FEATURE

*Dr Arnab Basu is CEO of Kromek Group plc.

Stretching the frontiers

Dr Arnab Basu* investigates the growing potential of cadmium zinc telluride, a semiconductor that is making waves, and asks, can it really transform the world of X-ray and gamma ray detectors?

Above: Raw CZT is turned into cylindrical ingots.

Outside of scientific circles, cadmium zinc telluride (CZT) may not be as well known as silicon, but its use as a semiconductor is changing radiation detection and nuclear medicine.

CZT is used extensively to diagnose and manage common diseases, such as osteoporosis and cancer, but it also has uses in security, to combat the threat of terrorism, and in the civil nuclear industry.

It could be said that its potential is only now being understood, as demonstrated by ongoing research that is looking at how to use CZT-based detectors to test for a wide range of diseases, including dementia, Parkinson's and cardiovascular conditions.

A step above the competition

CZT converts X-ray and gamma ray photons directly as an electrical signal that can be measured and analysed. Other semiconductors have been used in radiation detection, namely silicon and germanium, which are established materials but are either too inefficient in capturing high-energy radiation or require complex cooling to remove thermal noise.

Conventional scintillator detectors require a two-stage process to convert radiation into light and light to electrical signals, using either photomultiplier tubes or silicon photodetectors. However, a two-stage conversion process limits the spatial and energy resolution of the detectors and reduces their effectiveness in clinical applications. CZT, meanwhile, directly generates electrical signals without complex cooling, and is extremely sensitive to high-energy radiation.

Nevertheless, for most clinical applications, processing speed is not a high priority. Strict radiation limits for patients puts far more importance on detecting all the radiation.

Despite this, processing speeds in CZT continue to increase in Moore's law (that the number of transistors in a integrated circuit doubles every two years) fashion, opening up the possibility of spectral computed tomography (CT) – which can radically improve medical diagnostic capabilities by using cross-sectional images to show the inside of the body in high definition.

Based on technology developed by Durham University, UK, Kromek Group was founded in 2003 to commercialise CZT and now has nearly 300 patents granted or pending and sells to customers worldwide.

