OPTICAL ENGINEERING IN SOUTH AFRICA FROM 1960 TO 2010 AND BEYOND

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Abstract: From its humble beginnings in an optical workshop in the Mowbray Office for Triangulation in the 1930s and the subsequent formation of the Division for Optics and Spectroscopy at the National Physical Research Laboratory within the CSIR during the 1950s, optical engineering has blossomed to a vibrant electro-optical industry in the twenty-first century. From a primarily research-oriented origin in the 1960s, optical engineering has grown to an engineering and product driven industry today. The South African optical engineering industry focuses on small niche markets, with world class products. The paper closes with a review of lessons learnt. With a measure of anticipation, we then venture to predict some future outcomes in the exciting field of optical engineering in South Africa.

Key Words: South Africa, Optical Engineering, Photonics, Electro-Optics, Optics.

1. INTRODUCTION

The first known optical workshop was established in 1933 in the Scientific Instruments Branch workshop of the Office for Triangulation in Mowbray [1]. Today, South Africa harbours a wide ranging scientific and industrial optical engineering base.

This paper reviews the history of the key role players and technologies that contributed to South Africa's science, education and technology (SET) base in optical engineering. Optical engineering is defined as the design and manufacture of sensors or sources operating in the ultraviolet to 12 μm spectral region. Clearly, not all activities in the country can be covered in this review; emphasis is placed on the SET base originating from the early government funded work at the Council for Scientific and Industrial Research (CSIR).

2. ORGANISATIONS

2.1 The Early Days

At the start of the Second World War, the Scientific Instruments Branch in Mowbray was asked to manufacture lenses, prisms and optical systems [1]. The workshop, under the guidance of L V Holmgren appointed 127 technicians, who designed and built all the required manufacturing equipment in-house! Some of this equipment was still in use at the Naval base at Wingfield up to its closure around 1980. High quality glass was initially unobtainable during the war-time and the workshop skills base was built on processing normal window glass. When optical grade glass was eventually obtained, all processes had to be re-engineered. After the war, the workshop continued to serve the military and government needs for optical instrumentation. The workshop was closed in 1956 when a private company indicated an interest to create an optical workshop (which did not materialise).

The oldest remaining record [2] of a doublet and prism optical design, dated 1949, was by Mr Eric Tappere, working in an optical laboratory in Visagie Street, Pretoria.

2.2 NPRL, CSIR

After the establishment of the CSIR in 1945, the Division for Optics and Spectroscopy was created in the National Physics Research Laboratory (NPRL). The objective with this division was to provide towards the country's scientific independence and "reserve scientific and technological knowledge" by active research and development [3]. At the time the new division was the only research and development facility in the country, except for a joint laboratory for research into diamond photo-conductance at the University of the Witwatersrand and De Beers.

The NPRL optical workshop was founded in 1952, by Mr Ernst Hecker, a Master Optician, previously working at Carl Zeiss in Jena. Under Mr Hecker's guidance, the workshop was set up and a number of precision opticians were trained at the NPRL [4, 5].

During the 1960s, the Division for Optics and Spectroscopy was led by the inimitable Dr George J Ritter. He was a systematic person that kept copious notes [6]. The work of the division covered a broad range of activities ranging from optical design (with Dr N Lessing being the only designer in the country!), production of optical elements (lenses and mirrors), thin film coatings, diffraction optics and testing, spectroscopy, photo-electric effects and the budding field of lasers. The division experienced rapid growth in the latter part of the 1960s as new research projects started.

Dr Ritter pointed out that in 1968 the country imported R11m worth of optical components[1] [3]. At the time, he complained that all of the sponsored research work was fragmented, lacking a larger, long term research vehicle.

A novel mechanical optical design tool was designed by Dr Lessing: the dispersion of glasses was represented by rods of different lengths hanging from one reference plane, while strings linking rod endpoints and points on a second reference plane constituted the optical design. The device was actually built and it worked, but with some practical limitations [5]. Dr Lessing was internationally credited with a number of new optical design techniques and procedures. One of Dr Lessing's many firsts is that he programmed the first optical design software in South Africa.

Dr Maurice McDowell joined the NPRL in 1972. He was the major driving force in establishing the optical design group [5]. During the 1970s, the optical design group employed state-of-the-art software on a large number of advanced optical designs for research and external contracts. The designs included various lenses, telescopes and laser optics. In the early 1980s, aspherical surfaces were used. Many, if not all of the group's designs performed on par with the best commercial lenses. During the later years, the nature of the optical design group's work changed from basic research into advanced optical design. Mr Heinz Klee distinguished himself as a lateral thinking designer with novel ideas — he is widely regarded as one of South Africa's most innovative optical designers [8]. One of Mr Klee's later designs, convincingly beating a large field of international designers, was the 'Klee corrector' for a 2 m diameter, F/2 telescope, a variation of which is used currently in the search for potentially dangerous asteroids [5].

During Dr Ritter's period the optical workshop and evaluation laboratory employed some of the most modern and sophisticated equipment available. Where there was no suitable equipment available, it was built. Mr Eugene van Rooyen (later professor) designed and built a variable shear prism interferometer in 1968. Commercial interferometers were procured in later years. A number of fine optician artisans were trained, including Mr Danie van Staden, who would play a key role later in the CSIR/DPSS optical laboratory. These artisans were previously trained as instrument makers and hence were ideally suited for opto-mechanical work. The optical shop remained active in low volume production of specialised components and demonstrator construction, until 1997 when the group opted to form a new private company, called Optocon.

