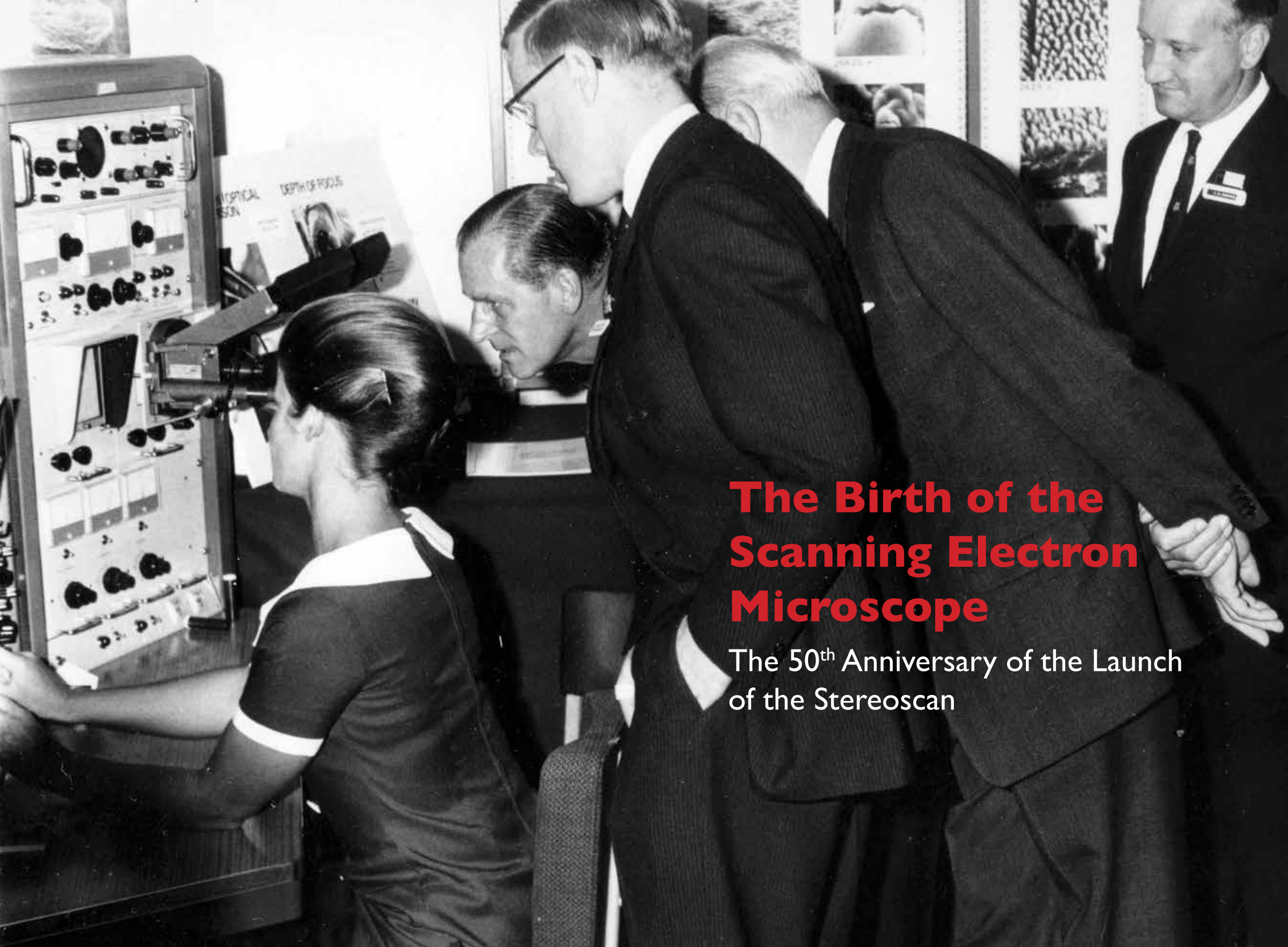




## **The Birth of the Scanning Electron Microscope**

The 50<sup>th</sup> Anniversary of the Launch  
of the Stereoscan

**2015 marks 50 years from the launch of the world's first commercial scanning electron microscope – the Cambridge Instrument Company (CIC) Stereoscan. A name which has almost become a generic title for any SEM.**

**How did this come about and what contributed to this seminal development in the world of microscopy and the evolution of a whole family of related electron optical products?**

### Early Days of SEM Research

The seeds of the Stereoscan were sown over the preceding 15 years in the Cambridge University Engineering Laboratories (CUEL) under the direction of Prof. Charles Oatley and other key players. Historically, electron optics at Cambridge was concentrated in two laboratories – the Cavendish under Dr Ellis Cosslett relating to the physics of electron interactions with materials and which notably spawned the X-Ray Micro Analyser, through the understanding of X-ray generation and electron interactions in complex materials, with ZAF correction procedures to refine and improve analytical accuracy.



