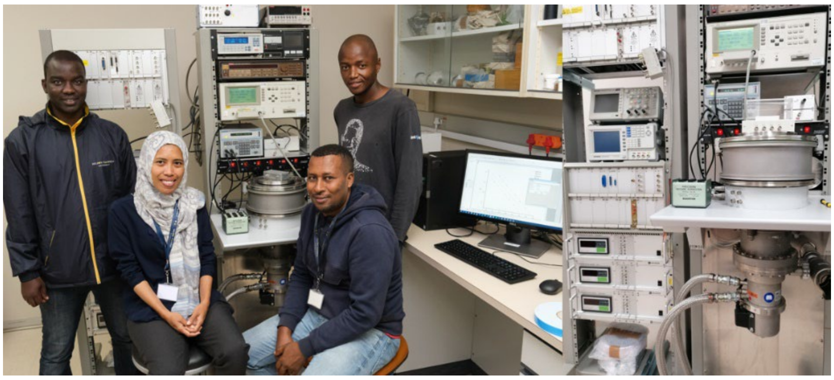
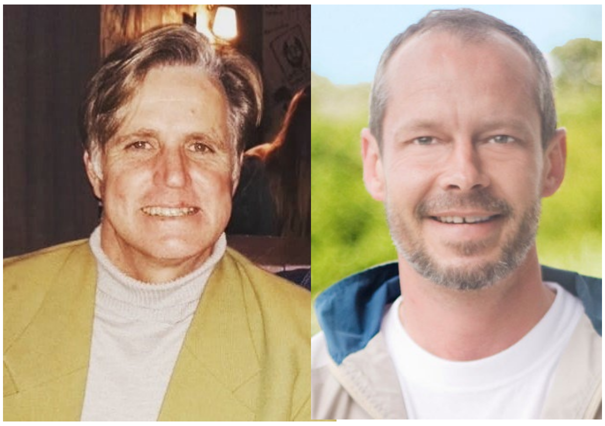
Mandela University Physics expands its impressive research facilities

Nelson Mandela University's Physics Department recently expanded its already comprehensive range of world-class facilities for semiconductor research and development. From synthesis to characterisation and limited device processing and testing, these facilities are unique in the country and Africa.



From left, Physics PhD students Assane Talla and Isni Pujirana, researcher and lecturer Dr Zola Urgessa and post-doc researcher Dr Ngcali Tile are involved in research using the new equipment.

Access to state-of-the-art equipment (all under one roof) for research in condensed matter physics is an advantage that few, if any, other institutions on the continent can offer, says Physics Department Head Professor André Venter (left in the photo).



"Semiconductors are the heartbeat of modern technology and everyday life", says Prof Venter. Just imagine your world without a cell phone or a personal computer or visiting your doctor without having access to diagnostic equipment such as X-rays, ultrasound NMR and CT scan facilities.

The Department recently acquired a multi-million-rand high-resolution electrical characterisation facility. This laboratory represents a significant upgrade to the Department's semiconductor device testing and postgraduate student training capabilities and is the result of several years of collaboration between Prof Venter, Prof Reinhard Botha (former Nanophotonics Chair-holder) (pictured right) and Prof Joachim Bollmann, formerly from the Technische Universität Bergakademie, Freiberg, Germany.

Their collaboration involved the optical and electrical characterisation of novel semiconductor materials and device structures to, among others, extend the absorption range of electromagnetic radiation, resulting in improved solar cell efficiencies. The exclusive nature of their research and the expertise at Mandela University is coupled with decades of specialisation in the field of Solid-State and Semiconductor Physics, which offers prospective students, guest researchers and industry, opportunities not available elsewhere in Africa - and all in one department.

Benefitting students

For more than 40 years the Physics Department has provided specialised, tertiary physics education in South Africa. Skilled graduates have been employed across the world in science, engineering, and technology-related enterprises.

Considering South Africa's present position and quoting from the Vision and Strategic Plan of the University, "the South African government has identified high-level skills shortages as a significant constraint in the development of a knowledge-based economy. This necessitates an investment in human capital development to produce a greater number of skilled individuals, particularly in science, engineering, and technology, he says.

Moreover, the Department of Science and Technology has prioritised the need to increase the number and improve the equity profile of honours, masters, doctoral and postdoctoral graduates to contribute to developing the next generation of researchers and academics in South Africa.

Considering this, the establishment of this new facility could not have come at a more opportune time for the university, and the Physics Department, Prof Venter says.