In the early 1970s, the processing of optical glasses was extended to a variety of crystalline infrared materials. Industry requirements led to the processing of ZnS and ZnSe in the early 1980s. The workshop produced the optics, etched reticle patterns and manufactured silicon domes for the early generation Kentron missiles. In the late 1970s, Mr Peter Trendler perfected a diamond fly cutting process for the machining of very good quality complex aluminium optical elements [5].

Thin film optics was an important field of research since 1963, under Dr Stoffel Kok and Mr Ettienne Theron. Initially, research was conducted in multi-layer laser mirror coatings and anti-reflection coatings. In order to manufacture of more advanced multi-layer interference filters and beam splitters, new appointments were made and new equipment purchased in 1967. By 1978 the group were able to produce very complex visible and infrared filters and laser mirrors. Filter and anti-reflection coatings were designed for crystalline Si and Ge in die 1970s and for ZnS and ZnSe in the 1980s. In 1970, new equipment and software were continually acquired to support the growing demand in the defence industry.

Dr Ritter spearheaded laser research [5] at the CSIR in a 1965 proposal [9]. The research initially focused on optically pumped solid state lasers and several different gas lasers. Quick initial progress was achieved from the work of visiting scientist, Dr Richard (Dick) Turner in 1968, who later headed the metrology section [4]. The laser group research included both the construction and application of lasers. Before 1974 the group worked on HeNe (320 mW), Nd:YAG (10 MW, 30 Hz), CO_2 (1 GW pulses) and CO chemical lasers. Mr Dieter Preussler demonstrated the first laser range finder in 1975. By 1978 the group registered a number of patents, emanating from the work of Dr Vic Hasson and Dr Hubertus M von Bergmann (later professor). The patents and publications on ultra-miniature gas lasers and pre-ionisation techniques brought international recognition to the laser group. Later work included HBr, Alexandrite, Erbium, Holmium and hard-sealed CO2 TEA lasers. When laser diodes became available, these were used to pump q-switched Nd:YAG lasers. Considerable work was done on increased stability in lasers, amongst else by employing crossed-Porro-prism resonators in q-switched solid-state lasers. Apart from research into lasers, various non-linear optics techniques were investigated as well. In order to reach wavelengths not reachable with discrete lasers, work was done on frequency doubling and Optical Parametric Oscillators using birefringent crystals, Brillouin scattering in liquids and Raman scattering in gases. "We had so much fun, building local versions of all the lasers imaginable!" [4].

[1] The current photonics business turnover in South Africa is estimated at R2500m per annum [7].

Since 1985 the group was led by Dr Johan Brink (later professor) and in 1990, Dr Dirk Bezuidenhout took over the leadership of the group. The laser group worked intensively on the industrial applications of lasers; in etch marking, cutting and welding. The laser group also worked on the application of lasers in military applications. A holography bench was established at the NPRL in 1969. One of its best known outputs was the hologram of the Taung child's skull fossil used on the cover of the November 1985 issue of National Geographic.

The division also worked extensively on image intensifier night vision tubes. The division's first photosensitive CsSb layer was demonstrated by 1969, while the first complete working tube, with a 400 μA/lm S25 photo cathode, was demonstrated some time before 1974. The night vision tube developed by the NPRL was the famous 'fountain tube', so called because of the peculiar path of the photo electrons. The resolution was very high at the time, 60 to 70 c/mm! Because of the construction it could, unfortunately, not be cascaded [5]. More advanced goggles with catadioptric telescopes followed in subsequent years. In the early 1980s, the group developed a local variation of second generation tubes and microchannel plates.

A small, low priority project demonstrated a PbS infrared detector in the early 1970s. Mixed results were obtained and the detectors were never commercially exploited. During the 1980s, Dr Harry Booyens led a team in an ambitious project to develop lasers, detectors and detector materials, including HgCdTe (8–12 μm and 3–5 μm), InSb, GaAs, InGaAsP and PbS. Some of the equipment, e.g. the organometallic vapour phase epitaxy (OMVPE) reactors was highly sophisticated. The project was terminated in the early 1990s when key personnel emigrated [10].

Optical glass melting facilities were set up, which were transferred to the new NPRL Physics of Materials Division in 1973. Work on different laser glasses, doped with Nd, was carried out by Dr. Res, visiting from Czechoslovakia.

In 1974 Eloptro was created (see Section 2.3), with a core team of optical experts from the NPRL. Eloptro's ambit was seen as the production of military optical systems, while the NPRL considered itself to be the research and development arm of the industry [6, 11] — this was, however, not to be. The NPRL and Eloptro both pursued independent trajectories in the ensuing years, being driven by different strategic and operational objectives. There were some areas of co-operation. One such area was thin film coatings in the period 1978-88 where the the groups did joint training and research. The NPRL designed some coatings and Me Joan Stapelberg led the manufacturing at Eloptro.

In the early 1980s, the personnel complement in the NPRL Optics Division varied around a nominal number of 40–50 technical personnel. The division was dependent on external contracts for about 40% of its income. These contracts served the civilian sector, the public sector and the military sector [11]. During the late 1980s the NPRL increasingly performed more contract work, leading to a decline in basic research. This was partly attributable to client pressure, but also to a decline in pure research funding, resulting from the CSIR's positioning change under Dr Brian Clark.