Figure 1: Prof. Charles William Oatley, O.B.E., F.R.S. (1904-1996) (by permission of the Royal Society)

Just along the road in the CUEL Prof. Oatley had returned from working at The Royal Signals & Radar Establishment (RSRE, Malvern) on radar research during WW2, he had not only brought a vision that electron optics could become a fruitful route for research but also many truckloads of surplus military electronic components! These were used for many years in the laboratories and allowed generations of students to hone their electronic design skills, they also provided the vital hardware for the ensuing SEM developments. There are other contributors to the SEM history book, notably von Ardenne in Germany and Zworykin at RCA in the USA but the real work was done by a series of highly competent research students at CUEL over the period 1948 to the mid 1970's.

The early key players and their contributions are summarised below but the skills of the laboratory and workshop assistants in support of their endeavours should also not be forgotten.

- Dennis McMullan (1948-1952) - Built the first working SEM (SEM1) shown in Figure 2
- Ken Smith (1952 -1956) - Improved SEM1 and in 1957/8 built SEM3 as a research laboratory tool for the Canadian Pulp and Paper Research Institute
- Oliver Wells (1953-1957) - Built SEM2; researched image contrast mechanisms
- Peter Spreadbury (1956-1958) - Built new simpler SEM in 2 yrs as MSc project
- Tom Everhart (1956-1958) - Signals, contrast and detector development

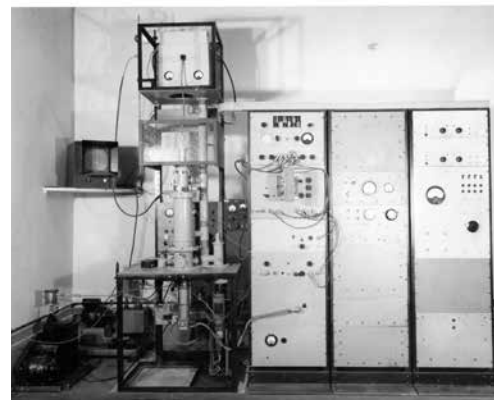


Figure 2: SEM1, The first SEM in CUEL (by permission of George Wilkinson (nephew))

- Richard Thornley (1957-1960) - Instrument and detector developments
- Bill Nixon (1959 onwards) - From 1947 worked with Dr Cosslett. In 1959 moved to CUEL and supervised many SEM projects
- Garry Stewart (1959 -1962) - ion source added to SEM2
- Fabian Pease (1960 -1963) - Built high resolution 10nm SEM (SEM5)
- Alec Broers (1961 -1963) - ion beam work on SEM2; first EB Lithography work
- Haroon Ahmed (1959-1962) - Imaging of heated cathodes with SEM2

These research students and those who followed contributed to the wealth of knowledge and experience in the design and development of the SEM in CUEL – sadly some have now passed away but their legacies are as important today as at the time.

Meanwhile, in the Cavendish laboratory other researchers under Dr Cosslett including Thomas, Green, Dolby, Nixon, Melford, Duncumb, and Jim Long (Dept. of Mineralogy and Petrology) contributed to the development and construction of the first X-Ray Micro Analyser (EPMA) and its subsequent manufacture by CIC as the Microscan. The interaction of all laboratories came to the forefront in these and subsequent developments

with the involvement of Tube Investments at Hinxton Hall in the EPMA design and then the EMMA analytical TEM. The novel monthly joint research seminars for all the laboratories were vital opportunities for networking in this association of engineers and physicists.

### Cambridge Instrument Company (CIC)

This long established scientific instrument company with very traditional business practices was based in Cambridge and traced its roots back to Darwin. In the 1960's it was a supplier of measuring and analytical instruments of all types to universities, hospitals and industry. The Chief Development officer was Steve Bergen. He was introduced to the Tube Investment engineered version of the EPMA in 1959 and took it into production at new buildings on Chesterton Road, Cambridge – over the next 5 years more than 75 Microscans were made, many for export, an unprecedented success for this product of the unique relationship (for that period) between commercial companies and University departments. This Microscan was the first in a long line of Wavelength Dispersive Spectrometer Microprobes manufactured by CIC over the next 25 years but that is another story!

