meet up with an old colleague from his AEI days, Mr Jim Neave, who had moved from Philips Research Laboratories (PRL), Redhill, with the director of the IRC, Professor Bruce Joyce (FRS 2000). Ray Murray did not stay with Ron for very long, though, because he preferred to set up his own activity on photoluminescence, an area of considerable importance to the overall IRC programme. John Tucker stayed rather longer, but he eventually moved to an administrative role within the IRC. Ron did, however, recruit some excellent postdoctoral workers and research students to help support his work.

His other main disappointment in the early stages was not being invited to meetings on epitaxy for the growth of low-dimensional semiconductor structures, one of the main topics of the IRC’s programme. However, this probably more reflected the differences in formality between Ron and the IRC’s director, Bruce Joyce, who was keen to establish the very informal regime he had enjoyed at PRL, where meetings tended to occur over coffee. Whatever the reason, it was clear that Ron was unhappy during the early days of the IRC, but it is perhaps worth noting that an IRC represented something very different from a conventional university.
department. They had responsibility only for research, not undergraduate teaching, and also had a maximum lifespan of 10 years. Ron did, however, have a real champion during this time in the form of the late Professor Tony Stradling, a member of the Physics Department, who very much shared Ron’s views on protocol.

IRCs were also committed to collaboration with UK industry, unfortunately just at the time when virtually all of the industrial semiconductor laboratories either had closed or were in the process of closing. Nevertheless, the IRC was told by the EPSRC that it must formally collaborate with UK industry or its funding would not continue. To this end, Professor Gareth Parry, then at University College London and an expert on semiconductor lasers, was made co-director, while £800,000 of the IRC funding was transferred annually to the EPSRC-supported III–V Centre at the University of Sheffield to pursue a more device and industry-focused programme. Apart from PRL’s very generous help to Bruce Joyce, with gifts of equipment and laboratory space with associated running costs, there was no support at all from any other company within the semiconductor sector of UK industry. Fortunately, however, the Japanese Government provided £5 million for a joint project directed by Professor Dimitri Vvedensky, associate director of the IRC, and Bruce Joyce, with no strings attached to the nature of the work to be undertaken.

Despite these internal difficulties, which were mainly procedural, Ron’s work on infrared flourished and included several collaborations with other universities and also with industry. As well as extending particular investigations, this was a requirement imposed by the EPSRC on the manner in which IRCs must operate: they were well funded, but the degree of control of their programmes was significant. Ron’s principal area of interest during this time related to identifying and understanding the properties of crystal defects and impurity atoms in Si and a range of III–V compound semiconductors, mainly using infrared absorption, but collaboratively including the use of Raman, X-ray and neutron scattering. His infrared work was greatly facilitated by the purchase of a Bruker interferometer by the IRC, with a resolution of 0.01 cm\(^{-1}\) and a very low noise level. The studies also benefited significantly from inputs by the theorists at Exeter and Reading universities.

It seems appropriate at this point to include a little more scientific detail of Ron’s major area of activity on silicon (8–18), because it is such a vital material in all our lives today. Work on all aspects of silicon technology is a huge worldwide effort to develop and produce the devices that underpin our present lifestyles, but without knowledge of its basic material behaviour, none of this would be possible. Ron was truly one of the pioneers of understanding diffusion and impurity effects in silicon crystals. The principal impurity in this context is oxygen and its importance to intrinsic gettering. Oxygen can form small clusters at temperatures below 500 °C and precipitates of SiO\(_2\) at temperatures above 600 °C. Fast-diffusing metallic impurities, which are extremely detrimental to device action, can be trapped by these particles. The rate of oxygen diffusion is enhanced by hydrogen, and Ron’s group examined in detail several aspects of this: (i) small oxygen clusters complexed with a hydrogen atom; (ii) an oxygen atom paired with a hydrogen atom; (iii) the possibility of O\(_2\) molecules being present in boron-doped silicon; and (iv) the solubility of hydrogen as a function of the Fermi level at the annealing temperature.

By heating Czochralski silicon in either hydrogen or deuterium gas at 1300 °C and atmospheric pressure, followed by quenching and subsequent heating at 470 °C, the group showed that families of shallow donors and thermal shallow donor centres with progressively
larger oxygen clusters were formed. From shifts in the infrared spectra they deduced that anharmonic coupling of the H atom to other atoms in the core of the centres occurred, and concluded that hydrogen atoms diffused to thermal donor defects and were then trapped to form single donors.