In the early 1970s Dr Franz Hengstberger designed and developed a room temperature absolute radiometer for the NPRL metrology laboratory. The radiometer serves as the country's primary standard in the realisation of the SI unit for light. In 1987 the National Metrology Laboratory seceded from the NPRL, in 2007 becoming the The National Metrology Institute of South Africa.

In 1983 Dr Maurice McDowell was appointed as head of the Optical Sciences Division in the NPRL. In 1987, the Optical Design and Evaluation, Thin Films and the Optical Workshop were merged into the Optical Engineering Programme, under the leadership of Mr Heinz Klee, operating in Productiontek. By now spectroscopy and the material-related research projects were transferred to Material Sciences (Mattek). Mr Klee managed the Optical Sciences group until 1992, when Dr Carl Miscke was appointed to lead the optical group. In 1997 Dr Dirk Bezuidenhout led the group, now called the 'Electro-Optics' group, active in optical design, thin film coatings, the optical shop and surveillance sensor demonstrator design. In 1998 work started on an accredited optics evaluation laboratory.

Dr Maurice McDowell passed away in 2008. While he was a good optical designer, he will be remembered for being Mr Optics, the face of optical sciences in the 1970s and the 1980s.

2.3 Eloptro

The need for military optical and electro-optical equipment during the early 1970s, led to the creation of Eloptro in 1974 as a subsidiary of the Armaments Corporation of South Africa (Armscor) [12]. Know-how and key personnel transferred from the NPRL formed the core of the new company, under the direction of Eugene van Rooyen [8]. In a flurry of excitement, new personnel were rapidly appointed and trained on newly purchased equipment.

Eloptro's initial brief was to produce night vision equipment and targeting sights for a variety of armoured cars. Eloptro established capabilities in lens and prism manufacture and a thin-film production capability to manufacture filters and mirrors. A very large variety of artillery sights (for the Ratel, Eland and Rooikat vehicles), G5 and G6 Howitzer sights, optical telescopes and various other optical systems were produced at Eloptro's plant on the East Rand, near Johannesburg.

Eloptro's night vision business included the initial manufacture of first generation tubes in 1974, and second generation tubes in the early 1980s [8]. The production of the first generation tubes were successful but the second generation tubes provided low yield during manufacture. Serial production of the image intensifier tubes was terminated in 1994 when the need for the tubes declined. The image intensifier tubes, as well as several products, such as the Eland night driver scope, were produced and deployed in service.

In 1978 Armscor's missile subsidiary, Kentron, was formed. Both Eloptro and Kentron reported to Mr Melt Hamman, with Mr Barry Kruger acting as Eloptro manager. When Kruger was later seconded to head office, Mr John Pitout led Eloptro to again become a full Armscor subsidiary, independent from Kentron. Mr Hans Pretorius managed Eloptro from 1993 until 1994 when he was appointed manager of Kentron. Mr Pretorius was superseded by Mr Jan Swanepoel.

1978 also saw Eloptro initiating development work on laser range finders. After an initial experimental model, Mr Johan Steyl and his team developed the hugely successful ELAM product. Variations of the ELAM was subsequently integrated into various sights and products. The ELAM product also served as the basis of a number of more advanced laser range finders. Later developments included the development and industrialisation of Erbium eye-safe lasers. The laser range finder product range is one of Eloptro's export success stories! [8].

The United Nations arms embargo forced Eloptro to start limited scale glass production in 1979. This facility focused on glasses with high index of refraction [12]. The objective was to supply in Eloptro's internal needs.

Eloptro developed a number of missile optics and subsystems for its sister company Kentron. Since 1978, Eloptro produced the optics and domes for practically all of Kentron's missiles. Eloptro industrialised and produced the Kentron-developed ZT3 anti-tank missile sight in the early 1980s. Several other missile related sights and sensor products followed.

The Eloptro optics workshop produced optics for systems operating in the ultraviolet, visible and infrared. These elements included lenses, advanced boresight alignment prisms and much more. In 1983 Eloptro opened a training facility for fine optician artisans to supply in the demand for optician artisans [12]. As a result of the decline in business, the training facility was later closed down.

Under Me Joan Stapelberg, Eloptro established a strong thin-film capability, covering a spectral range from ultraviolet to far infrared. The facility produced a full range of filters, reticles, mirrors, beam splitters and related components.

Eloptro initiated a thermal imager development programme in 1986. This ambitious project included the design and manufacture of practically all major components in the imager. The technology establishment project included the local development of a Stirling Cycle cooler, a 8–12 μm detector, optics, thin film coatings and a scanner. A first prototype was built, but the project was closed down because of a too small a client base and unviable economics.

During the brief South African space programme in the late 1980s, the Eloptro team, led by Mr Herman Meyer, developed a number of space cameras and sensors, including a small field of view camera, a wide angle camera, a solar camera and a horizon sensor. The space programme was closed down and the equipment was not launched into space.

Eloptro excelled at the design and manufacture of submarine periscope sights. Ably guided by Mr Len Dicks and Mr Martin Wilkenson, the periscope team achieved world class performance and international recognition for their periscope for the Daphne class submarines. Eloptro was subsequently invited by Carl Zeiss to design the periscopes for new South African Heroine class submarines — leading to sales on other submarines as well.

In 2002 Eloptro, then managed by Mr Knox Msebenzi, and Cumulus, part of Kentron, were joined as Denel Optronics under Mr Norman Clarke.

