Automated Absorber Attachment for X-ray Microcalorimeter Arrays

NASA, GODDARD SPACE FLIGHT CENTER

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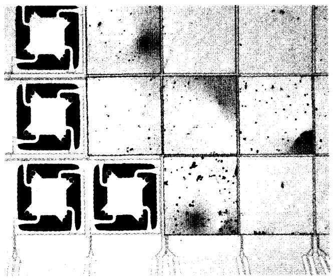
Category: Exploration of the Universe

OBJECTIVE:

Our goal is to develop a method for the automated attachment of large numbers of absorber tiles to large format detector arrays. This development includes the fabrication of high quality, closely spaced HgTe absorber tiles that are properly positioned for pick-and-place by our FC150 flip chip bonder. The FC150 also transfers the appropriate minute amount of epoxy to the detectors for permanent attachment of the absorbers. The success of this development will replace an arduous, risky and highly manual task with a reliable, high-precision automated process.

INTRODUCTION:

Future imaging x-ray spectroscopy missions (NeXT, Constellation-X, Gen-X) require arrays of microcalorimeters with 400 or more pixels. Manual attachment of individual x-ray absorbers, barely tolerable at the 32-pixel scale of XRS/Astro-E2 and XQC, does not have the precision, reproducibility, scalability, or yield required for arrays with over an order of magnitude more pixels. HgTe, the absorber material for XRS and XQC, is not a material which can be directly deposited on silicon, yet silicon thermistors with HgTe absorbers are presently the leading array technology for NeXT, a Japanese x-ray astronomy mission in formulation for which Goddard will propose to supply the detector assembly. In order to fulfill the anticipated NeXT requirement of large format arrays, we are developing an automated absorber attachment process.

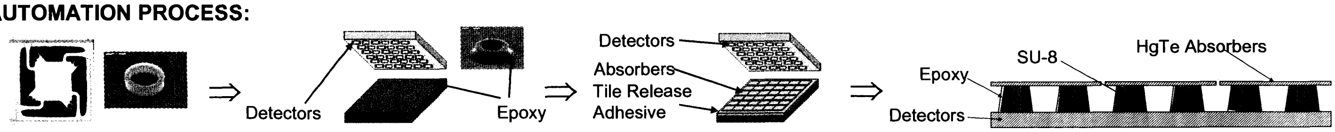


This is an SEM image of a partially competed XRS detector array with manually attached HgTe absorbers.

Historically, HgTe absorbers have been laboriously attached to absorber-spacers on individual pixels of microcalorimeter arrays. The figure on the left shows the partially assembled XRS2 flight array and conveys some idea of how fragile the process is. Attachment to significantly greater numbers of pixels in this manner is not feasible.

Under the Fy 2006 CDDF program we continued to develop a process to place all the absorbers on a multi-pixel calorimeter array in only two steps. In the first step, a tiny volume of epoxy was transferred to each thermistor pixel simultaneously. In the next step, an array of absorbers were affixed to the epoxy joints and held in place until the epoxy cured.

AUTOMATION PROCESS:



(a) Make detectors with SU-8 absorber attachment posts.

(b) Using FC150 flip chip bonder, pick up epoxy on SU-8 Posts

(c) Using the FC150, attach absorbers to detectors. Absorbers are held temporarily by tile release adhesive.

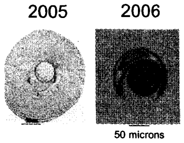
Above is depicted a side view of the completed array with attached HgTe Absorbers

Phase II Progress (FY 2006):

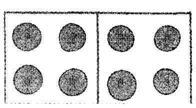
Achieved Goals of 2006

- Improved epoxy pick-up.
- Modeled XeF_2 detector release and strategies.
- Tested Unity 2000 as a dry-release agent for absorber tiles.
- Demonstrated attachment and release of 6x6 dummy absorber tiles.

In 2006 procedures where developed that made it possible to use Stycast 1266 epoxy with out solvent thinners and apply it to the surface of the SU-8 post in a controllable manner.



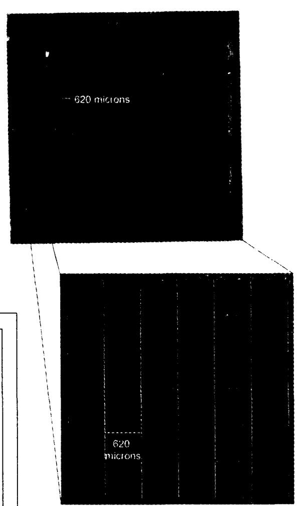
Above are shown the improvements made in controlling the amount of epoxy applied to the post.



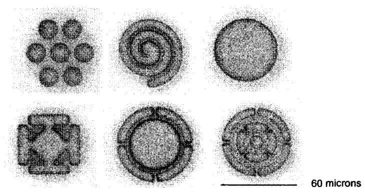
The photograph above shows a small section of glass that has SU-8 posts on it. The epoxy was applied to the posts and the posts were bonded to Si tiles. This view is from below the tiles looking through the glass.

