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Authors	LO CICERO, UGO, Arnone, Claudio, BARBERA, Marco, COLLURA, Alfonso, Lullo, Giuseppe
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Electroplated indium bumps as thermal and electrical connections of NTD-Ge sensors for the fabrication of microcalorimeter arrays

U. Lo Cicero^{1,2}, C. Arnone², M. Barbera^{3,1}, A. Collura¹, G. Lullo²

¹INAF-OAPA, Piazza del Parlamento 1, 90134 Palermo, IT; ²DIEET Università di Palermo, Viale delle Scienze, edificio 9 - 90128 Palermo, IT; ³DIFI Università di Palermo, Via Archirafi, 36 I - 90123 Palermo, IT

Abstract. We are developing a method to build arrays of Ge-based microcalorimeters for soft X-rays detection using micro-photolithographic techniques. A key element of the process is the electrical and thermal connection between the germanium sensors and the interconnection electrical tracks, that lay on a substrate acting as mechanical support and thermal sink. The geometry of the sensors, that have a square base truncated pyramid shape, makes feasible a connection through indium soldering. We describe a technique, based on microlithography and electroplating, adopted to grow indium bumps of a few tens of square microns of area and several microns high on top of the contact pads patterned on the substrate. The sensor array is placed over the bumps and a subsequent baking melts the indium, soldering the sensors to the pads.

Keywords: Microcalorimeter array, NTD-Ge, Indium bumps, Flip-chip bonding, X-ray detectors, X-ray spectroscopy

INTRODUCTION

A process to build arrays of NTD-Ge based microcalorimeters is being studied by our group. We have developed the technological steps to create a Sn absorbing layer [1], to shape the sensors in form of square based 60 μm -high truncated pyramids [2], and to deposit electric contacts on two opposite lateral 45° inclined faces of each sensor [3]. In the present work we show how we solder the sensors to electrical pads and tracks connected to the front-end electronics. Each sensor of the array has to be thermally connected to the thermal sink, that is a substrate held at 60 mK. The same heat sink substrate is used to pattern the interconnection electric tracks that are connected to wires going to the read-out electronics. In order to make the electrical connections between sensors and tracks a flip-chip bonding technique has been adopted.

FLIP-CHIP BONDING

The flip-chip bonding technique consists first in depositing a soldering material, in form of small bumps, on pads at the end of each track. Then the sensor array and the tracks on their substrate are joined, with a controlled force, rising the temperature until the soldering material melt, providing a stable mechanical and electrical connection. The size of each pyramidal sensor is 180 μm x 180 μm for the large base (the one attached to the absorber) and 60 μm x 60

μm for the small base. The spacing between the sensors is 400 μm from center to center (Fig. 1).

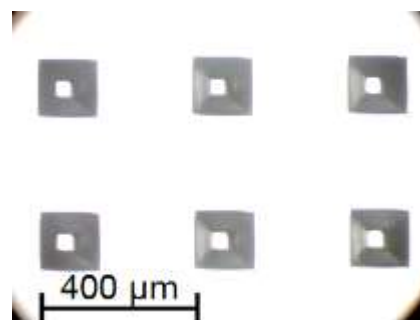


FIGURE 1. Ge pyramidal sensors

The distinctive adopted shape of the sensors in the array, together with the needed size of the bumps, and the requirements for the soldering material, makes the common paste-based dispensing technique unsuitable for the bumps deposition. It is also critical that the amount of material for each bump be the same, since the soldering material can influence the performances of the sensor because of the contribution to its heat capacity. We therefore use a masked electroplating deposition to grow the bumps. Figure 2 shows a schematic drawing of the main technological steps involved in the process.

Bumps material

Indium has been chosen as soldering material to be deposited in form of bumps or pillars. There are several motivations for this choice:

- the low melting point (156.6 °C) is compatible with the presence of the Sn absorbing layer;
- indium is elastic even at cryogenic temperatures, and is less subject to fractures than stiffer materials;
- indium is a superconductor at the operating temperature of the device ($T_c = 3.41$ K), so its contribution to the heat capacity of the sensors is limited;
- it has excellent adhesion and wetting on gold;
- it can be deposited using a non-toxic electroplating process.

