Evolution of long wavelength astronomy sensors

Robert E. Mills, Eric Beuville, and Elizabeth Corrales

End-user demands continue to push the state of the art and evolution of large format, impurity-band conductor detectors for both space- and ground-based telescopes.

Astronomers have been interested in performing observations in the very long wavelength infrared band (5–28 μm) for decades. IR telescopes are useful to detect very cold or distant objects, so they are important for studying star formation regions, cold stars and extragalactic objects, among others. To this purpose, both ground- and space-based observatories have to be equipped with specific sensors that can collect infrared radiation. These so-called impurity band conductor (IBC) sensors have a sensitivity adequate to detect light in the desired spectral range (see Figure 1). They use impurities in the semiconductor to convert long-wavelength photons into an electrical current.

We have been manufacturing IBC detectors for many decades. These arrays, in multiple formats, can be found in numerous space and ground-based instruments. For example, NASA's Spitzer Space Telescope’s Infrared Array Camera, for example, uses two IBC detectors and two InSb (Indium antimonide) detectors. Observers used this early instrument for a wide range of astronomical research programs and produced images such as those in Figure 2.

The success of Spitzer encouraged the use of large format (wider field of view) IBC arrays. With these devices, astronomers benefit from increased sky coverage and improved sensitivity, thereby decreasing observation time. For instance, we recently delivered 1k×1k IBC mid-infrared detectors to the Jet Propulsion Laboratory (JPL) for the Mid-Infrared Instrument. This device is expected to be on board the planned James Webb space telescope (JWST), successor of the famous Hubble telescope. JPL performed qualification testing and characterization of dark current (the excess current present when a detector has no incoming photons) and noise on these detectors, and both should be minimal for higher performance. While the results delivered by these new IBC arrays will have to wait until the launch of the JWST mission (now delayed by several years), tests showed that the devices met or exceeded key requirements such as noise and dark current.

In the meantime, ground-based telescope requirements have also been changing. Several instruments have used an IBC detector array mated to a custom integrated circuit that ‘reads out’ the individual pixel information, which is called a read-out integrated circuit (ROIC). The first ROIC custom-designed to operate with an IBC detector—CRC-774 (the 774th circuit produced by the Carlsbad Research Center)—consists of 320 columns × 240 rows of unit cells, each 50 μm × 50 μm in size, with 16 or 32 selectable outputs arranged in blocks of 20 columns each. This particular design of IBC has been integrated into several instruments, including the Cooled Mid-infrared Camera and Spectrometer on the National Astronomical Observatory of Japan Subaru Telescope. This instrument demonstrates the power of IBC sensors to reveal complex dust structures in the mid-infrared wavelength band (see Figure 3).

Presently, the state-of-the-art IBC detector for ground-based telescopes is Aquarius-1k, a device we developed in collaboration with the European Southern Observatory (ESO). It is a 1024×1024, 30 μm high-performance array featuring high

Continued on next page
quantum efficiency IBC detectors, low noise, low dark current, and on-chip clocking for ease of operation. The Aquarius-1k was designed and delivered primarily for ground-based astronomy applications. The focal plane arrays are currently undergoing initial system testing at ESO.

While the Aquarius-1k is mainly for use in ground-based observatories, the next generation instrument—Aquarius-2k—will also be appropriate for space-based astronomy. According to Chris Packham, an astronomer from the University of Florida (personal communication, May 11, 2011), “The 2k Aquarius array has been baselined for several instruments in their planning phase for use on the 30m-class of telescopes and NASA’s SOFIA [Stratospheric Observatory for Infrared Astronomy] airborne telescope. The large format of the Aquarius makes it ideal where either a wide spectral range or a wide field of view is required by the science drivers of the instrument. Coupled with the sensitivity, readout noise and other key parameters of the Aquarius array, it is becoming the default option for instruments operating at 7–25μ. The science drivers are typically diverse, spanning the search of planets in discs around nearby stars to investigations of the effects of supermassive black holes in distant galaxies.”

In conclusion, we see that the evolution of IBC focal plane arrays is far from over as end-user demand consistently pushes for larger and larger formats with improved performance (e.g., lower noise and detector dark current, smaller unit cells, and greater ROIC functionality). In the future, we plan to collaborate with Japan’s Aerospace Exploration Agency to reconfigure

Continued on next page
an existing 2048×2048, 25µm high performance array (named Phoenix) that will feature high quantum efficiency and state-of-the-art IBC detectors. This version will also incorporate flight qualified packaging to support space-based astronomy applications: see Figure 4 (far right).

Author Information

Robert E. Mills, Eric Beuville and Elizabeth Corrales
Raytheon Vision Systems
Goleta, CA

Robert Mills is a senior focal plane design engineer. He has been involved in the design, test, and study of radiation effects on impurity band conductor sensors for 29 years.

References