Multiple complete 6x6 arrays were released from handle wafers with three distinct approaches.

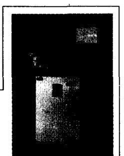
1. Unity ™ 2000 was used as an adhesive to hold the tiles to the handle wafer. The SU-8 posts were adhered to the pixels with epoxy. The chip was then heated in an inert atmosphere to 180 C for 8 hr where the Unity ™ sublimated leaving a completely tiled array.
2. The second technique used Black Wax instead of Unity ™ as the tile release adhesive. Then the wax was dissolved in TCE or Opticlear.
3. In our third approach we physically pulled the array from the solidified Black Wax.



This is a photograph of a mechanical model that was fully tiled by the automated process we have developed.



This image shows several designs of posts that may aid in picking up the right amount of epoxy to attach the absorber to the pixel. The optimal post design is still under consideration.



XeF_2 etching was optimized for the GISMO project by Timothy Miller. This data will be used in the release of future x-ray detector arrays.

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Phase III Plans (FY 2007):

- This work is continuing under a GSFC Directed IRAD, targeting technology development for the Japanese NeXT mission.
- Demonstrate a full scale mechanical model of absorber tile attachment to a large scale pixel array.
- Continue to optimize the XeF_2 etching using XRS style detector mask set.
- Continue to optimize the tile release process.

Automated Hybridization of X-ray Absorber Elements- A Path to Large Format Microcalorimeter Arrays

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Abstract

In the design of microcalorimeters, it is often desirable to produce the X-ray absorber separately from the detector element. In this case, the attachment of the absorber to the detector element with the required thermal and mechanical characteristics is a major challenge. In such arrays, the attachment has been done by hand. This process is not easily extended to the large format arrays required for future X-ray astronomy missions such as NEXT.

In this paper we present an automated process for attaching absorber tiles to the surface of a large-scale X-ray detector arrays. The absorbers are attached with a thermally isolating polymer structure made of SU-8 and epoxy.

We describe the fabrication of the X-ray absorbers and their suspension on the handle die in an adhesive matrix. We describe the production process for the polymer isolators on the detector elements. We have developed a new process for the alignment, and simultaneous bonding of the absorber tiles to an entire detector array. This process uses equipment and techniques borrowed from the flip-chip bonding industry and approaches developed in the fabrication of the XRS-2 instrument. We describe the process and show examples of sample arrays produced by this process. Arrays with up to 300 elements have been bonded. The present tests have used dummy absorbers made of Si. In future work, we will demonstrate bonding of HgTe absorbers.

Introduction

To produce a high performance microcalorimeter, one must simultaneously optimize three detector elements. The absorber must efficiently absorb and thermalize the X-ray photon, using the smallest possible heat capacity. The thermometer element must measure the temperature rise in the absorber caused by the absorption of the X-ray. The thermal link between absorber and thermometer on the detector must be optimized for best performance. It must be high enough to rapidly transfer thermal energy from the absorber, but weak enough that the absorber is thermalized before the energy is transferred to the detector element. All these functions are difficult to accomplish using silicon only, so one must assemble components made of different materials. In the case of the XRS II microcalorimeters, a process was developed which produced very high performance detectors (ref). In this process, photopatterened polymer posts were used to produce the proper thermal link between absorber and detector. The absorbers were made from HgTe, and were attached to the detectors with epoxy in a manual process. This was achievable for the 36-element XRS array, but the manual process in impractical for large arrays being proposed for future missions.

In this paper, we describe wafer-level process of attaching absorber elements to arrays of detector elements. This process is a natural outgrowth of the XRS II detector development, which defined the basic detector architecture, the SU-8 polymer isolating post for absorber attachement, and the epoxy attachment of the absorber. Here, we describe the design and fabrication processes required to attach absorbers to large arrays of detectors simultaneously. We have demonstrated the production of integrated arrays of mechanical models of detector arrays. We used Si absorber tiles in this work; in parallel work, EPIR Technologies is developing techniques for producing gridded of HgTe tiles mounted with a polymer to a rigid flat substrate. In all other aspects, this work is representative of what will be done in functional arrays. We describe the approaches by which we create the simulated absorbers, detector models, and isolating posts. The development has successful, resulting in high yield attachment of absorbers to arrays at the wafer level.

Technical Approach

A complete detector with attached absorber is shown in Fig. x. The X-ray absorber is attached to the detector element through an epoxy joint on a polymer post. Here, we discuss the important steps in producing this detector; producing the detector arrays, applying the polymer post structures, producing the tiles in a regular grid to mate to the detector elements, the epoxy bonding of the absorber to the mounting post, and the release of detectors and absorbers from their handling matrix.