### The Birth of the Stereoscan

It was into this environment that the possibility of making a commercial SEM was mooted in discussions in 1960/61 between Drs Nixon & Smith and Steve Bergen and with the support of Paul Goudime MD of CIC it was decided that the transfer of knowledge would be greatly enhanced by having the right person to introduce the new requirements for scanning microscopy, which were to prove significantly different from those used in the Microscan. A.D.G. (Garry) Stewart was at this time completing his post graduate research work at CUEL and it was proposed that he should come to CIC to assist in the project, he joined the company in April 1962. A lash-up instrument based on Microscan hardware was assembled by Mike

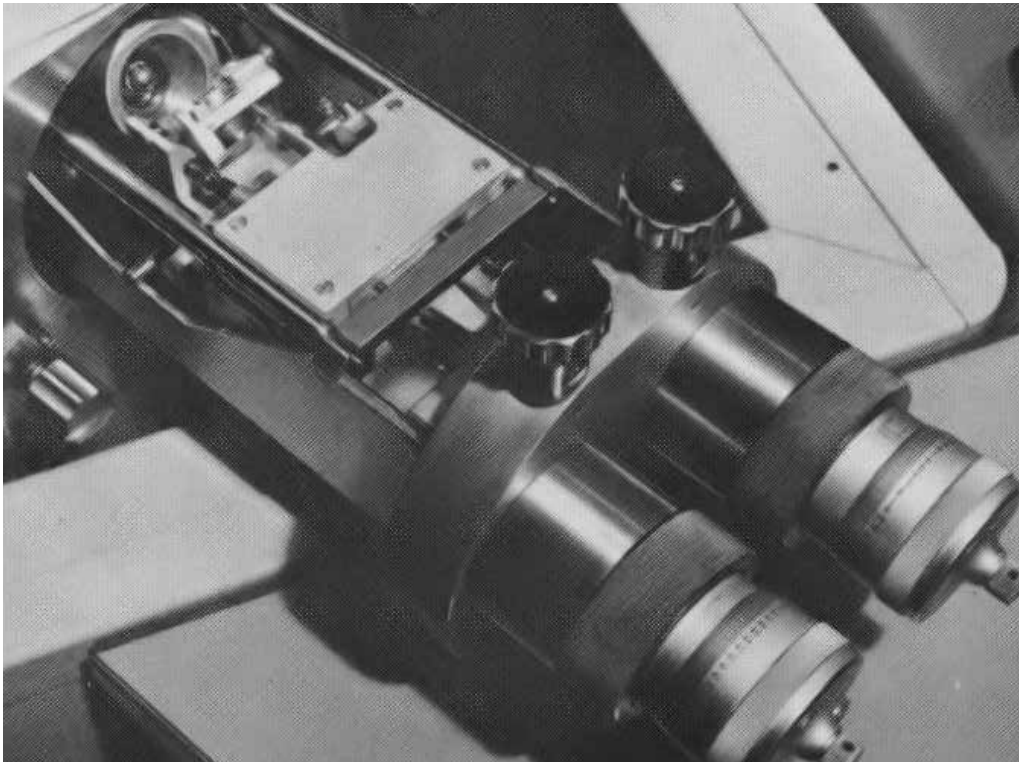


Figure 3: Specimen Stage withdrawn for Sample Loading

Snelling but Stewart quickly discovered that this was not the right way to develop the new instrument (he met, not unexpectedly, a degree of opposition on the way).

Stewart introduced a number of novel features and functions into the design which laid the foundations for the new SEM – Steve Bergen coined the name **Stereoscan** because of the incredible depth of focus and pseudo 3D appearance of the microscope images.

Stewart realised from the outset that in order to achieve a consistent and reliable operation for microscopists from all fields, the SEM had to be easy to use, such that routine users would achieve good results.

It has to be appreciated that in 1963 no precedent existed to determine what was needed in the instrument design or capabilities! Even sample preparation methods had to evolve and be taught to the user as these skills were unknown.

## Column and Vacuum System

First and foremost in the design was the need to make the column as a prealigned assembly and this was a big culture change for a company accustomed to hand finishing individual instruments – the emphasis on close toleranced components was vital in the quest for consistent performance and the need to service in the field. A three lens column design was determined as the best approach and advice on lens design was solicited from the team at AEI including Mulvey, Liebmman, Agar and Haine. The final lens was to be an asymmetric pinhole design so the sample was in a field-free region. The calculations for the mechanical tolerances on concentricity, eccentricity and alignment accuracy for the prealigned lenses set a new standard for the machine shop and manufacturing techniques.

