CZT Detectors

Converging assembly technologies open new application opportunities.

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Cadmium Zinc Telluride (CZT), CdZnTe, is a semiconductor that directly converts X-ray or Gamma-ray photons into electrons. CZT is unique compared with silicon and germanium detectors in that it operates at room temperature and is capable of processing more than one million photons per second per square millimeter. The spectroscopic resolution of CZT outperforms that of most other detectors.

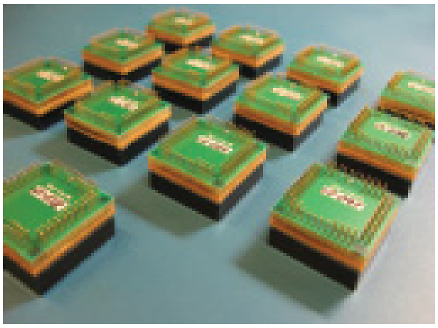

Figure 1. Completed detectors prepared for a large-scale array to be used in a space telescope application (Courtesy of Quik-Pak, a division of Delphon Industries)

Preparation for assembly requires critical shaping, polishing, and specialized crystal metallization. Assembly needs unusually low temperature flip chip mounting techniques, often coupled with attachment and bonding to complete the module. This convergence of multiple technologies enables the assembly of CZT crystals into a detector module but requires specialized technical skills.

The CZT Detector

The role of a gamma radiation detector is to capture any gamma ray photons which penetrate the crystal and convert this energy into electron-hole pairs that migrate to the anode and cathode at the top and bottom of the crystal. The resulting electrical signal is picked up at the terminals of the device which are connected to sensitive amplifiers and analysis circuitry, usually located on a custom ASIC chip.

A key parameter of the CZT crystal is its thickness which varies according to the application. The higher the energy to be measured, the thicker the crystal required to detect the excited particles. For low energy applications, thinner crystals are needed. Typical crystal thickness ranges from 1mm for low energy to as much as 15mm for very high energy capture.

Applications

The combination of spectroscopic resolution and very high count rate at room temperature makes CZT an excellent detector for medical, security, astrophysics, and industrial measurement applications. It is a market segment that is enjoying rapid growth.

Medical applications include bone density measurements, nuclear medicine and probes for gamma-guided surgical procedures. Since these are subjecting human and animal bodies to gamma rays, the energy levels are kept low and the CZT crystals are generally thinner, ranging from 1 mm to 3 mm. Such medical applications typically need high density pixel, low radiation level crystal assemblies.

According to the US National Coalition on Health Care, total health spending represents 16 percent of the gross domestic product (GDP). It is expected to reach $4.2 trillion in 2016, or 20 percent of GDP. Given the pressure on the medical profession for increased productivity, the improved accuracy and faster imaging of CZT detectors can only help the market for CZT-based medical imaging systems over the next few years.

Security system applications strive to detect and identify radiation sources. Uses may be airport screening, first responders, or buildings with restricted access to radioactive sources such as hospitals and clinics. The equipment to achieve this includes radioactive isotope detectors, and spectrometers. General monitoring of nuclear/gamma radiation yielding devices typically requires 5-10 mm thick crystals. CZT technology has the advantage over traditional X-ray systems of giving a complete spectroscopic identification of the scanned items and not simply their shape. This capability is generating substantial interest from airport security. The explosives detection market has been estimated at over $1 billion annually and the CZT segment within it is growing rapidly.

Astrophysics applications present a wide range of demands, often from one device. These can include high imaging resolution, detection of widely varying radiation strengths, and identification and directionality of the source. The CZT-

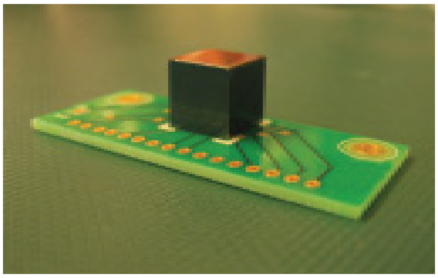

Figure 2. A detector assembly with 15mm crystal directly mounted for use in a high-energy experiment (Courtesy of Quik-Pak, a division of Delphon Industries)

based detectors used in space imaging systems are typically in the range from 5-15mm thick.

There are a variety of industrial measurement applications for the food and beverage sector. These include the ability to accurately sense the level of liquids or solids within closed containers where optical inspection is not possible. Other industrial uses include monitoring the flow of liquids and gases, and the

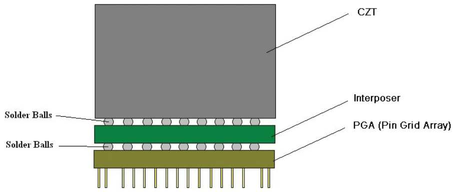

Figure 3. Representation showing the stack-up of the CZT, interposer and PGA connected with solder balls.

distillation fractions during the purification of liquids such as gasoline.

Detector Structures

Detectors can be built either as a single crystal of up to 20mm square or as a mosaic of smaller elements assembled precisely in an array on a substrate. For larger substrates, the CZT crystal manufacturing suffers lower yields, whereas the array of smaller crystals has better yield but higher manufacturing costs.