The effects occurring with hydrogen in boron-doped silicon, which related to the fabrication of high-quality microprocessor devices based on active structures in a p-type epitaxial layer grown on a p⁺ substrate, were also investigated. When boron-doped silicon is heated at high temperature (ca. 900 °C) in hydrogen at atmospheric pressure, the molecules dissociate at the surface and the atoms diffuse very rapidly throughout the sample. If such samples are quenched, some of the diffusing atoms become trapped by the boron acceptors and form close pairs. About 30% of the in-diffused H forms such pairs and the remainder is non-active. A low-temperature (ca. 175 °C) anneal, however, activates these remaining H atoms, but details of this ‘double activation’ are not clear. Nor is the location of the H atoms before the low-temperature pairing occurs. Nevertheless, Ron did propose a possible mechanism by invoking a fast-diffusing metallic impurity species that catalysed the dissociation of H₂ molecules. In addition, Ron and his group were also the first to detect the presence of hydrogen molecules in Si, and to measure the solubility of hydrogen together with its low-temperature diffusivity, using infrared absorption spectroscopy.

**POST-IRC: THE CENTRE FOR ELECTRONIC MATERIALS AND DEVICES AT IMPERIAL COLLEGE, LONDON**

The rule established by the EPSRC for the IRCs was that they were to be funded for only 10 years, after which time they would be closed or would transform into different organizations with alternative funding. In the case of the Semiconductor Materials IRC, funding formally ceased in April 1999 and it became the Centre for Electronic Materials and Devices, directed by Professor Gareth Parry, a co-director of the IRC. The other co-director, Professor Bruce Joyce, became an Emeritus Professor and Senior Research Investigator in the Department of Physics. Ron spent 18 months in the new centre before he retired, but one of the consequences was that his co-workers at the time, Dr Ashwin, Dr Pritchard and Dr Davidson, all moved to new projects, while John Tucker formally retired and left Imperial College. Ron’s main area of activity during his time with the new centre was to study further the behaviour of hydrogen in Si.

During this period, as well as being appointed an Emeritus Professor and Senior Research Investigator at Imperial College London, Ron also continued his Visiting Professorship at Reading University and was appointed to a Visiting Professorship at the then University of Manchester Institute of Science and Technology, and as an EPSRC consultant, to enable him to continue his work on hydrogen in silicon.

In the year leading up to the change, Ron learned that he had been elected a Fellow of the Royal Society and he returned early from a Gordon Research Conference in New Hampshire, USA, to attend the formal ceremony with his wife Jill, other members of his family and Professor and Mrs Bullough. His election gave him enormous pleasure.
Biographical Memoirs

Professional and personal interests and achievements

Ron Newman was internationally renowned as a semiconductor physicist whose major achievements were in the field of impurity and dopant behaviour in silicon and III–V compounds. It was his application of LVM spectroscopy in particular that led to his being regarded as a leading world figure, especially for his work on carbon and oxygen impurities in silicon. Even conventional retirement did not see the end of his research contributions, and his favourite quotation in this regard, attributed to Harold Macmillan FRS, was ‘The past should be a springboard, not a sofa.’

Ron was a stereotypical Englishman, perhaps best illustrated by the way in which he sought out the nearest McDonald's on visits to countries where exotic food was served, most notably Japan. Nevertheless, overseas travel was one of his favourite pastimes, and he visited many parts of the world, accompanied by his wife when work was not involved.

He met his wife, Jill Weeks, at a church youth club when he was only 16 years old, and 8 years later they were married, on 7 April 1956. They had two daughters: Susan, born in 1959, and Vivienne, born in 1962, and eventually four grandchildren. Susan worked in banking and stockbroking and married Michael Lee; they have two children, a boy and girl. Vivienne worked in local government, specializing in software problems, and married Christopher Cadman; they have two daughters.

There is little doubt that science, and of course his family, had a very dominant influence on Ron’s life, but especially in his younger days he had several outside interests and hobbies that were well removed from the laboratory. These included cycling and the Youth Hostel Association, sea fishing in the English Channel (figure 1), walking in the Scottish Highlands,

Figure 1. Ron enjoyed deep-sea fishing in the English Channel, where he caught numerous cod and ray. (Online version in colour.)
Ronald Charles Newman

Ron loved foreign travel and visited numerous countries. One of his favourites was Australia despite having to wear a mosquito net! (Online version in colour.)

Unfortunately, Ron’s later years were blighted by ill-health, but he received devoted care from Jill and his family during this time.

Awards and Committee Appointments

1971  Fellow of the Institute of Physics
1982–85  Defence Scientific and Advisory Council: Electronic Materials and Devices, MoD
1985–88  Physics Committee, Science and Engineering Research Council (SERC)
         Semiconductor and Surfaces Subcommittee, SERC
         Neutron Beam Research Committee, SERC
         Semiconductor Group Committee, Institute of Physics
1988–91  Silicon Technology Committee, SERC/Department of Trade and Industry
1998  Fellow of the Royal Society
Acknowledgements

I am indebted to Mrs Jill Newman, who requested me to write this memoir of her husband and for providing me with a copy of Ron’s autobiographical notes. I am also very grateful to Ron’s son-in-law, Mr Chris Cadman, for an electronic version of Ron’s complete list of publications.

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