The need to provide quick sample interchange without an airlock determined that the vacuum system should be fully automatic, using the best technology of the time – ubiquitous Post Office

relays were built into a dedicated state logic control system at CIC. The vacuum performance was achieved by the use of two high speed diffusion pumps with a novel column isolation valve built into the final aperture changer. These features ensured that a sample could be routinely exchanged in less than 3 minutes.

Stewart also realised from experience that vibration and AC magnetic fields could limit performance. So with the mechanical design team under Don Unwin, developed a low compliance coil spring suspension system for the whole column and chamber; they incorporated extensive Mu-metal screening in critical sections of the column. The design of the microscope predated widespread use of semiconductors and all the main electronics employed thermionic valves requiring multiple power supplies giving highly stable 250v DC power rails. Not only did these have to be designed specifically for the instrument by outside contractors but they also had to be located many metres away from the column to reduce field interference. The effects of chromatic aberration were well understood and the demanding highly stable design for the electron gun

EHT set (which also used thermionic valves) was performed by Brandenburg Instruments. Although initially only 20kv this was increased to 30kv very soon after introduction. The electron gun was the only major component in the Stereoscan common with the Microscan in the first instruments – although Stewart quickly replaced this with a better design!

## Scanning and Signal Detection

The heart of any SEM is the scanning system and the electron detector design – the work at CUEL had clearly shown that the use of the secondary electrons derived from the sample gave the most useful images at that time. Stewart refined the design of the Thornley-Everhart detector with the use of a plastic scintillator, efficient light pipe and an improved photomultiplier tube and video amplifier chain allowing stable back-off for image enhancement to be achieved. Stewart also appreciated that low magnification was just as important as high magnification capability. He derived from the work of Peter Duncumb in the EPMA that the use of a dog leg deflection scan coil assembly that would give

