Manufacturing & Prototyping

Fabrication of a Cryogenic Terahertz Emitter for Bolometer Focal Plane Calibrations

The methods used produce an emitter that features greater precision.

Goddard Space Flight Center, Greenbelt, Maryland

A fabrication process is reported for prototype emitters of THz radiation, which operate cryogenically, and should provide a fast, stable blackbody source suitable for characterization of THz devices. The fabrication has been demonstrated and, at the time of this reporting, testing was underway. The emitter is similar to a monolithic silicon bolometer in design, using both a low-noise thermometer and a heater element on a thermally isolated stage. An impedance-matched, high-emissivity coating is also integrated to tune the blackbody properties.

This emitter is designed to emit a precise amount of power as a blackbody spectrum centered on terahertz frequencies. The emission is a function of the blackbody temperature. An integrated resistive heater and thermometer system can control the temperature of the blackbody with greater precision than previous incarnations of calibration sources that relied on blackbody emission.

The emitter is fabricated using a silicon-on-insulator substrate wafer. The buried oxide is chosen to be less than 1 micron thick, and the silicon device thickness is 1–2 microns. Layers of phosphorus compensated with boron are implanted into and diffused throughout the full thickness of the silicon device layer to create the thermometer and heater components. Degenerately doped wiring is implanted to connect the devices to wire-bondable contact pads at the edge of the emitter chip. Then the device is micromachined to remove the thick-handle silicon behind the thermometer and heater components, and to thermally isolate it on a silicon membrane. An impedance-matched emissive coating (ion assisted evaporated Bi) is applied to the back of the membrane to enable high-efficiency emission of the blackbody spectrum.

In operation, the heater is supplied with a voltage that is PID-controlled (proportional-integral-derivative-controlled) by the output of the thermometer. Both components are quiet, and require low-noise readout and power supplies to function correctly. The fabricated chip is mounted and heat-sunk to a copper housing that directs and collimates the beam of terahertz power emitted from the chip. Filtering in the optical column in the copper housing with metal mesh or neutral density components is also possible. The implanted silicon is highly reliable and stable. The Bi coating is robust but may require passivation if the environment for installation has corrosives (i.e., acid flux, heavy solvents from a Dewar).

This work was done by James Chervenak, Ari Brown, and Edward Wollack of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16131-1

Fabrication of an Absorber-Coupled MKID Detector

This allows for multiplexed microwave readout and, consequently, good spatial discrimination between pixels in the array.

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Absorber-coupled microwave kinetic inductance detector (MKID) arrays were developed for submillimeter and far-infrared astronomy. These sensors comprise arrays of lambda/2 stepped microwave impedance resonators patterned on a 1.5-mm-thick silicon membrane, which is optimized for optical coupling. The detector elements are supported on a 380-mm-thick micro-machined silicon wafer. The resonators consist of parallel plate aluminum transmission lines coupled to low-impedance Nb microstrip traces of variable length, which set the resonant frequency of each resonator. This allows for multiplexed microwave readout and, consequently, good spatial discrimination between pixels in the array. The transmission lines simultaneously act to absorb optical power and employ an appropriate surface impedance and effective filling fraction. The fabrication techniques demonstrate high-fabrication yield of MKID arrays on large, single-crystal membranes and sub-micron front-to-back alignment of the microstrip circuit.

An MKID is a detector that operates upon the principle that a superconducting material's kinetic inductance and surface resistance will change in response to being exposed to radiation with a power density sufficient to break its Cooper pairs. When integrated as part of a resonant circuit, the change in surface impedance will result in a shift in its resonance frequency and a decrease of its quality factor. In this approach, incident power creates quasiparticles inside a superconducting resonator, which is configured to match the impedance of free space in order to absorb the radiation being detected. For this reason MKIDs are attractive for use in large-format focal plane arrays, because they are easily multiplexed in the frequency domain and their fabrication is straightforward.

