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Authors	LO CICERO, UGO; Arnone, Claudio; BARBERA, Marco; COLLURA, Alfonso; Lullo, Giuseppe
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Fabrication of electrical contacts on pyramid-shaped NTD-Ge microcalorimeters using free-standing shadow masks

U. Lo Cicero[1,2], C. Arnone[2], M. Barbera[3,1], A. Collura[1], G. Lullo[2]

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

Abstract. In our effort to fabricate arrays of germanium microcalorimeters for X-ray detection, a truncated square-based pyramid shape has been identified as a suitable geometry for the sensors. It allows to obtain a uniform current spreading across each sensor, and represents a good compromise between having a large support area for the radiation absorber and for maintaining an overall small bolometer volume. This three-dimensional geometry, however, does not allow to create the electrical contacts for the sensors using a regular photoresist-based lift-off metallization process. In this paper we show how to deposit metal contacts on the lateral faces of the pyramidal sensors by metal evaporation through a butterfly shaped shadow mask, made of a five microns thick free-standing microstructured copper film. The process to fabricate the shadow mask, using microlithography and electrodeposition techniques, is also described.

Keywords: Microcalorimeter array, NTD-Ge, Shadow evaporation, Free-standing mask.

INTRODUCTION

We are working on a technological process aimed at building arrays of NTD germanium microcalorimeters for X-Rays detection. After the deposition of the absorbers [1] and the chemical shaping of the sensors [2], we create the metallic contacts on the sensors in order to electrically connect the array to interconnection tracks on a substrate. The electrical connection is made trough a flip-chip technique, using electroplating-deposited indium bumps [3]. The shape selected for the sensors is a square-based truncated pyramid, that makes difficult the standard lift-off technique for the deposition of the contacts. Each sensor is 60 µm high, with a 180 µm large-base, and the pitch between the sensors is 400 µm (Fig. 4 - 5). This kind of three-dimensional structure is incompatible with standard micro-photolithography, since it is hard to obtain an uniform distribution of photoresist and - depending on the technique adopted – it is difficult to correctly expose it. We therefore deposit the contacts using a shadow evaporation, i.e. a metal evaporation trough a free-standing perforated mask.

Pyramid shaped sensors

The square-based truncated pyramid shape has several advantages over a parallelepipidal or cubic one. Maintaining the same contact area to the absorber, it has a reduced volume, that translates in less heat capacity and better sensitivity. If two opposite faces of a truncated pyramid are metalized, it is possible to obtain a uniform current density across the sensor since, due to the square section, the resistance is the same for any horizontal slice of the pyramid. The electric field across the metalized faces of the pyramid changes by only a factor 3 going from the large base to the small base. We expect that this moderate change in electric field should not significantly affect the overall sensitivity of the sensor; however, this issue will be the subject of further investigation on complete devices.

The obtained 45° contacts are suitable for the chip-flip bonding. Using a cubic sensor shape instead of the proposed pyramidal one, the contacts could easily be deposited on the bottom face; that would however make the current distribution across the sensor strongly uneven. Contacts on the lateral faces of a cube can be produced by a shadowed tilted evaporation, but the process is less immediate and the flip-chip bonding is not feasible. Another advantage of the pyramid shape is that it can be easily obtained by chemical wet etch instead of requiring expensive deep ion etching equipment.

SHADOW-MASK FABRICATION

The free-standing copper shadow-mask is fabricated coupling microphotolithography and electroplating techniques. The process is composed by the following steps (Fig.1):

- deposition of a photoresist sacrificial release-layer on a substrate;

- deposition of seed layer;
- thick photoresist deposition and lithography;
- Cu electroplating;
- sacrificial release-layer removal, separation from the substrate;
- electroless Sn plating.

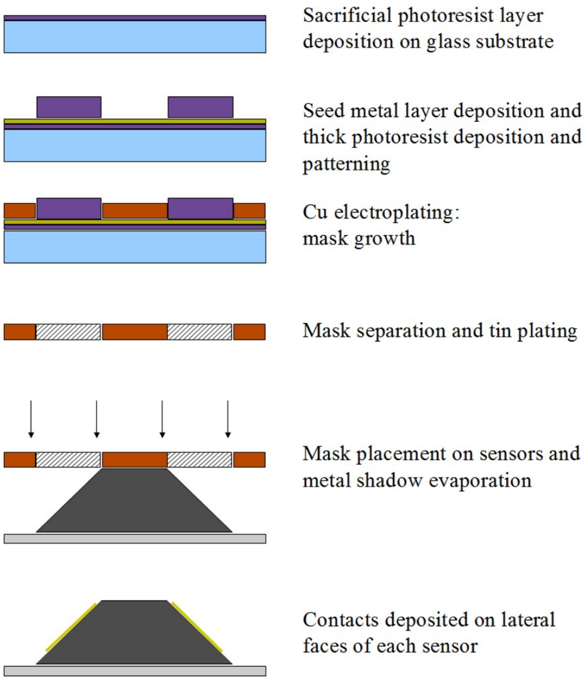

FIGURE 1. Schematic view of the main steps of the adopted process.