Denel Optronics' range of excellent products attracted Carl Zeiss. A substantial share of Denel Optronics was sold to Carl Zeiss in 2007, forming the new company Carl Zeiss Optronics.

2.4 Carl Zeiss Optronics

Carl Zeiss was already operating in South Africa since the mid-1920s and opened a service department in 1938 under Mr Anton Hausler. During the war, a private company 'Optical Instruments' was formed by a Mr Erich Meier, to continue support of Carl Zeiss equipment. Later Mr Klaus Harth and Mr Harald Krahmann joined 'Optical Instruments'. In 1974 'Optical Instruments' was taken over by Carl Zeiss [13].

The Carl Zeiss Optronics strategy, under the guidance of Mr Kobus Viljoen, is to be a world leader in its product range, offering products from large scale serial production. Carl Zeiss has invested heavily in the last 24 months in product development and production systems, equipment and technologies. More investment will be made in the next 18 months in building a new optical production facility, as well as procuring new optical coating equipment [14].

The company focuses on commercially viable, high performance niche military and security products in a highly competitive open market. The company is successfully run as a commercial enterprise, investing 8–10% of turnover in new product development. The optics manufacturing plant runs at full capacity, mostly fulfilling in-house optics requirements.

Carl Zeiss Optronics provides a wide range of military and civilian products The laser range finder and target locator products, developed under Mr Johan Steyl, are produced at relatively high volumes. Sophisticated submarine periscope systems, initially spearheaded by the late Mr Len Dicks and Mr Friedl Kohlmeyer, are in operation in a number of submarines world-wide. A number of stabilised observation systems for helicopters, fixed wing aircraft and unmanned aerial vehicles (UAV) are in production. The helmet tracker (originally developed by Kentron and Cumulus) is a world leader and fitted to Gripen and Eurofighter Typhoon.

2.5 NIRRD and NIDR, CSIR

In 1963 the National Institute for Rocket Research and Development (NIRRD), an institute of the CSIR, was founded. This was followed in 1965 by the founding of the National Institute for Defence Research (NIDR) [15]. A few of the initial research tasks for the NIDR were to become acquainted with the Crotale/Cactus air defence system (personnel were seconded to France), to develop an air-to-air missile for the South African Air Force's (SAAF) fighter aircraft and to develop means to protect SAAF aircraft against enemy missile attacks.

NIDR built two air-to-air missile research platforms, the V1 and V2 or 'Voorslag' (whip-lash), essentially clones of the Sidewinder AIM-9B [16]. These missiles had infrared seeker heads and optical proximity fuses. The SAAF placed an order for next-generation V3A air-to-air missiles in 1969, with a production run of 20, starting in 1973. This was followed by 450 V3B missiles produced from 1979 onwards, by the spin-off company Kentron. The V3B had an InSb 3–5 μm seeker, a PbS optical proximity fuse and a world first: the seeker sightline could be slaved to a sight on the pilot's helmet. The helmet tracker employed light emitting diodes on the helmet and linear array sensors in the cockpit.

Research and development of a long range, guided dive bomb, Hanto, started in the late 1970s. The bomb employed a vidicon TV tube on a stabilised platform, transmitting (radio frequency link) the video signal to an operator that guided the bomb to its target. The Optics group in the NPRL designed the optics and spectral filters, while the NIDR designed the control electronics and mechanics. This project became the precursor to the future H2 and later Raptor guided bomb, produced today by Denel Dynamics.

The Infrared Group in the NIDR focused on aircraft self-protection research, developing countermeasures against, at the time, mainly Soviet shoulder launched missiles. The group performed signature measurements and modelling with home-built radiometers and target signature simulators. Successful active (pulsating infrared radiation and countermeasure flares) and passive countermeasures (signature management) were developed and deployed. This know-how, together with the V3A/B missile knowledge, formed the basis of the infrared technology in the future Kentron.

After the formation of Somchem and Kentron (1978), the remaining NIDR staff members were combined with those of the Aeronautical Research Unit to form the new National Institute for Aeronautics and Systems Technology (later referred to as Aerotek, Defence Technology, and currently, Defence, Peace Safety and Security [DPSS]).

The Electro-Optics group's involvement in remote vehicle detection indirectly led to the development of a perimeter intrusion protection system, the ACL Fence[2]. The sophisticated optical beam system employed beam coding and neural network technology to classify and reject false alarm events. The system was installed at a number of sites and sold off as a product.

In early 1990s the group, under the leadership of Mr Johan Kotze demonstrated an ultraviolet missile approach warning system (UV-MAW). The UV-MAW stretched available technologies at the time, requiring operation at the UV individual-photon-count flux levels. The system employed a solar blind filter developed by Mr Ettienne Theron and a photomultiplier detector. At the same time, a laser warning receiver prototype was developed. Both the UV-MAW and the laser warning receiver concepts were later industrialised by Grinaker Avitronics (today Saab Avitronics).

In 1990 Dr Pieter Vermeulen and Dr Stef Roux demonstrated pattern recognition using mathematically generated holograms [10].

