ACT Node & WA Node NEWS

Providing nano and microfabrication facilities for Australia's researchers

Australian National Fabrication Facility

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Next Generation Room Temperature Semiconductor Nuclear Radiation Detectors

Semiconductor gamma-ray and X-ray detectors are being used increasingly in medicine, industry, astronomy and national security. Conventional semiconductor detectors are manufactured from germanium and silicon. Such materials have become less useful in many emerging applications due to their physical limitations such as low detection efficiency or their need to operate at cryogenic temperatures. Next generation nuclear radiation detectors are advanced sensors which utilise innovative technologies developed for the wide band-gap compound semiconductor industry and microelectronics. This research project is aimed at developing room-temperature operating nuclear radiation detectors based on cadmium manganese telluride (CdMnTe). Now in their second generation, major improvements in the performance of these detectors have been demonstrated. This research is paving the way for the realisation of advanced CdMnTe sensors for use in nuclear medical imaging and accurate in-field radiological threat detection.

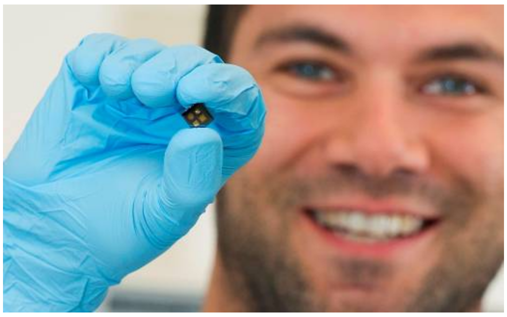

Figure 1: Ramin Rafiei holding a CdMnTe radiation detector (Image courtesy ANSTO).

CdMnTe is a promising compound semi-conductor. While previously investigated for applications in optical isolators and tuneable solid state lasers, its application for nuclear radiation detection was first investigated in 1999. Its distinct advantage of excellent compositional homogeneity compared to CdZnTe, which has been the leading room temperature detector candidate for over three decades, enables the growth of large-volume uniform CdMnTe crystals. Inhomogeneity of CdZnTe crystals continues to limit the industrial yields of usable material to 10% or lower, resulting in very high material costs. A collaboration led by Ramin Rafiei between the WA Node of the Australian National Fabrication Facility (ANFF) at The University of Western Australia, The Australian Nuclear Science and Technology Organisation (ANSTO), and Brookhaven National Laboratory (USA), investigates CdMnTe crystal growth, detector fabrication and detector performance.

The CdMnTe crystals were grown by the vertical Bridgman technique. A manganese fraction of 5%, corresponding to a band-gap of 1.59 eV, was chosen for optimum room temperature spectral performance. To grow high resistivity CdMnTe, the crystal was doped with indium. Indium, which is a donor, compensates for the high concentration of Cd vacancies which act as acceptor centres in CdMnTe. Major obstacles towards realising CdMnTe crystals that are advantageous in nuclear radiation detector applications have been high levels of residual impurities in the Mn source material and high concentrations of tellurium (Te) inclusions which are known to act as charge trapping centres. These issues have been overcome in the growth of generation II CdMnTe crystals where the MnTe source material was purified by a zone-refining method with molten Te solvent, and control over the size and distribution of the Te inclusions was also achieved. The fabrication of these devices was carried out at the ANFF WA Node utilising the expertise of this node in II-VI semiconductor processing and their experience in II-VI semiconductor device fabrication. A fabricated CdMnTe detector of size $10 \times 10 \times 2.6 mm^3$ is shown in Fig. 1 (above).

A detailed understanding of the fundamental charge transport properties of CdMnTe radiation detectors is essential for detector development. The most useful figure of merit is the mobility-lifetime product which quantifies the charge carrier transport through the detector. A low mobility-lifetime product results in short carrier drift lengths and limits the maximum detector thickness and, hence, its application. Time-resolved transient current measurements and alpha-spectroscopy measurements have been used to measure the charge-collection efficiency of CdMnTe detectors. From the dependence of the charge collection efficiency on the applied bias an average electron mobility-lifetime value has been calculated and shows an improvement from 5×10^{-4} cm^2V^{-1} for a generation I device to 3×10^{-3} cm^2V^{-1} for a generation II device.

Uniform charge-carrier transport is critical to the spectroscopic performance of CdMnTe detectors. Ion beam induced charge (IBIC) measurements, utilising $^4He^{2+}$ beams from the ANTARES accelerator at ANSTO, have revealed the spatial distribution of charge transport in these devices down to micron scale resolution. Fig. 2 (top panel, over) is an IBIC image of a generation I detector showing the charge collection efficiency (CCE) across an area of 1450 x 1450 μm^2. Such images have quantified how major impurities such as tellurium inclusions

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Well how did that happen!! *The end of another year and Christmas is upon us.*

Last newsletter we farewelled Jie Tian, our well respected FIB Process Engineer, but since then we have welcomed our new EBL Process Engineer - Dr Naeem Shahid! Naeem received his B.Sc degree from University of the Punjab, Lahore, Pakistan, and M.Sc degree from University of Engineering and Technology, Lahore, Pakistan. Subsequently, he has worked for five years on the ISO-coordination for a public sector organisation in Islamabad Pakistan. He later joined the School of Information and Communication Technology, KTH Royal Institute of Technology, Kista, Sweden and obtained his PhD. You can find out more about Naeem on the "Staff" page of our website.

All the staff of both the ACT and WA nodes of the ANFF would like to wish you all a very merry, and safe, festive season and look forward to our continued relationship in the New Year. Cheers!!