The fabrication process can be summarized in seven steps: (1) Alignment marks are lithographically patterned and etched all the way through a silicon on insulator (SOI) wafer, which consists of a thin silicon membrane bonded to a thick silicon handle wafer. (2) The metal microwave circuitry on the front of the membrane is patterned and etched. (3) The wafer is then temporarily bonded with wafer wax to a Pyrex wafer, with the SOI side abutting the Pyrex. (4) The silicon handle component of the SOI wafer is subsequently etched away so as to expose the membrane backside. (5) The wafer is flipped over, and metal microwave circuitry is patterned and etched on the membrane backside. Furthermore, cuts in the membrane are made so as to define the individual detector array chips. (6) Silicon frames are micromachined and glued to the silicon membrane. (7) The membranes, which are now attached to the frames, are released from the Pyrex wafer via dissolution of the wafer wax in acetone.

This work was done by Ari Brown, Wen-Ting Hsieh, Samuel Moseley, Thomas Stevenson, Kongpop U-Yen, and Edward Wollack of Goddard Space Flight Center. GSC-16202-1

Graphene Transparent Conductive Electrodes for Next-Generation Microshutter Arrays

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Graphene is a single atomic layer of graphite. It is optically transparent and has high electron mobility, and thus has great potential to make transparent conductive electrodes. This invention contributes towards the development of graphene transparent conductive electrodes for next-generation microshutter arrays.

The original design for the electrodes of the next generation of microshutters uses indium-tin-oxide (ITO) as the electrode material. ITO is widely used in NASA flight missions. The optical transparency of ITO is limited, and the material is brittle. Also, ITO has been getting more expensive in recent years. The objective of the invention is to develop a graphene transparent conductive electrode that will replace ITO. An exfoliation procedure was developed to make graphene out of graphite crystals. In addition, large areas of single-layer graphene were produced using low-pressure chemical vapor deposition (LPCVD) with high optical transparency. A special graphene transport procedure was developed for transferring graphene from copper substrates to arbitrary substrates.

The concept is to grow large-size graphene sheets using the LPCVD system through chemical reaction, transfer the graphene film to a substrate, dope graphene to reduce the sheet resistance, and pattern the film to the dimension of the electrodes in the microshutter array.

Graphene transparent conductive electrodes are expected to have a transparency of 97.7%. This covers the electromagnetic spectrum from UV to IR. In comparison, ITO electrodes currently used in microshutter arrays have 85% transparency in mid-IR, and suffer from dramatic transparency drop at a wavelength of near-IR or shorter. Thus, graphene also has potential application as transparent conductive electrodes for Schottky photodiodes in the UV region.

This work was done by Mary Li, Mahmooda Sultana, and Larry Hess of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16148-1

Method of Bonding Optical Elements With Near-Zero Displacement

Displacement caused by epoxy shrinking as it cures is reduced less than 200 nm.

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The International X-ray Project seeks to build an x-ray telescope using thousands of pieces of thin and flexible glass mirror segments. Each mirror segment must be bonded into a housing in nearly perfect optical alignment without distortion. Forces greater than 0.001 Newton, or displacements greater than 0.5 μm of the glass, cause unacceptable optical distortion. All known epoxies shrink as they cure. Even the epoxies with the least amount of shrinkage (<0.01%) cause unacceptable optical distortion and misalignment by pulling the mirror segments towards the housing as it cures. A related problem is that the shrinkage is not consistent or predictable so that it cannot be accounted for in the setup (i.e., if all of the bonds shrunk an equal amount, there would be no problem).

A method has been developed that allows two components to be joined with epoxy in such a way that reduces the displacement caused by epoxy shrinking as it cures to less than 200 nm. The method involves using ultraviolet-cured epoxy with a displacement sensor and a nano-actuator in a control loop. The epoxy is cured by short-duration exposures to UV light. In between each exposure, the nano-actuator zeroes out the displacement caused by epoxy shrinkage and thermal expansion. After a few exposures, the epoxy has cured sufficiently to prevent further displacement of the two components.

Bonding of optical elements has been done for many years, but most optics are thick and rigid elements that resist micro-Newton-level forces without causing distortion. When bonding thin glass optics such as the 0.40-mm thick IXO X-ray mirrors, forces in the micro- and milli-Newton levels cause unacceptable optical figure error. This innovation can now repeatedly and reliably bond a thin glass mirror to a metal housing with less than 0.2 μm of displacement (<200 nm).

This is an enabling technology that allows the installation of virtually stress-