Production of Detector Models

In this phase of the project, we produced a mechanical model which was mechanically identical to the XRS II detector arrays (ref). The detectors models were produced starting with a Silicon on Insulator (SOI) wafer with a 1.5 μm device layer on a 0.2 μm buried oxide layer. These were attached to a 380 μm thick two side polished handle wafer, with a 1.4 μm oxide layer on the back. The device layer was patterned to define the shape of the detector elements and etched down to the buried oxide, defining the detector elements. The device layer was protected with photoresist, and the backside of the detector was patterned to allow the production of wells aligned with the detector elements. The oxide was etched to reveal the Si at the well locations. The polymer posts for absorber attachment are produced next. A 2μm thick layer of SU8 is patterened to produce a "foot" for the tall SU8 post structure. This creates a large area for adhesion of the post and it protects Si from damage in a subsequent XeF2 etching step. Next, a thicker layer of photoresist is applied to the wafer, allowing the creation of a 20 μm tall post over the "foot" applied earlier. A layer of Shipley 1811 photoresist is applied to the wafer front and is patterened with two masks, one being the "foot" mask and another which opens areas around the pixel for the XeF2 to enter unimpeded to etch the handle wafer under the location of the back wells in a subsequent step. Next, we bond the SOI wafer to a Pyrex wafer using black wax. This allows us to etch the back wells through the handle wafer to the buried oxide under the detector element and to separate the detector die from each other. We then release the detectors from the Pyrex handle by dissolving the black wax in TCE.

Simulated Absorber Tile Production

The tiles were manufactured from an SOI wafer with a 10 μm thick device layer over 2 μm of oxide on a 500 μm thick handle wafer. A photoresist pattern was applied to the device layer to produce arrays of 590 μm x 590 μm tiles with a 10 μm spacing between the tiles. This was etched for 20 cycles in the STS Deep Reactive Ion Etcher (DRIE) which cut the gap between tile down to the oxide layer, delineating the tiles. The surface of the tiles was spin coated with Shipley 4620 photoresist and baked at 90 C for 30 minutes, and patterned to cover the tiles only, that is, removed from the gaps. The device layer was bonded to a Pyrex wafer with black wax. The handle wafer was mechanically lapped down to within 50 μm of the oxide layer. Then, the DRIE is used with no passivation cycle to remove the handle wafer, leaving the buried oxide exposed. We protected the exposed Pyrex with photoresist and removed the buried oxide layer with a buffered HF etch. Adhesive tape was placed over the imbedded tiles, a 4 x 4 array of 36 element simulated absorbers is delineated using a dicing saw (fig). The adhesive tape is removed, and the absorber arrays are ready for bonding to the detector arrays.

Application of adhesive to interface

The absorber tiles will be attached to the detector arrays with epoxy which is applied to the polymer post. The epoxy is spun onto a double side polished Si wafer to a thickness of 10 μm or less. Using the Suss 150 Indium Bump Bonder, the detector wafer is stamped onto the wafer carrying the epoxy, transferring epoxy to the tips of the polymer posts. Without additional processing, the epoxy wicks up the post and onto the surface of the detector array, leaving insufficient epoxy on the tip of the post to make the bond to the tile. To create the proper surface characteristics to constrain the epoxy to the tip of the post, we expose the detector die to C4F8, the passivating material for the Bosch process in the DRIE. This applies a thin layer of passivant primarily to the tip of the post and the surface of the die. With this preparation, the epoxy transfers only to the tip of the post, keeping the sides of the post and the die surface adhesive free.

Attachment of absorber tiles to detectors.

Once the glue has been applied to the posts, the epoxy application wafer is removed from the aligner, and in its place is positioned a tile array, still attached to its Pyrex wafer. The detector array is aligned in x-y to the absorber tiles, and a laser leveling process assures coplanarity of the wafers. The bonder then brings the wafers into contact, and can apply up to a 4 kg load while both wafers are heated to 70 C for 1 hr. Once the array and tiles are cooled to room temp, the load is removed, and the bonded unit can be removed from the machine.

Release of tiles from handle

Now that the array is bonded to the array, the tiles must be removed from the handle wafer by dissolving the black wax. This is done by soaking the entire structure in TCE for up to 10 hours. This releases the tiles from the handle, but leaves a layer of photoresist. This is easily removed with an RIE oxygen plasma, leaving the released tile on the surface of the detector array.

Release of Mechanical Supports in Back Wells

In the XRS II project, the wells behind the detector elements were etched to reveal the entire detector element from behind. This provided sufficient mechanical support when the epoxy was being applied to one post at a time. Given the large forces involved in our bonding process, some method of back support for the detectors must be developed. We tried four different techniques for detector bonding support. In all cases, the supports must be removed in XeF_2 after bonding is complete. The XeF_2 must etch laterally enough to release the posts from the backing structure, but not attack the detector elements (fig). Finish this section

Removal of Oxide Barrier

Barrel Ashing Photoresist from the Detector Elements

Show pictures, any test results

Plans and Goals

Future plans, objectives