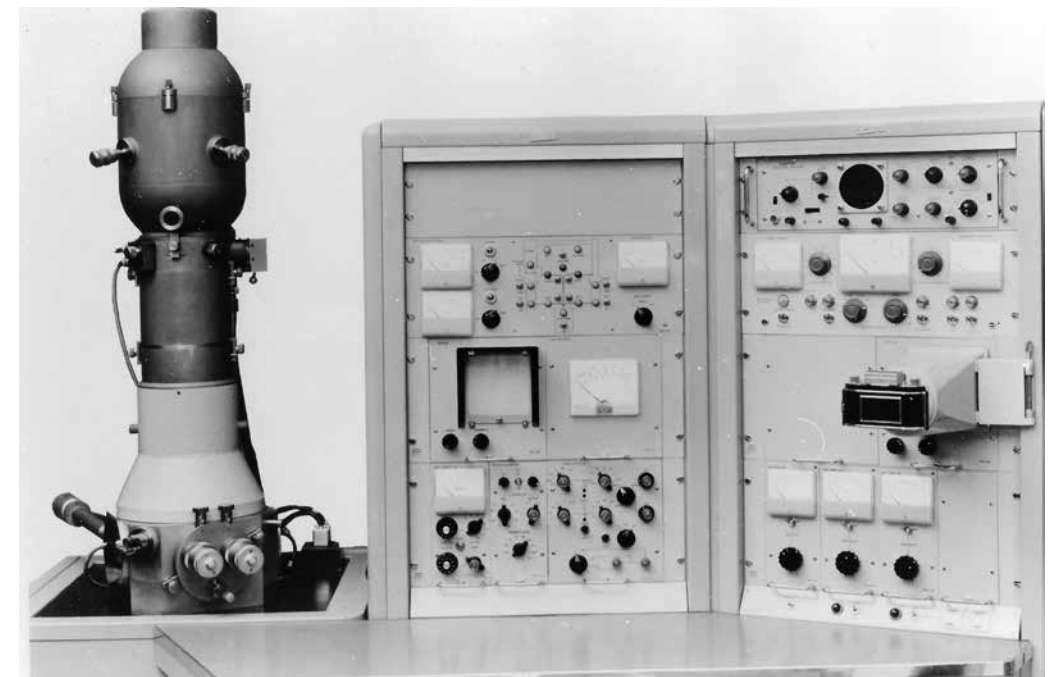


Figure 4: The First Stereoscan SEM

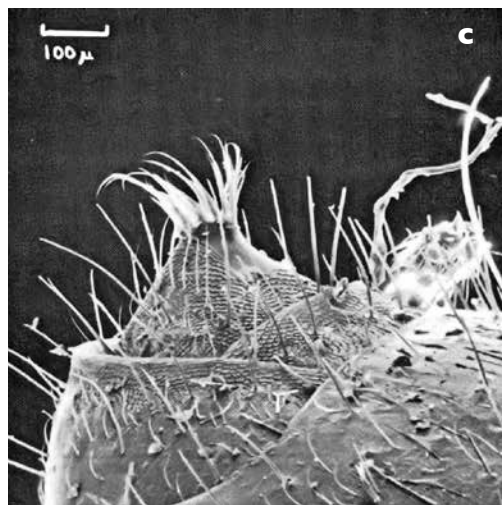
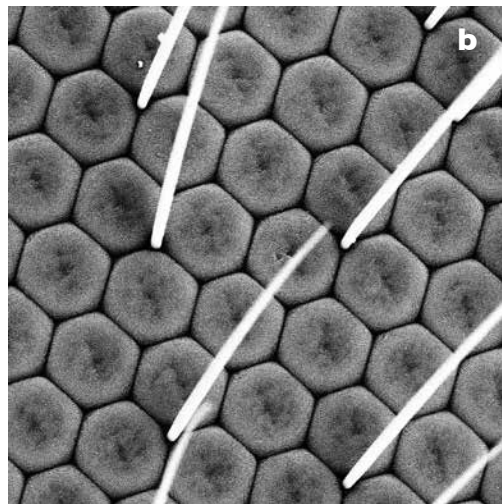
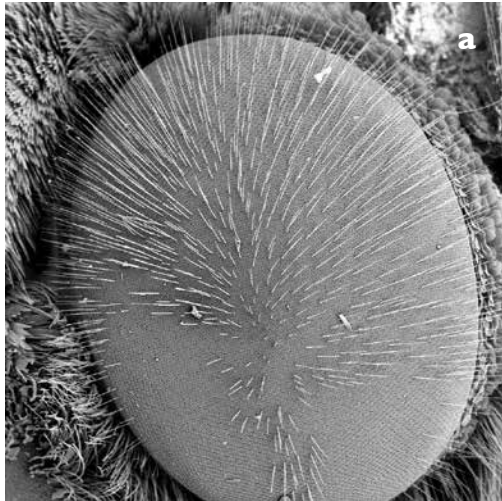


Figure 5(a): Butterfly Eye, (b): Eye Details, (c): Ant Sternite

20 x magnifications at 11mm working distance thus bridging the gap between what could be seen with an eye glass and in the microscope. The other end of the scale exceeded 50kx – the scan coil used the principle of the electron beam crossing the optic axis in the principal plane of the final lens and thus provided images with very little edge distortion.

The stability of the overall electronics was addressed, so that recording times of many minutes could be achieved if required using a high resolution short persistence phosphor Cathode Ray Tube. This gave a 1000 line image (just 1Mpixel in today's terms!) with either Polaroid™ or 35mm roll film cameras allowing images to be recorded before the days of digital image storage. Viewing of live images was an acquired skill as the scans were sometimes several seconds long and the long persistence viewing tubes only displayed a 100mm square image.

TV viewing was still to come and microscopists dwelt in darkened rooms and were not infrequently found asleep after lunch, especially if the room was warm!

### Sample Chamber and Stage

All of these novel design features would be to no avail if the need to mount and move samples was not addressed. The chamber design and stage within it were subject to many discussions until, it is recounted, on a late night train journey back to Cambridge the idea of the octagonal shaped chamber was developed on the so called "fag packet" and this became the trademark feature of the Stereoscan for many years. This versatile mechanical design by Don Unwin and his engineering team allowed a whole range of in-house and third party accessories to be developed, thus turning the microscope into the "micro laboratory" that it has become and more than fulfilling the highest hopes of those earlier engineers and experimenters.

The sample chamber and stage (Figure 3) are inextricably linked as anyone involved in microscope design knows; this talented team set the standard for

# SORRY

BUT YOU'LL JUST HAVE TO WAIT!



We will have a couple of interesting surprises on our stand and look forward to welcoming you.