In 1993 the group was moved to Productiontek and called the Infrared Electronic Warfare (IREW) group under Mr Ralph Matzner. The IREW group continued research in active and passive countermeasures and camouflage. In 1995, the group

[2] The fence product is named after its designers Mr Antoon Uys, Mr Christie van Deventer and a Mr Louw Kruger

was moved back to Defencetek, under the guidance of Dr Jan Roodt and later Mr Hendrik Theron. Considerable work was done on signature management and self protection, resulting in the design of new generation flares, infrared stealth research and the development of signature simulation tools. New imaging and spectral measurement instruments were procured and measurement processes developed. Research into future surveillance needs were undertaken [10]. In 1997 the Electro-Optics group was transferred to Defencetek. In 2003 the IREW group and Electro-Optics groups joined together in the 'Optronic Sensor Systems' (OSS) under Mr Lee Annamalai. The group is currently managed by Dr Dirk Bezuidenhout.

Work on a directed energy infrared countermeasure (DIRCM) started during 1995 (phase 1, led by Dr Jan Roodt, Mr Francois le Roux and Mr Roy Blatch) and 1998 (phase 2, led by Mr Hendrik Theron and Mr Alwyn Smit). The DIRCM project jointly involved Defencetek, the National Laser Centre (NLC) and an overseas company. The Defencetek team provided the missile jamming codes and systems engineering, Mr Dieter Preussler and Mr Daniel Esser of the NLC designed and built a multi-band infrared laser, while the overseas partner provided the missile warning and missile tracking hardware. In 2005/6, the DIRCM, mounted in a helicopter, had successfully decoyed a number of shoulder launched missile seekers.

Throughout its history Kentron (now Denel Dynamics) and the CSIR have used computer simulations for sensor modelling, image processing algorithm development, flight test preparation, infrared system performance prediction and countermeasure evaluation (refer to SIMIS in Section 2.6). In 2004, OSS and Denel Dynamics started on a joint development programme for a second generation, comprehensive and radiometrically accurate scene and sensor simulator, called 'Optronics Scene Simulator' (OSSIM) [17, 18], under the joint guidance of Mr Nelis Willers and Me Riana Willers. In 2008, the OSSIM product was specialised towards infrared electronic-warfare (IREW) applications in the CSIR and real-time HILS work in Denel Dynamics.

2.6 Kentron

The CSIR's missile business (NIRRD and part of NIDR) was growing rapidly and spun out as an Armscor subsidiary, briefly called Brimstone. In 1978, the company was formally launched under the name Kentron — South Africa's missile industry. 350 of the 500 staff members of the NIDR moved to Kentron and new personnel were rapidly appointed.

In 1978 Kentron had only one specialist electro-optics engineer, Mr Geoff Carter[3]. This author was appointed in Kentron to establish an infrared capability. Carter was to become one of Kentron's experimental electro-optics specialists and Willers laid the theoretical foundation for infrared radiometry, measurements, signature modelling and infrared scene simulation.

Kentron's first two projects, V3B and Hanto, both employed electro-optics sensors. During the early 1980s an anti-tank missile development project (ZT3) was initiated — employing a laser free-space communication link and an infrared guidance system. It is evident that the initial Kentron products relied heavily on electro-optical subsystems. This trend was to continue for the majority of Kentron's business.

The V3B production was followed by the development (1980) of the V3C air-intercept missile, with an amplitude modulation (AM) reticle seeker operating in two spectral bands, with an active laser proximity fuse. The two-colour system measured the relative ratio of signal in two spectral bands in order to reject cloud clutter and countermeasure flares. The V3C seeker was later used as a seeker in the ground launched New Generation Missile, which later became the Umkhonto missile. The seeker was continually updated and improved, to the current status as an advanced frequency modulation (FM) reticle with advanced spatial signal processing capabilities to reject background clutter and countermeasures.

The ZT3 anti-tank system stimulated the local development of silicon, silicon pin and germanium detectors in various spatial configurations and sizes [19]. These detectors were developed under the guidance of Prof Pieter Rademeyer and Dr Monuko du Plessis (later professor), at CEFIM (see below). The original ZT3 guidance system proved difficult to manufacture, but the system was successfully produced and deployed.

The follow-up to ZT3, the ZT36/INGWE was built around beam-rider and optical axis alignment concepts conceived and perfected by Mr Christo van der Merwe in a development project that started in 1997. The guidance system coded spatial information in the beam, such that the missile could measure and correct its deviation. The INGWE guidance system was highly successful and resulted in a number of spin-off variants.

The INGWE beam-rider subsystem was built into a large number of targeting sights, together with infrared imagers, laser range finders, visual imagers and direct view optics. These targeting sights found application in a variety of vehicles and helicopters.

The Mokopa laser guided anti-tank missile, developed in the mid 1990s, is guided by semi-active laser

[3] Although there were other engineers with a good working knowledge of the field: Mr Bert Quinn, Mr Christo Visser, Mr Chris van Heerden and others.

guidance, employing a silicon pin quadrant detector for guidance.

Kentron developed several different optical proximity fuses. These fuses can detect the proximity of a target and trigger the warhead. The V3A/B missiles employed a passive PbS detector, while the V3C fuse, developed by Mr Geoff Carter, was an active laser fuse with a 6 m range. The INGWE anti-tank missile had a tandem warhead and required a long standoff distance — the standoff distance was achieved by an active fuse that could measure distance to the target. A number of optical altitude fuses were also developed for the glide bomb variants.

Kentron constructed a number of non-missile electro-optical systems such as a fibre guided submarine mine hunter, a Cactus gathering sensor to track the missile position immediately after launch, and diverse demonstrators and products.