Crystals are cut from CZT ingots into the required size, inspected, selected, and then precisely shaped and polished to the customer specification. Following this, the top and bottom sides must be metallized with the cathode and anode terminals having the required pixel pattern plus any steering grid or guard rings to control the electrical parameters and sensitivity.

With metallization complete, the CZT crystal is ready to be mounted, either directly to a target substrate, or indirectly via an interposer. The substrate connects the custom silicon chip with sense amplifiers.

Each CZT-based product has its own unique needs, making it a custom design and build. Product designers need to find detector assembly resources that can help with the design, source the crystals,

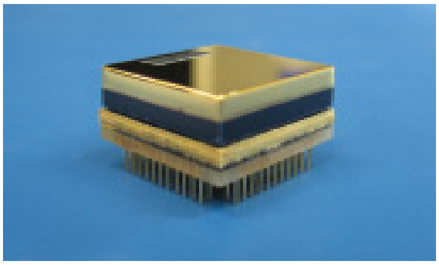

Figure 4. Detector with 20x20x10mm CZT crystal showing planar cathode and guard ring. (Courtesy of Quik-Pak, a division of Delphon Industries)

metallize the pixel pattern, and complete the subassembly with interposer and ASIC.

Assembly

CZT crystals are extremely brittle and require low stress designs in order to produce reliable assemblies. Various methods are used to attach these crystals either to an interposer or directly to an ASIC die. The assembly process temperature must not exceed 120°C. Most flip chip processes, which require adhesive and underfill curing temperatures of 140°C or greater, are therefore not suitable for assembly of CZT material. Metallurgical and mechanical properties further limit bumping the surface of these detectors. The key to packaging CZT crystals is having access to reliable electrode metallization and low temperature bonding technologies.

For commercial applications, there are two generally accepted bonding methods. One is to use low temperature conductive epoxy and the other is to use proprietary low temperature polymer flux with reflow at 120°C. With low temperature conductive epoxy, the epoxy must be contacted to a raised bonding pad or bump to prevent the epoxy from spilling over to the opposite surface. For low temperature soldered bonds precise temperature control is required. Also needed is a flux that provides the cleaning action necessary to make a good solder joint as well as an underfill for robust mechanical strength.

The metallization on the crystal surface is critical in order to produce a reliable low temperature interconnect and noble metals are often used to ensure adhesion and integrity. The metallization is patterned to suit the design for the application. A common approach is to have the cathode on top as a solid metallized plate and the anode on the bottom as an array of small square plates that represent each pixel which will capture the signal. This requires the cathode and each individual anode to be bonded out. Another approach involves an x-y coordinate system where the anode is patterned with parallel lines in one direction and the cathode is patterned with similar lines in an orthogonal direction. In this way, an individual pixel can be selected by an x-y coordinate. The former approach will result in lower noise and better signal capture compared to the performance of the x-y method. These are only two of several design approaches, but they show how the better performing approach requires a larger number of high density contacts to be bonded.

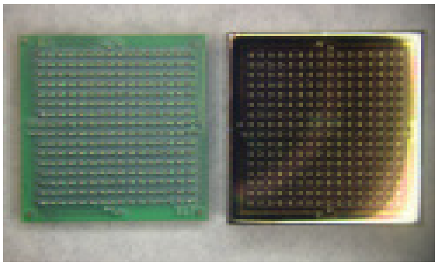

Figure 5. On the right is the high-density layout of anode pixels on the CZT crystal, surrounded by a guard ring and steering grid layout. On the left is the interposer with matching 300um bumps on a 500um pitch grid. (Courtesy of Quik-Pak, a division of Delphon Industries)

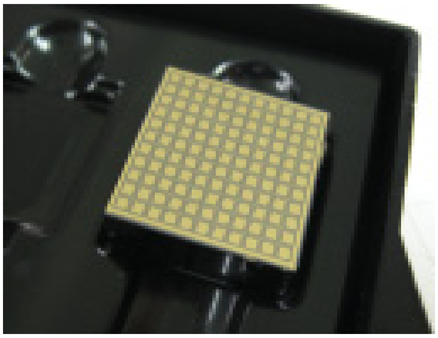

Figure 6. A crystal that was re-shaped and polished from an original highly irregular shape and then metallized with a solderable pixel pattern in a steering grid / guard ring arrangement. (Courtesy of Quik-Pak, a division of Delphon Industries)

Another metallization requirement is to form steering grids or guard rings. The purpose of the guard ring is to effectively allow the user to apply a small voltage to help "steer" the electron-hole pairs to the appropriate pixels and keep the event going in the direction it entered the crystal. If left unchecked, photons hitting the outermost pixels will tend to drift away from the targeted metallized pixels and end up escaping from the sides of the CZT crystal. To control this, it is common to apply a metal film around all four sides of the crystal. This can be applied via a conductive tape product.

Conclusion

Regardless of the application, CZT has proven to be a suitable material for gamma radiation detection systems for over 20 years. Robust packaging solutions have been developed and are currently available with a combination of proprietary low temperature polymer fluxes, high density capable solder interconnects, and high reliability metallization processes. With these types of process material sets, radiation detection with CZT is finding its way into an increasing number of varied applications.