

Walter Eric Spear

Walter Spear, whose work laid the foundations for thin film displays and large area electronics, died on 21st February 2008 in Dundee. He was born on 20th January 1921 in Frankfurt on Main. His father, who came from an old-established Jewish family in the Odenwald, not far from Heidelberg, was a graphic artist who eventually turned towards photography, pioneering colour photography and processing. His mother, the daughter of a Lutheran pastor, was a professional violinist, a well-known soloist and teacher in Frankfurt. He grew up in an atmosphere of musical activity which led to a lifelong love of chamber music. He began violoncello lessons on a half-size instrument at the age of eight. A few years later he inherited a beautiful seventeenth century Italian 'cello which he played and cherished all his life.

By the time he had completed his final school examinations in 1938, the Nazi persecution of Jewish and partly Jewish persons made life extremely difficult for his family. Through the generous efforts of friends and relatives in Britain, the family was able to join them and escape imminent arrest and deportation.

Walter arrived in London with his suitcase and cello. He was determined to follow a scientific career and as a first step, he attended evening classes to work for the Entrance Examination of the University of London which he duly attained. At that point all members of the family were briefly interned on the Isle of Man. By 1940 he had joined the Pioneer Corps, later transferring to the Royal Artillery. He was demobilized in 1946 with the rank of 'Bombardier' and returned to London where he enrolled for an External London University Physics degree at the Regent Street Polytechnic, supported by a modest Further Education Grant.

In 1947 he was accepted by Professor J.D. Bernal of Birkbeck College, University of London to work for a PhD degree in the newly established Crystallography Research Laboratory. His supervisor was Werner Ehrenberg and his project was in the field of electron optics, aimed at investigating and developing a compact electrostatic focusing system to produce an intense, fine electron focus with applications in a fine focus X-ray tube, which could open up new possibilities in crystallographic studies of complex organic molecules and virus structures. At that time, like many of his contemporaries because of lack of finance, basic apparatus had to be constructed from EX-MOD stock and from captured German equipment. By 1949 he had designed and built an elegant demountable all-metal X-ray tube using the small but very effective electron optical system he had developed. This development played an important role in the discovery of the DNA structure. In 1950 Bernal gave one of his X-ray tubes to Maurice Wilkins of King's College London, for work on the DNA structure. Diffraction patterns were obtained with this X-ray tube that provided important experimental evidence for the eventual double helix interpretation of the DNA structure.

He graduated with a PhD in 1950 and obtained a College Fellowship which enabled him to continue research and lecture at Birkbeck College. In 1952 he married Hilda King who at that time was doing postgraduate work in English Literature at Birkbeck College. It was to be a happy marriage with many common interests.

In 1953 he left Birkbeck College to take up a lectureship at the then University College of Leicester. Initially he managed to gather enough equipment to continue the work he had started at Birkbeck after his PhD, and he investigated the electron bombardment of dielectric layers. The most interesting results that he obtained in this work came from the study of amorphous selenium films. He recognised that this material was an electronic system with two mobile carriers and remarkably long lifetimes for excess electrons and holes. This gave him the idea of extending the investigation into the time-resolved domain, which proved a fruitful approach for much of his subsequent research on transport properties. Typical transit times of carriers in amorphous selenium were in the microsecond range, much shorter than the dielectric relaxation time of the highly insulating material; in this respect the approach differed fundamentally from the well-known Shockley-Haynes experiment in crystalline semiconductors. He interpreted the results of these experiments in terms of a multi-trapping transport. Although this was received with considerable doubt at the time, it turned out to be correct.

During his period at Leicester he established a successful research group specifically for the study of low-mobility amorphous and crystalline solids. Throughout this time the Xerox Corporation was greatly interested in his work and appointed him as a consultant, providing funding support for

research of common interest. He was also a consultant for EMI where he was involved in Vidicon image tube development.

In the 1960s he embarked on a number of successful new research projects. These included work on the transient interaction of generated excess electrons (and holes) with acoustic phonons in CdS and ZnS crystals with his research student and eventually his long-time research colleague, Peter LeComber. A detailed study of transport mechanisms in orthorhombic sulphur crystals, where the results fitted Holstein's small polaron transport theory, was also made as well as a study of the fundamental relation between transport and band structure where simple solids such as rare gas crystals of argon, krypton and xenon were ideal materials.

In 1968, after fourteen years at Leicester, he was appointed to the Harris Chair of Physics at the University of Dundee, where he was offered the Jute Shed, a large refurbished old stone building, as his research area. This had been a former jute store that was located in the Geddes Quadrangle of the University opposite the main Carnegie Physics Building. In 1972 he was elected to the Royal Society of Edinburgh.

This period of his research was to prove the most productive and significant in both fundamental research and potential applications in consumer electronics. He decided with Peter LeComber that one of the main research aims in the new laboratory should be to obtain meaningful experimental tests of Mott's electronic models of the non-crystalline state. They had been in close contact with Nevill Mott throughout the 1960s through their common interest in the physics of the non-crystalline state. It was decided that a study of amorphous silicon (*a*-Si) would be a suitable model material, and comparison of optical and electrical properties with the crystalline counterpart would be informative. It was soon found that deposition of *a*-Si films from silane in a radio frequency glow discharge had considerable potential in the study of the basic electronic properties of disordered semiconductors by comparison with films prepared by other techniques, where structural defects obscured phenomena associated with structural disorder relevant to Mott's work. In his 1977 Nobel Lecture, Mott was later to highlight the brilliant experimental work of Walter and Peter on amorphous silicon deposited from SiH₄ in a glow discharge.