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Figure 6: Stereoscan at Micro 66

sample mounts (some are still used today) - the 1/2" (13mm) aluminium pin stub - enabling quick sample interchanges to be made. By modern microscope standards the stage movements designed into the first stage were very small, allowing just 13mm in X and Y together with 11mm in Z, 90° of tilt and 360° rotation. The skill of designing precision movements was already known in the company, using micrometer anti-backlash drives gave this stage the smoothness of movement needed in microscopy up to the highest magnifications, serving the Stereoscan for many years. Even the earliest stage had insulated sample mounts in the anticipation that the sample current would be of interest in future work or analysis applications although at the launch no such devices even existed – another example of the engineering foresight that was the hall mark of the Stereoscan,

That the whole SEM was so right from day one is an incredible tribute to the design, engineering and leadership capabilities of one person - Garry Stewart, who coordinated the team of talented engineers and contractors under conditions which were not always as supportive as one might have wished. In effect Garry had to manage and direct a

unique start-up high technology company within the constraints of a traditional instrumentation company without the knowledge of making a product that would sell. This was a feat in its own right and all credit must be given to this diffident engineer without whose contribution CIC would not have become a world leader in scanning microscopy.

### The First production SEMs and onwards

The company resolved to make a small batch of microscopes capable of achieving a resolution of 30nm as a number of possible users had come forward. These were delivered during 1964 and 1965 Figure 4 shows the console and column of this first model of the Stereoscan range – the tall power supply racks are located many metres away. One prototype SEM destined for the Dupont labs in USA was transported by sea and as it was unloaded in the docks the stevedores managed to drop the whole crated SEM from a considerable height – sadly, although the SEM was robust, this was one step too far. The whole unit had to be returned to Cambridge to be rebuilt and thereafter air freight was used almost exclusively.

DuPont did eventually get their Stereoscan and it proved to be a vital tool in their synthetic fibre research laboratory. Other SEMs from the initial batch found homes in the Central Electricity Research Laboratories, Universities of Bangor (Dr. Thornton) and Leeds (Dr Sikorski) and in Munster (Prof Pfefferkorn). These were the vanguard of what turned into a veritable flood of orders once published results and the amazing images with their incredible depth of focus were seen in the literature and at conferences and exhibitions.

Who, even now, is not enthralled by the eye of an insect (Figure 5) and similar images where the depth of focus provides such stunning detail? Celia Moss remembers the total euphoria shown by ICI scientists when they saw the full length of the bore of a fibre spinneret for the very first time in a single image!

The fitting postscript to this article is encapsulated in Figure 6 which shows the Stereoscan at the first public exhibition in the UK - the RMS Micro meeting at Imperial College in 1966. Celia Moss is operating the SEM with an especially intent Duke of Edinburgh looking at the visual monitor - nearest the camera is Garry Stewart in his characteristic pose of total involvement. Despite much encouragement the Duke declined to operate the microscope!

In the first 3 years of production more than 200 Stereoscans were sold and this resulted in great changes within the company - an increased R&D budget for new products, the creation of a field service organisation and sales teams, training of overseas agents, customers, engineers, product marketing with exhibitions, application work etc. The company became a very vibrant workplace for many including this articles author who joined in 1967 (from CUEL needless to say) and for many years was involved in new SEM designs and accessory development for the company.

I feel very privileged to have been involved with SEMs for the whole of my working life. I have enjoyed every minute of it and had it not been for

a meeting with Garry Stewart in my sitting room in 1966 I would not have had that opportunity – I owe him a great personal debt for this, but the whole world of scanning microscopy owes Garry Stewart an even greater debt for his abilities, enthusiasm and foresight and we continue to benefit and reap the rewards from this ground breaking work of 50 and more years ago.

**Dr Richard S Paden Hon FRMS**

### References and Acknowledgements

There are many literature references to these historical events but by far the most comprehensive is the book published in 2004 to celebrate the centenary of the birth of Charles William Oatley, O.B.E., F.R.S. which contains contributions from many of the scientists and engineers involved and which served me as a valuable reference in compiling this article

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I also acknowledge with gratitude the help, recollections and advice received from Garry Stewart himself, David Kynaston, Bernie and Jane Breton, Celia Moss and other colleagues in the world of microscopy – many thanks to all.

There were many other contributors to the Stereoscan story - their individual inputs and endeavours were no less significant in creating this unique product whose benefits we so richly value today.

### Further reading

The Alan Agar autobiography in infocus issues 15 and 16 contains more information about the history of electron microscopy and is available from the RMS website here: [www.rms.org.uk/publications/infocus/Past/2009/Sept](http://www.rms.org.uk/publications/infocus/Past/2009/Sept) & [www.rms.org.uk/publications/infocus/Past/2009/Dec](http://www.rms.org.uk/publications/infocus/Past/2009/Dec)