The first step is a deposition of a 2 µm thick photoresist layer on a planar glass substrate. The substrate acts as mechanical holder and temporary support for the following steps. The release-layer allow the subsequent removal of the formed mask from the substrate. It is a conformal coating, so it guarantees the same high planarity degree of the glass substrate.

As a second step, 5 nm of chromium and 10 nm of copper are deposited by thermal evaporation on the release-layer. The chromium is used for adherence improvement, since its adhesion to the photoresist is good and stable during the electroplating. A following 4.5 min copper electroplating, with a current density of 1 mA/cm2, increases the thickness of the copper layer to 100 nm. Using electroplating instead of evaporation to increase the copper seed layer facilitates the closing of some pin-holes that can be present after the evaporation because of undesired particles deposited on the surface. The sample is washed before the electroplating and the plating bath prevents more particle to adhere on the surface. Lateral growth during electroplating closes the holes once the occluding particles have been removed.

A 8 µm thick photoresist layer is then deposited on the metallic seed, and it is patterned by laser micro-photolithography. The thickness of the patterned photoresist is enough to accommodate the copper mask while it is being formed, guiding and containing the electroplating process to avoid uncontrolled lateral growth.

The copper electroplating is done using a commercial acid bath, with a current density of 1 mA/cm2 at room temperature. After 4 h a 5 µm thick mask has been formed (Fig. 2 - 3). The 5 µm thickness represents a good compromise between the quality of the mask, that gets worse with the thickness, and its mechanical strength.

The mask is finally separated from the substrate removing the photoresist release-layer. A 4 min ultrasonic wash in acetone at 40 °C removes the sacrificial photoresist and breaks the thin seed layer according to the mask shape. The now released copper mask is then coated with a thin layer of tin by immersion in an electroless plating solution for 5 min to prevent copper oxidation.

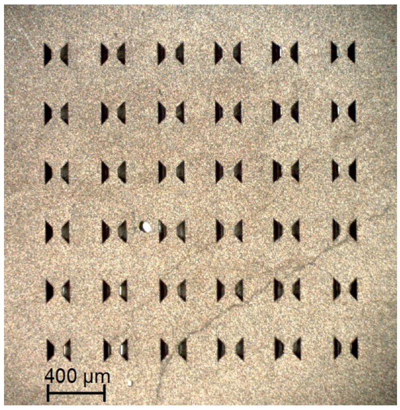

FIGURE 2. Free-standing 5 µm thick copper mask, placed on top of the sensor array

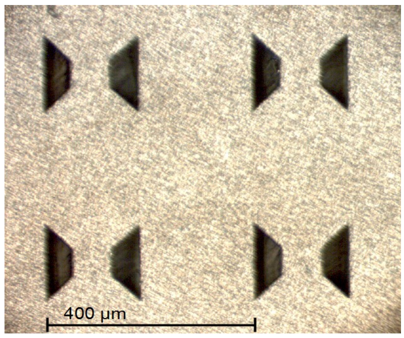

FIGURE 3. Detail of the copper mask, placed on top of the sensor array

Shadow evaporation

Once ready, the shadow-mask is aligned with the germanium pyramidal sensor array and it is temporary glued to its frame using bonding wax. Metal contacts are then deposited on the sensors by evaporation trough the openings in the mask. During evaporation it is necessary to maintain an adequate distance between the metal target and the sample to avoid an unwanted spreading of the evaporated metal under the shadow-mask. Our tests involved the deposition of titanium (25 nm) and gold (100 nm) to obtain electrical contacts on the sensors (Fig. 4 – 5).

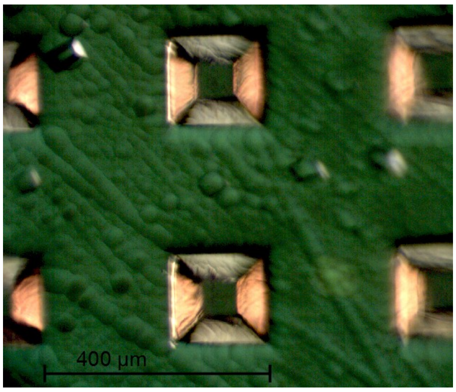

FIGURE 4. Germanium sensors with metalized lateral faces

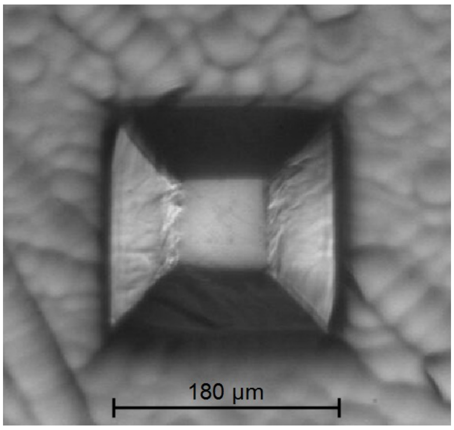

FIGURE 5. Detail of a germanium sensor with deposited contacts

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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