Commonly used Under Bump Metallurgy (UBM) consists of Ti-Ni-Au: titanium is the adhesive layer, nickel is wettable by indium and acts as diffusion barrier, gold is a protective layer [4,5]. Although we plan to use Ti-Ni or Ti-Ni-Au pads, in the present work the nickel layer has been left out to study the performances of the Ti-Au UBM suggested by Aliane et al. [6]. On the sensor side we plan to use a direct indium-germanium interface to produce an ohmic contact. Indium on germanium was employed in alloy transistors and the junction is known to be stable at room temperature and below [7]. Thin indium contacts will be deposited on two opposite lateral 45° inclined faces of each pyramidal sensors. A thin protective layer of gold or silver could be added to avoid indium oxidation during the time interval between contacts deposition and flip-chip bonding [8].

The link to the thermal sink, necessary to remove the excess heat provided by absorbed X-ray photons, has to be weak, on the order of a few tens of pW/K. As explained in [2] we want to suspend each sensor on a silicon nitride membrane, so that it would be possible to trim the thermal conductance with great accuracy. Thus we have two possibilities to make the thermal resistance of the suspended membranes prominent: 1) to obtain a good thermal contact only through the indium bumps by choosing a proper UBM, 2) to improve the contact between the small base of the truncated pyramid and the membrane itself. At temperatures around 100 mK phonon transport is mostly ballistic and interface resistances play a determinant role, so we can achieve an higher thermal conductance by reducing the number of interfaces to a minimum of 4. Aliane et al. measured a 14.5 pW/K thermal conductance through an indium bump with a diameter of 40 μm and a total of 8 interfaces between

different UBM layers [6]. The results of our study for the selection of the best performing UBM will be presented in further communications.

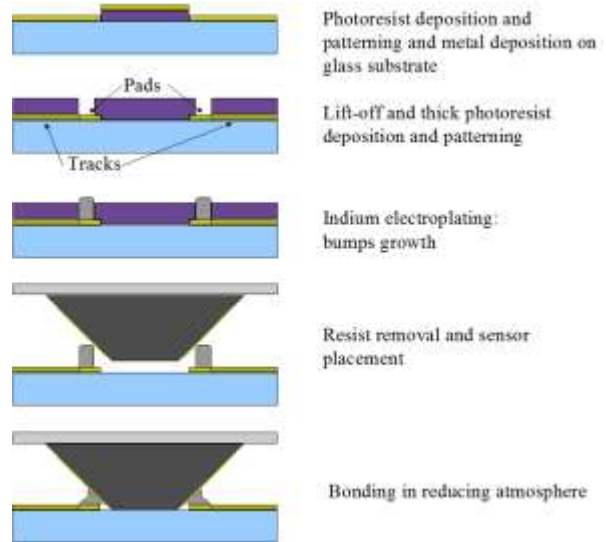


FIGURE 2. Schematic view of the main steps of the adopted process.

Bumps deposition

Gold interconnection test tracks have been fabricated for a 6x6 sensor array on a glass substrate with a lift-off process. The glass substrate has been used for valuation purposes, since its transparency allows to see how the indium is behaving during the bonding. The size and the length of the tracks (two for each sensor) is such that all of them have the same electrical resistance. Each track has a bottleneck just before the contact pad, so the indium is less susceptible to move toward the track and away from the pad during melting.

A 8 μm thick photoresist layer has been deposited on the substrate to coat the tracks. 10x50 μm windows have been opened in the photoresist by laser lithography in correspondence with each pad. Opening the photoresist leaves the underlying gold uncovered. It can so act as seed layer for the indium electroplating deposition. The openings are smaller than the actual pads, and the separation between the two bumps of the same sensor will be slightly larger than 60 μm in order to allow a certain degree of tolerance in positioning the pyramidal sensor in between. However, when the indium melts, it tends to wet all the pad, moving toward the sensor and providing a good electrical contact.

The indium bumps, 10 μm high, have been deposited by electroplating, using an indium sulfamate plating bath (Fig. 3-4-5). The following process

parameters were used: current density 0.2 mA/mm², room temperature, no agitation, total time 20 min.