Kentron products include imaging sensors based on CCD-TV and infrared sensor technology. TV sensors have been included in Kentron's products since the Hanto missile. During 1995 Kentron was one of the first companies to show infrared images obtained from the first infrared focal plane detectors developed outside the USA. This work later led to the Kenis infrared camera produced by Cumulus/Eloptro, used in a number of European weapon systems.

Helmet sights were one of Kentron's key products, since its incorporation. The V3 helmet sight, used with the V3A missile allowed the pilot to steer the missile seeker with a sight on his helmet. Several helmet sight variants followed through the years, but the highlight product was engineered by Mr Pieter Grobler (signal processing) and Mr Tony Viljoen (sensor) in the late 1990s. Light emitting diodes (LED) are placed on the pilot's helmet and a number of sensors are placed in the cockpit. Images of the LEDs are processed to determine the location of each LED to sub-pixel accuracy. This concept was later industrialised by Cumulus (a division of Kentron) and is currently produced by Carl Zeiss Optronics.

Kentron developed two very complex targeting sights, the Potter navy targeting sight and the TDATS helicopter sight. Prototypes of these sights were constructed but large scale production did not follow. This work did however result in the development of smaller, less complex stabilised sighting systems for helicopters and unmanned aerial vehicles (UAV). This technology was later industrialised by Cumulus.

In the mid 1990s, the Kentron personnel that developed helmet sights, weapon system sights and stabilised observation systems were consolidated in a new business unit called Cumulus, led by Mr Berthold Alheit and later by Mr Jan Wessels. The Cumulus stabilised sights (LEO and ARGOS) typically contain a TV camera, an infrared imager and sometimes a laser rangefinder. Some variants have missile guidance systems, such as for INGWE. These sights were very successful in their markets and are currently produced by Carl Zeiss Optronics.

In 1985 Mr Nelis Willers and Prof Pieter Rademeyer discussed the feasibility of an imaging air-intercept missile. Funds were allocated and a research project was initiated. Willers' strategy for the project comprised three elements: a target signature measurement programme, a hardware development project and a computer based image simulation for algorithm development. The signature measurement capability was already established under V3C. A capability to manufacture single element detectors existed at CEFIM, but a long, hard walk was required to develop the linear array envisaged for this seeker. Credit for the detector development must go to Dr Christo Schutte (Kentron) and Dr Monuko du Plessis (CEFIM). Development of the image simulation software tool 'Simulation for Imaging Systems' (SIMIS), was initiated in 1991 by Willers and Me Riana Wheeler. In 2007 Denel Dynamics announced the joint development of an imaging air-intercept missile, the A-Darter, with Brazil.

2.7 CSIR Corocam

In 1997 the CSIR and Eskom were the first to present a paper on the development of a daylight corona discharge observation and recording system, at the International Symposium on High Voltage Engineering (ISH). As a result of this partnership a range of corona detection cameras evolved which have been used by various utilities worldwide [20]. The opto-mechanical designer, Jaco Hart, came from the NPRL group.

The Corocam products comprise an integrated suite of ultraviolet (UV), visual and thermal imaging cameras. The system allows the user to observe the same scene in all three spectral bands, superimposed in one image. The product is selling successfully in the world market.

2.8 CEFIM

During the period 1982 to 1990 there was a strong research effort at Carl and Emily Fuchs Institute for Microelectronics (CEFIM) in the fields of optical signal processing and optical detection [21].

In the optical detection field, under the guidance of Prof Monuko du Plessis, several silicon based detectors were developed, which included p-n, PIN and avalanche types. Two-colour detectors were also realised by the team with the main thrust in silicon/germanium for the visible and near infrared ranges.

Mr Callie Marè, a senior researcher and his team did some forefront research and development on InSb and MCT detectors for the 3–5 μm and the 9–12 μm spectral ranges respectively. Prof Eugene van Rooyen and his group of researchers built up a signal processing laboratory at CEFIM, which formed the basis for research in parallel optical signal processing and computer generated holograms. Several PhD and MEng degrees were bestowed on top class engineers during this period, from which the optical engineering fraternity benefitted enormously, still to this day.

In 1991, the University of Pretoria decided not to pursue high-risk contract research in university institutes. The detector manufacturing equipment and personnel were transferred to Detek, a laboratory of Eloptro.

Since the early 1990s, under the leadership of Prof Monuko du Plessis, research was conducted to develop efficient silicon-based light emitting diodes that can easily be integrated into state-of-the-art CMOS technology [22]. After the successful filing of two USA patents in 2000, the effort at CEFIM has been intensified leading to the funding of the project by the government Innovation Fund, as well as the venture capital South African Intellectual Property Fund since 2004. A spin-off company INSiAVA was founded in 2007 to commercialise the CMOS light emitting technology developed at CEFIM. Improvement in the external power efficiency of the avalanche electroluminescent CMOS light sources has been achieved by novel carrier injection techniques, as well as quantum confinement in SOI (silicon on insulator) structures. Technology demonstrators for near-eye-displays, chip-to-chip, on-chip optical interconnect and lab-on-chip applications have been realised.

2.9 Detek

Detek is the detector manufacturing laboratory of Denel, led by Dr Christo Schutte. When Detek was spun off from CEFIM in 1991, it originally reported to Eloptro, but since 1997, Detek reports to Denel Dynamics [23].

Detek controls all the critical detector technologies: a number of detector device processes and vacuum and integration technologies. Detectors are manufactured from raw material to final product within the laboratory.