The early work by his research group on *a*-Si showed clearly that the density and distribution of localised states in the forbidden gap of an amorphous semiconductor is of crucial importance in determining its properties. The first field effect studies of *a*-Si were also carried out during this time, and gave an indication of the state distribution in the gap of *a*-Si. This work also laid the foundations for the subsequent *a*-Si field effect transistor development. The next development, and perhaps the most important breakthrough in the field, was achieved in 1975 when contrary to the prevailing opinion, the Dundee group was able to demonstrate that r.f. plasma-deposited *a*-Si (and *a*-Ge) could be doped very effectively and accurately from the gas phase during deposition. Measurements on the first amorphous electronic device, an *a*-Si *p-n* junction, were then published by the Dundee team. Photovoltaic activity of the devices was reported, and at this time the group also took part in the world-wide investigation of the potential large area photovoltaic applications of *a*-Si.

Throughout the 1970s Walter and his group began to extend the range of experimental work to enhance understanding of *a*-Si. These included studies of the effect of *n*-type doping on the movement of the Fermi energy, thermoelectric power studies of the movement of the Fermi energy of *a*-Si and *a*-Ge with temperature, doping and deposition conditions, study of electronic properties as a function of hydrogen content in *a*-Si and the investigation of the Hall effect in *n*- and *p*-type *a*-Si, where Peter LeComber and David Jones discovered a curious double reversal in the sign of the Hall coefficient – negative for *p*-type samples and positive for *n*-type material, opposite to that expected from classical theory. The theoretical work of Friedman, based on small polaron theory, had shown that that the interpretation of the Hall effect in a solid lacking long-range order is fundamentally different from that in the crystalline material. He predicted a single sign reversal (the *p-n* anomaly) and indeed a straightforward satisfactory explanation of the observed double reversal still poses theoretical problems.

By the late 1970s Walter's achievements became more widely recognised. In 1976 he was awarded the European Physical Society Europhysics Prize, in 1977 he was awarded the Max Born Medal by the Institute of Physics and the German Physical Society. In 1980 he was elected to the

Royal Society and in that year the Royal Society of Edinburgh presented him with its Makdougall-Brisbane Medal for his work in the field of amorphous semiconductors. In 1988 he was awarded the Rank Prize in Optoelectronics.

During the 1980s his fundamental studies of amorphous materials continued. Mobility measurements in *a*-Si were extended to higher and also lower temperatures, and transport in compensated *a*-Si was studied. At about this time, Japanese researchers had found that by modifying the plasma preparation conditions, nanocrystalline silicon films could be prepared, and an investigation was made of the electronic properties of nanocrystalline silicon as a function of crystallite size. The anomalous sign of the Hall effect was found to revert to that predicted by classical theory at crystallite sizes of 2-3 nm.

His interest in device applications, particularly of *a*-Si, increased during this period. It was clear that the doping in the amorphous phase had opened up exciting new possibilities for plasma-deposited device structures. Thin layers composed of *p*, *n* and *i* sections, as well as SiN_x and SiC_x insulating regions, could be produced in a continuous deposition process on a range of substrate materials. There was no fundamental limit to the size of the deposited films; a factor which would be important in large area applications. At this point, as the leading laboratory in this field, the group were approached by an increasing number of UK and European industrial laboratories for help and collaboration on new device ideas.

In the applied field, two important developments were pioneered by Walter and his colleagues, Peter LeComber and Tony Snell in the 1980s. The first was the *a*-Si field effect transistor. The fabrication of minute arrays of these FETs at Dundee was the forerunner of the matrix of millions of these devices that now form the vital pixel switching elements in the now ubiquitous large-area liquid-crystal colour displays. This development was the critical step in spawning a multi-billion pound industry.

The second device development arose from collaboration with Alan Owen and colleagues at the University of Edinburgh. It was based on the discovery that certain metal/*a*-Si junctions, such as a Cr-*p*⁺-*n*-*i*-Cr, behaved after forming, as an electronically non-volatile element. This device was found to exist in two states that differ in electrical conductivity by several orders of magnitude, the state remaining unchanged if the supply voltage was removed. Small voltage pulses of opposite polarity, a few nanoseconds in duration, could change the memory state. The initial work indicated that in terms of speed, retention time and stability, these thin film memory elements compared very favourably with crystalline devices used for non-volatile, programmable storage available at that time. The first joint paper on this work by collaborating groups was awarded the 1981-1982 Maxwell Premium of the IEE. A further joint project involved the application of these memory elements in artificial neural networks.

In 1988 he was invited to present the Royal Society Bakerian Lecture on '*Amorphous Semiconductors: a new generation of electronic materials*'. Two years later he was awarded the Rumford Medal of the Royal Society. He retired soon after this, in 1990. In his retirement he enjoyed the freedom to become involved in many of the activities he had not had time for during an active scientific career. Walter and Hilda decided that they should move from their large family house. They split up their large garden and built a smaller modern house which they designed themselves. Walter installed some of the customised electrical fittings and did the internal carpentry. During his retirement he returned to his early love, chamber music. He met regularly with several pianist friends and enjoyed the classical cello sonata repertoire. He also enjoyed reading British, German and French literature. Walter and Hilda also enjoyed visits from their two grandchildren who lived close to their home.

Walter Spear was a true experimentalist who enjoyed working with equipment and interpreting the complexities of the movement of charge carriers through disordered materials. He was also a gifted teacher, and he was proud that many of his students went on to form important research groups across Europe and the USA.

He is survived by Hilda, his two daughters, Gillian and Kathryn and his two grandchildren.

Alexander G Fitzgerald

Walter Eric Spear BSc, PhD, DSc (London), FR_S, FInstP. Born 20 January 1921, elected FRSE 6 March 1972, died 21 February 2008.