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

Goddard Space Flight Center, Greenbelt, Maryland

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.

Goddard Space Flight Center, Greenbelt, Maryland

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 stressfree, undistorted thin optics onto structures. This innovation is applicable to the bonding of thin optical elements, or any thin/flexible structures, that must be attached in an undistorted, consistent, and aligned way.

This work was done by David Robinson of Goddard Space Flight Center and Ryan McClelland, Glenn Byron, and Tyler Evans of SGT, Inc.Further information is contained in a TSP (see page 1).GSC-16110-1