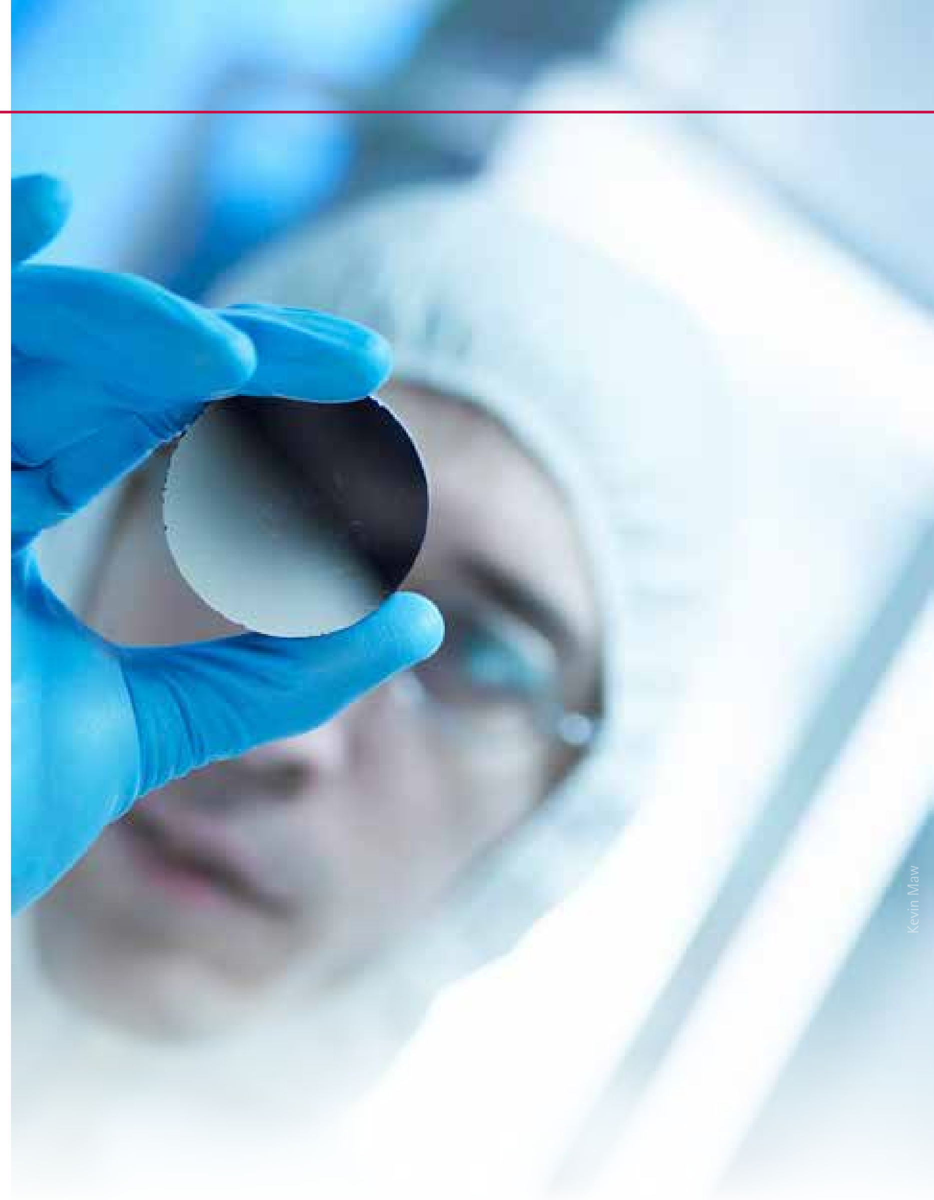
Making it usable

However, to get cadmium zinc telluride to a point where it can begin to challenge the likes of silicon, it is necessary to move it from a semiconductor crystal into a usable radiation detector.

Cylindrical ingots are produced in furnaces and these are sliced to a required thickness, which depends on the type of energy being measured. For the detection of X-rays, they would be between 1mm and 3mm thick, and for gamma rays, which have more energy and penetrate further, it would be 5mm and 20mm.

These slices are then diced into the final shape and the surfaces are polished and treated, ready for depositing a metal coating to enable electrical contacts. Photolithography is used to create a pattern that turns one surface into a cathode for collecting radiation and the other into an anode to connect read out electronics.

The coated crystal can be bonded to a silicon chip or robotically aligned and mounted on a circuit board, so that the electrical signals can be passed through pre-amplifiers, amplifiers and analysers. Detectors can be made up of a single unit or assembled into linear or 2D arrays, depending on their final use.



Above: CZT is cut into thin slices ready to make radiation detectors.

Hoping for a medical marvel

It could be argued that this is one of the most exciting periods in the use of radiation in medicine since Wilhelm Roentgen discovered X-rays in 1895 and Hal Anger pioneered the scintillation camera in the 1950s. CZT is helping to push the boundaries and turning what used to be an area of science fiction into the reality of nuclear medicine.

CZT-based devices are now used in bone mineral densitometry (BMD), measuring how much radiation passes through bones to diagnose and manage diseases such as osteoporosis. There are between 5,000 and 7,000 machines in operation worldwide using Kromek components to measure BMD.

Another tried and tested area of use is for gamma probes used in radio-guided surgery on lymph nodes, where radioactive tracers are injected into a patient so that surgeons can remove the lymph node and test whether cancer cells are present.

However, more can be done. The next area of development is in single-photon emission computed tomography (SPECT) scanners where CZT gamma ray detectors could provide better spatial resolution than scintillators, allowing physicians to pinpoint the location of tumours. Small cameras can look at specific areas such as the thyroid, while arrays of detectors can be used in whole body scanners. And, although cancer is the focus of the early use of CZT in SPECT, research is underway to test its effectiveness in the diagnosis of other diseases such as Alzheimer's and Parkinson's.

In addition, CZT is being trialled in computerised tomography scans used to detect heart disease and investigations are on-going to understand its use in molecular breast imaging to complement or replace traditional mammography, where the density of breast tissue can hamper effective screening.

Ultimately, CZT systems have the potential to drive down the costs of healthcare, whether funded privately or by taxpayers. In a time where the ageing population is increasing the pressure on health services worldwide, this could prove invaluable.

Security and fighting terrorism

Aside from healthcare, it can be used as a security tool, particularly in airports. Kromek has developed a system – used in more than 50 airports – that can scan bottled liquids, distinguishing innocent items from dangerous or potentially dangerous ingredients that could be mixed to form explosives.

There is also the issue of baggage screening, where tougher regulation is driving innovation. More accurate systems will eliminate the need for laptops and smartphones to be removed from bags, reducing inconvenience for passengers and speeding up traffic through security.

What about the nuclear industry? There are examples where CZT is being used to detect and identify radiation, as well as leaks, while some also believe it could find its way into the food industry to check for contamination. The work, therefore, continues.