About semi-conductors

Wrist smartwatches measure heart rates, sleeping patterns, calories consumed, blood oxygen levels, running speed and distance and communicate with the global positioning (GPS) satellite constellation. Similar technology facilitates communication with your automated coffee machine, your Wi-Fi connected HiFi system and TV and the streaming of music via smartphone apps. Additionally, smart fridges could notify you when the milk levels are low while cell phones can measure the water content of fresh produce in your local supermarket. Sadly, these technologies are also used to deploy and control sophisticated missile attack and defence systems.

All these applications rely on the emission of electromagnetic radiation and the detection and processing of ensuing electronic signals.

At the core of these sophisticated electronic systems lie semiconductors, a very special class of solid-state material with unique electrical and optical properties. Solid-state detectors are semiconductor devices with properties such that when a particular wavelength of radiation (visible light, infra-red etc.) is detected, a small current is generated through the absorption of the energy that the light carries.

Conversely, emitters are devices that emit light (photons) when an excited electron occupies a lower energy state.

We can explain it as follows: like humans, electrons do not like to be in a state where it is working extensively - called an excited state – and, therefore, would rather like to occupy a lower energy state (almost like us lounging after a day's hard labour). When doing so, the energy lowering may be accompanied by the emission of light with an energy equivalent to the amount by which the electron's energy is reduced. In semiconductors, these amounts of energy are very specific (quantised).

The colour of the emitted light is a function of the amount of energy the electron loses. The smartwatches mentioned earlier are equipped with green-light emitters because this wavelength (green) is readily absorbed by blood cells. Some of this light is reflected and then detected. Both emitter and detector devices are tiny semiconductor diodes, fitted to the smartwatch.

Semiconductor materials can be engineered for just about any imaginable electronic application and are used to manufacture transistors, diodes and capacitors, to perform the logic operations that generate the binary code upon which all the input instructions on your PC keyboard are based. The speed at which these operations are performed is determined by the switching frequency of the devices and, fundamentally, the properties (such as the electron mobility) of a semiconductor.

Semiconductor devices often also need to operate in extreme conditions and environments, such as high temperatures, high voltages, and high energy radiation. For example, communication satellites are continuously exposed to particle radiation, a by-product of the nuclear reactions in the sun, which may cause significant damage to onboard computers and devices and even destroy them.

Semiconducting diamond, because it is radiation hard, is very suitable for these applications. As with the Olympic credo "faster, higher, stronger" semiconducting materials research is driven by faster, more, but smaller. PCs must process information faster, and store more data, while at the same time being miniaturized. The future awaits the arrival of the quantum computer of which semiconductor materials will form the basis.

As with all things in life, semiconductor materials are not perfect. They are, instead, riddled with defects or crystal imperfections, such as vacancies and impurities, which alter the structural, electrical, and optical properties of the material, and consequently the performance of devices made from it.

For example, when developing light emitters, the recombination of electrons (as explained, facilitated by lowering their energy via recombing with a hole) often does not produce light (photons) of the desired colour or wavelength (the green light in our smartwatch emitter application) or, in some cases, no light at all. This is often due to a defect (called a trap) capturing the electron on its way to occupying a lower energy state and, instead of light, rather produce heat which results in enhanced atomic vibrations (called phonons), thereby reducing the performance of devices.

It is therefore vital that the fundamental properties of the materials must be well understood. With the new characterization equipment added to the impressive range of equipment in Physics, it is now possible to study the electrically active defects in semiconductors with a resolution of 10^{-12} (one impurity atom amongst a million-million host atoms). Additionally, with the advent of the Laplace DLTS technique, defects previously thought to be single defects can now be resolved with astonishing accuracy (a few milli-electron volts) when considering their emission behaviour.

Research and consultation

The Physics Department does fundamental semiconductor material development and characterisation work for ESKOM, DENEL, ARMSCOR, and several private industries. They also consult on the fundamental challenges related to the development of reliable optoelectronic devices for optical fibre communication, particle and environmental gas sensing, and solar cell technology.

Graduates

Physics graduates are employed across the world in academia, materials research and related device development industries, biomedicine and biophysics, as well as in the renewable energy sector and engineering. Interestingly our students are in high demand in the banking sector, where their problem-solving skills are used in risk modelling.

Some of our own Physics Alumni work at Capco Brazil (Technology Consultant), Pro Photonix Ireland (Application Engineer), Jaguar Land Rover UK (Thermal Engineer), Incomar Aerospace and Defence Systems Pretoria (Scientist), Chrysos PhotonAssay Australia (Programne Manager) and ITyukt Digital Solutions (Software Developer and subsequently Executive Director).