Still under CEFIM, the InSb process development started in the early 1980s, with the first photovoltaic device demonstrated in 1984. Photoconductive HgCdTe was demonstrated in 1986. Photovoltaic planar HgCdTe was demonstrated in 1987 by Mr Callie Marè. A number of single element and common-module compatible detectors were manufactured in serial production.

In 1990, planar InSb processes were established with the aim to develop linear arrays and focal plane arrays. The silicon readout chips for the detectors were developed by the company 'Solid State Technology' (SST). Linear array InSb devices were produced in low volume, in 1997. Research on a flip-chip staring array was initiated in 1999, and is continuing at a low level of funding.

Detek currently produces detectors for Denel's internal use, with ad-hoc overseas contracts from time to time. The laboratory is currently undergoing modernisation to meet future needs.

2.10 Solid State Technology (SST)

In 1992 Prof M du Plessis and Dr Trudi-Heleen Joubert formed the company 'Solid State Technology' to develop a variety of silicon pin detector and focal plane silicon processing devices for infrared detectors. Over the years, SST remained a critically important player in the South African detector industry.

2.11 Atomic Energy Corporation

The Atomic Energy Corporation (AEC), initiated the molecular laser isotope separation (MLIS) uranium enriching project in 1982, under Dr Daan Kemp [24]. The initial team consisted of less than 10 people and were led by Dr Einar Ronander. A number of CSIR personnel[4] joined the team [25].

The MLIS process is based on the selective excitation of the required UF_6 molecule by frequency stable 16 μm laser radiation. The solution was to use a high energy, high pulse repetition rate CO_2 laser and a hydrogen Raman cell. During development, both the laser as well as the Raman cells proved to be major technical challenges. This research required people with skills ranging from high voltage high power pulsed power systems to experts in gas dynamics.

By the end of 1980s the team produced the highest average power 16 μm source in the world. By 1992, the single step laser enrichment of uranium to the level required by a commercial reactor, was demonstrated.

In 1994, a joint venture was formed between the French institute COGEMA and the AEC. In 1996 the combined investment of the two groups was approximately R100m per year with a team of more than 100 people, both South African and French, working on it. At this stage it was probably one of the largest optical engineering projects in South Africa and it can safely be said that this project was truly a world leader in molecular laser isotope separation technologies.

[4] Dr Johan Strauss, Dr Hennie Human, Dr Hubertus von Bergmann (contracting from Randse Afrikaanse Universiteit) and Dr Tamas Salamon.

In 1997 the AEC decided that it would no longer be able to contribute its R50m of the joint venture contract and the project was terminated. This meant that lasers and ancillary equipment were no longer required by the AEC. A few of the scientists then approached the Department for Arts, Culture, Science and Technology (DACST, now DST) with the proposal to form a National Laser Centre. It was decided that the National Laser Centre (NLC) was established as an independent research centre reporting directly to DACST. The Centre started operations in 2000. The Centre was constituted by staff that remained after the closure of the MLIS program at AEC, and the CSIR laser group which was at that stage focusing largely on compact solid state laser sources.

A number of the ex-MLIS scientists emigrated to Australia where they were employed by an Australian laser company called SILEX (separation of isotopes by laser excitation). The SILEX process proved to be so successful that GE of the USA bought the rights to use its uranium enrichment process. The program, as well as most of the South Africans working on it in Australia, were moved to the USA and at this stage they are in the process of developing an industrial demonstration plant.

Another group of ex-MLIS scientists formed a laser company called Scientific Development and Integration (SDI) in 1998. SDI specialises in the development and production of world class high power high energy pulsed CO_2 lasers.

2.12 National Laser Centre

The NLC initially operated as an independent institute under the DST, managed by the CSIR. In 2003 the NLC was incorporated as a national research centre within the CSIR. The NLC research is funded by DST funding as well as contract research.

The NLC currently performs research in the areas of novel laser sources (mainly mid IR laser research), ultra short physics spectroscopy, mathematical optics, biophotonics (focussing largely on photodynamic therapy), advanced photonic materials and laser materials processing (welding an cladding of light metals such as Al and Ti alloys). The NLC has excellent laser laboratories, including two femto-second laser systems, clean rooms to support their laser research programs, and industrial laser systems to support research and development activities in the manufacturing industry.

One of the key programs of the NLC is the Laser rental pool program. This program, funded by the DST, provides equipment, maintenance support, and scientific and technical expertise to researchers at South African Higher Education Institutes (HEI). A similar program is also supported to enable laser research across the African continent, the the African Laser Centre [26].

2.13 Avitronics

Grinaker Avitronics, in the late 1980s, was primarily an avionics, radio-frequency and radar company. Mr Johan Kotze, Mr Johan Viljoen and Mr Christie van Deventer joined Avitronics in 1993, and brought with them the CSIR UV-MAW and laser warning receiver technology. Avitronics industrialised the products and offered it on the world market. In 2005, Saab bought a majority share in Avitronics to form Saab Avitronics. The UV-MAW technology is available today in the form of the MAW-300 product.

Saab Avitronics develops and produces laser warning sensors (detecting range finders, designators, beam riders and dazzlers) for naval, land and airborne platforms. Additionally a range of solar-blind UV missile approach warning systems are developed and produced to protect helicopters, transport aircraft and fighters. Other electro-optical support equipment include flight-line testers, long-range stimulator sources, optical signature generators and tactical displays. The pride of the company is the fully integrated suite of self-protection systems: radar, laser and missile approach warning [27].