Next Issue: due March 2013

ACT Node & WA Node info:

- The ACT Node specialises in III-V compound semi-conductors.
- The WA Node specialises in II-VI compound semi-conductors and MEMS.
- We can provide full support with the use of the equip-ment available.
- Full pricing policy and rates are available on the ANFF website at www.anff.org.au or contact us direct for more information - see contact details overleaf.

ACT Node Facility Equipment & Capability Update

It has been a while since we have reported on new equipment purchases, facility capability updates and year-end seemed like an ideal time to re-cap and bring everyone up-to-date.

All our regular existing and NCRIS funded Flagship equipment has been operating well this year and use of the facility is increasing with both existing and new customers - in particular the FIB and E-beam Evaporator showing above forecasted usage. We are in the process of installing and commissioning two new MOCVD reactors - one for GaN-based materials and one for GaAs and InP based structures, reducing the load of the existing MOCVD reactor. These will hopefully be up and running by the end of the first quarter of 2013. Additionally we are upgrading the High Energy Ion Implanter to implant full 6" wafers.

The Node has also extended the fabrication facility to include some new small equipment and other tools essential for a full micro and nano-fabrication facility such as:

- Desktop SEM sputter system;
- Barrel Etcher for soft wafers cleaning (this can also be used to change surface properties - hydrophylic or hydrophobic);
- Vacuum oven (400˚C max temp);
- Rapid Thermal Annealing (up to 1400˚C in N_2/H_2, Ar or O_2);
- Surface Profiler (accuracy of 10nm);
- Retrofit a TEOS capability (terta-ethyl-ortho-silicate) to our PECVD system enabling high quality SiO_2 deposition at even low temperatures (150˚C) - this capability is unique in Australia;
- Plasma-assisted atomic layer deposition extending the capabilities of the existing in-kind thermal ALD system to nitride layers, SiO_2 and Ta_2O_5. Also we are looking to fit a silver source (Q1-2013);
- Flip-Chip Bonder;
- Spectral Ellipsometer covering the UV region up to mid infra-red (190-1700nm).

As always, if you have any issue related to micro and/or nano-fabrication contact us as we may be able to assist you.

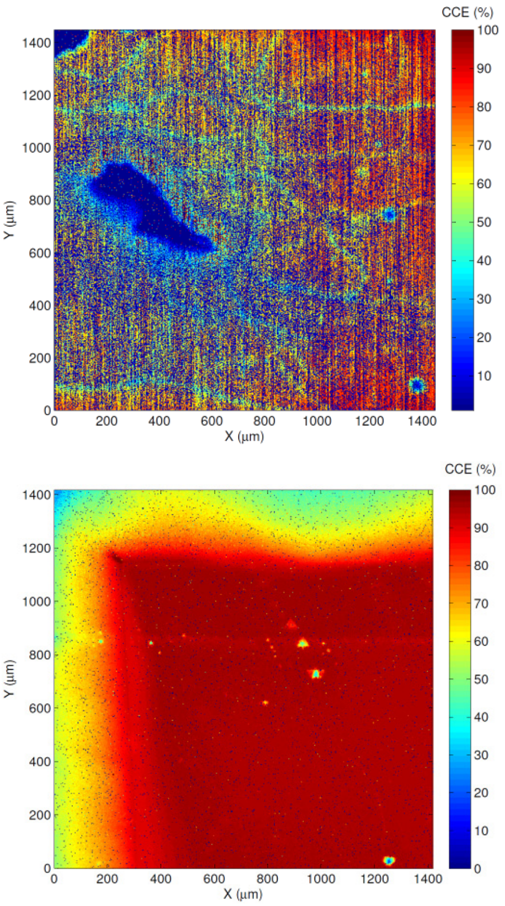

Figure 2: Spatially resolved charge-collection efficiency maps of Gen I (top panel) and Gen II (bottom panel) CdMnTe detectors. The edges of the detector are clearly visible in the bottom panel.

(Continued from page 1)

present within the detector bulk (and clearly visible in Fig. 2 (top panel) as areas of reduced charge collection), affect the charge collection of these devices. In contrast to the top panel of Fig. 2, the bottom panel is an IBIC image of a generation II detector showing for the first time uniform large-area charge collection at a value of 100%.

Generation II detectors are currently the world's most advanced CdMnTe radiation detectors and their charge transport properties are compared to commercially available CdZnTe (see Table 1). While the current performance of state-of-the-art CdZnTe detectors represents over four decades of research and development, recent advances in CdMnTe detector technology has been the result of a relatively short 12 month intensive international effort.

Detector	Bandgap (eV)	Mobility-Lifetime (cm^2/V)	Mobility (cm^2/Vs)	Lifetime (μs)
$Cd_{0.95}Mn_{0.05}Te$	1.59	3×10^{-3}	990(±50)	3.1(±0.3)
$Cd_{0.90}Zn_{0.10}Te$	1.57	10^{-2}	1200	5

Table 1: Comparison of electron charge transport properties of generation II CdMnTe detectors with commercially available CdZnTe detectors.

With continued progress in crystal growth, purity and fabrication processes, the achievement of advanced CdMnTe sensors with spectroscopic performance superior to that of CdZnTe combined with an imaging capability is within reach. It is anticipated that over the next decade investment in next generation nuclear radiation detectors will be mainly driven by their application in nuclear medical imaging. While CdZnTe medical probes have recently become commercially available, their application in more advanced capabilities such as X-ray computed tomography and positron emission tomography is being aggressively pursued. With the increased demand for compound semiconductor nuclear radiation detectors, higher yield advanced CdMnTe sensors may define the economical way forward.

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