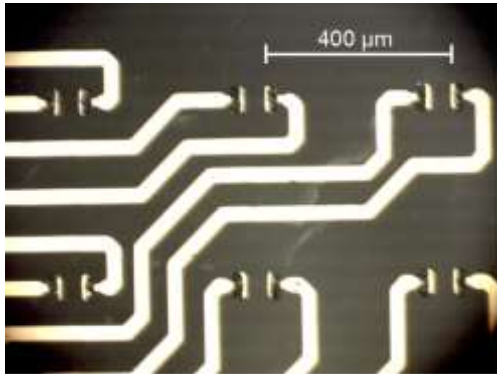


FIGURE 3. Indium bumps grown on gold pads

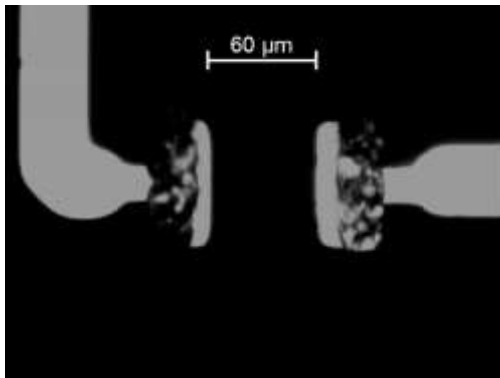


FIGURE 4. Detail of grown indium bumps

Bonding

The sensor array and the interconnection tracks have been bonded in reducing atmosphere (nitrogen, <5% hydrogen) (Fig. 6). The placement has been done using a modified probe-station, looking through the glass substrate to check the alignment. The parallelism between the two parts to be joined has proved to be a critical issue. The instrument used doesn't allow to achieve the necessary precision required in tilt correction. This has affected negatively the resulting bonding.

An obvious solution is to use a better equipment, able to bring higher parallelism precision. A second, more interesting, solution under study, is to exploit the geometry of the sensor array to obtain an auto-alignment during the bonding. The array can simply be placed over the bumps, so that each pyramid is allocated between two indium pillars. Once the indium melts, its adhesion with the strongly wettable gold keeps the bumps in position, avoiding lateral drifts.

Presently, the sensor array is a matrix of about 2x2 mm², and it is embedded in a 1x1 cm² germanium sample. Such extra area and weight disturbs the auto-alignment process, since the weight can be unbalanced. In order to achieve auto-alignment, the sensor array will be cut off from the rest of the sample.

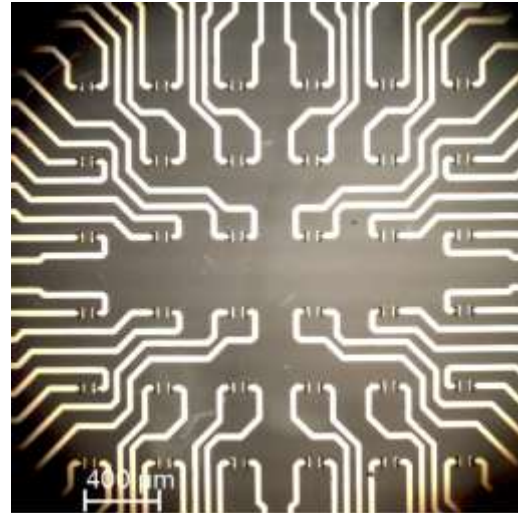


FIGURE 5. Interconnection tracks with deposited indium bumps, for a 6x6 sensor array.

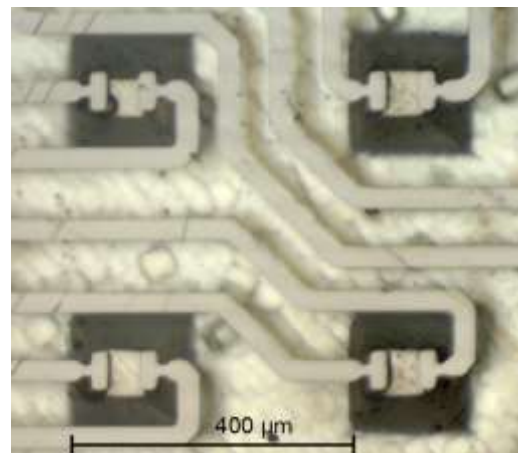


FIGURE 6. Bonding between sensors and interconnection tracks, seen through the glass substrate

CONCLUSIONS

As part of a research program aimed at developing large format arrays of NTD Ge microcalorimeters, we have set up a technique to deposit metallic contacts on pyramid shaped germanium sensors. The pyramidal shape of the sensors, which presents significant advantages with respect to a more standard

parallelepiped shape, prevents the use of standard lift-off technique for the deposition of the contacts.

We have chosen to use shadow-evaporation through a patterned copper mask as the most efficient way to obtain metal deposition on the lateral faces of the pyramid. This process has been developed and tested. The process to fabricate a suitable 5 μm thick free-standing copper mask has also been presented. In this paper we show results to demonstrate the effectiveness of the developed micro-technological processes and provide instructions to replicate them.

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