2.14 Optocon Systems

In 1997, when the NPRL optical shop was to be closed down, Mr Ronald Brown and Mr Gary King, formed Optocon. They bought out the equipment and rented the floor space from the CSIR, to continue operations as an optical element manufacturer. In 2005, Mr Tristan Goss bought into the company and brought electronic and product development skills to the company. Ansys bought Optocon Systems in 2008 and injected capital for new products and growth [28].

Optocon Systems is an electro-optical engineering company doing design, modelling and manufacture of electro-optical systems. The company's skills base covers electronics, optical design and manufacture, opto-mechanical design, systems engineering and systems integration. The company's offerings include thermal imaging cameras, the design and build of specialist electro-optical instruments and the design and manufacture of advanced optical systems for civilian and military clients.

3. PISA

The notion of developing a national strategy for Photonics R&D in South Africa, led to the formation of the Photonics Initiative of South Africa (PISA) [7][5].

[5] The CSIR National Laser Centre and the University of Stellenbosch Laser Research Institute were the originators and early drivers of the initiative [25].

The need for a centralised strategy is driven from an appreciation of the wide-ranging techno-economic impact of a coordinated photonics SET programme.

In August 2008, a national workshop was held where more than 60 invited role players from industry, the science councils and the HEI community discussed and debated the proposed strategy. The strategy has a vision to position South Africa as a globally competitive player in photonics and is built on three specific interventions to: (1) Develop human capital to create a critical mass in photonics skills, (2) Support directed and focussed research programs aligned with specific national priorities, (3) Support innovation and the strengthening of the South African Photonics industry through a technology nursery, enabling mechanisms to support technology transfer between the research community and the photonics business community, and by stimulating direct foreign investment.

At present the strategy has been accepted in principle by the DST, and an implementation plan is being developed to initiate the program.

4. LESSONS LEARNT

One of the departure points in this paper is that Dr Ritter could be regarded as the father of optics in South Africa. It should also be evident that a large number of dedicated, hard working people assisted in bringing the optical engineering industry to its current maturity. Some of these people are named in this paper, but most are not. The top of the pyramid is only as strong as the base on which it stands [14]. It is critical that a powerful and stable work force be maintained to achieve the visionary leader's dream.

A golden line flows through all the success stories: leadership, personnel empowerment and project funding. The work force can be empowered by training, motivating and leadership. Funding of research and development projects is required, but does not necessarily guarantee success. Visionary leadership is critical to success.

In the early years of its existence, the NPRL performed long term research and technology establishment. In later years, however, the 'blue sky' research declined in favour of shorter term, contract focused, research [6]. Too strong a focus on the short term needs and exploiting available technology, eroded the development of forward looking, new cutting edge technology. Grossly generalising, it can be observed that, prior to 1980, the optical community acquired and consolidated a skills base. During the Golden 1980s, demonstrator and product development became fashionable while basic, long term research fell into disfavour. During the 1990s, rationalisation shrunk the range of products to a handful of competitive products. This sifting process established (and rightly so) a mind-set of commercial focus on products and medium term product research. However, in some areas, the basic, long term research fell by the wayside in the struggle for survival[6]. During the SMEOS 2009 conference, Prof Anthony Walton [29] confirmed this tendency also in the United Kingdom. One can only hope that the South African SET planners will not loose sight of the importance of long term research!

It is evident that the time from the initial conceptualisation of a technology to its successful industrial exploitation took several decades. The big advances required multi-decade funding, good facilities and sustained knowledge building in stable teams. With such long cycle times, it is critical to maintain a continual flow of new technology initiatives.

There are strong indications that a country's research output correlates well with its long term industrial success[7] [7]. Formal, broad-based HEI education and research in optical engineering/photonics is generally lacking in South Africa (there are notable exceptions!). Industry is currently relying on in-house vocational training, which is not a substitute for solid academic grounding.

5. THE FUTURE

"The more time you spend talking about what you have been doing, the less time you have to spend doing what you have been talking about". (Norman Augustine). Enough about the past, consider the future!

Current weaknesses are the lack of sustained academic and trade training of the future workforce and establishing long term research that would support the industry ten or twenty years into the future. There are indeed planning for such forward looking research currently underway. The recent developments by government to support photonics research is encouraging. Now, will the next Dr Ritter please rise to put together his team?

PISA holds great promise to bring together all the role players in the country to address the weaknesses and exploit the strengths of the industry.

South Africa has a small, but optimistic and highly aggressive optical engineering industry. The companies have good products competing successfully with the best in the world! These companies are supported by highly capable scientists and engineers,

[6]Industry hopes that the PISA initiative by DST may bring all stakeholders together resulting in alignment between 'blue-sky' research, product development, production technologies and foreign revenue streams, while stimulation employment and human capital development across all [14].

[7]While correlation does not imply causation, the evidence is quite strong in this case.

managed with good business principles, thereby ensuring long term survival. The industry, exploiting mature technologies, is thriving and moving forward with an anticipation of a great future.

6. IN MEMORIAM

Dr Ritter passed away on June 5, 2009, but he left South Africa with an immense legacy: a successful optical engineering industry. He was fortunate to have observed the growth of the industry for which he laid the cornerstone. One only wonders if he had really envisaged, in his wildest dreams, all of this in 1965?

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