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2014 J. Phys.: Conf. Ser. 507 042004

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Large Area Superconducting TES Spiderweb Bolometer for Multi-mode Cavity Microwave Detect

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Abstract. For the cosmic microwave background, the increase of the sensitivity of present superconducting TES Spiderweb Bolometers can be done coupling them to a large set of modes of the EM radiation inside the cavity. This will require a proper shaping of the horn-cavity assembly for the focal plane of the microwave telescope and the use of large area bolometers. Large area spiderweb bolometers of 8 mm diameter and a mesh size of 250 μm are fabricated in order to couple with approximately the first 20 modes of the cavity at about 140 GHz. These bolometers are fabricated with micro machining techniques from silicon wafer covered with SiO_2 - Si_3N_4 CVD thick films, 0.3 μm and 1 μm respectively. The sensor is a Ti/Au/Ti 3 layer TES sensor with T_c tuned in the 330-380 mK and 2 mK transition width. The TES is electronically coupled to the EM gold absorber that is grown on to the spiderweb mesh in order to sense the temperature of the electron gas heated by the EM radiation. The gold absorber mesh has 5 μm beam size over a Si_3N_4 10 μm beam size supporting mesh. The Si_3N_4 mesh is then fully suspended by means of DRIE back etching of the Si substrate. Here we present the first results of these large area bolometers.

1. Introduction

Measuring the large scale polarization of the Cosmic Microwave Background (CMB) is one of the major challenges of modern observational cosmology. The inflationary scenario, proposed within the framework of the standard cosmological model, implies the existence of primordial gravitational waves which generate a tiny curl component ("B-mode") in the pattern of CMB polarization at large angular scales [1]. The amplitude of this signal, if any, is expected to be dependent on the energy scales of the inflationary phase transition, and on the nature of the small density perturbations in the primordial universe. Therefore, a direct measurement of large scale B-modes of the CMB would provide a strong confirmation of the inflationary theories [2]. This signal has been, so far, very elusive. Being at most 1% of the main CMB polarized component, its detection requires high sensitivity, state-of-the-art system stability, exquisite control and characterization of the instrumental systematics, and careful monitoring of polarized foregrounds through multifrequency observations across the mm-band. Modern bolometric balloon-borne polarimeters, like EBEX [3] and SPIDER [4], are designed to operate thousands of independent single-mode detectors to beat the single-detector photon noise limit and achieve sub- μK effective sensitivity. An alternative approach is to meet the sensitivity requirements by designing a multi-mode system. In principle, when the detectors efficiently coupled to



a number N_{eff} of EM modes at a given frequency, the photon noise limit scales down as $1/\sqrt{N_{eff}}$. Such a detector suffers, of course, of degradation in angular resolution respect to a single-mode bolometer operating at the same wavelength from the same telescope. Anyway, this is an acceptable tradeoff for B-mode searches, since most of the signal is distributed at large angular scales (~ 10 deg) across the sky. Such a solution is adopted in the PIXIE spectro-polarimeter [5] and is currently planned as baseline field optics design for the SWIPE polarimeter [6], the high frequency (95-145-245 GHz) instrument aboard of the Large Scale Polarization Explorer balloon-borne experiment. The use of multi-mode field optics is not a novelty in mm astronomy; anyway, the planned implementation into a system with strict requirements on calibration accuracy and subsystem characterization has motivated the development of a modeling-prototyping-validation pipeline which complies with the standards of a CMB polarization experiment for precision cosmology.

In this work we present the early results on the development of a large area superconducting spiderweb bolometer. Spiderweb superconductive bolometer has been already presented in the past [8-9]. Anyway one of largest micromesh absorber was presented by Mauskopf et al. who shows an absorber with 5.6 mm in diameter, and use a neutron transmuted doped germanium thermistor [10]. Our device achieves 8 mm of diameter for a better multi-mode coupling in the cavity, and uses a Ti/Au TES.

In section 2 we describe the detector design and the fabrication process, in section 3 the preliminary low temperature measurements.

2. Detector design and fabrication process

The detector is designed to work at about 350 mK, with a thermal conductance of about 10^{-10} W/K that should give a NEP of 10^{-17} W/Hz $^{1/2}$, and couples with the first 20 modes at 140 GHz. The spiderweb design is required for minimizing the cross section to the cosmic rays and the heat capacity of the absorber. For these reasons we have chosen to produce a freestanding $1 \mu\text{m}$ thick silicon nitride spiderweb membrane with a mesh size of $250 \mu\text{m}$ onto which the gold absorber and the titanium/gold TES are grown. The silicon nitride spider-web with the gold circular absorber (8 mm in diameter) has been modeled together with the cylindrical resonant cavity where it is suspended. The cavity and detector are assembled within the feed-horn antenna and the EM coupling was studied using High Frequency Structure Simulator (HFSS). The simulation study was presented by Lamagna et al. to the International Conference on electromagnetics in advanced application [11]. This is a typical assembly for single-pixel microwave bolometers, and its single-mode performance has been already extensively modeled and optimized with respect to different technical needs [12].

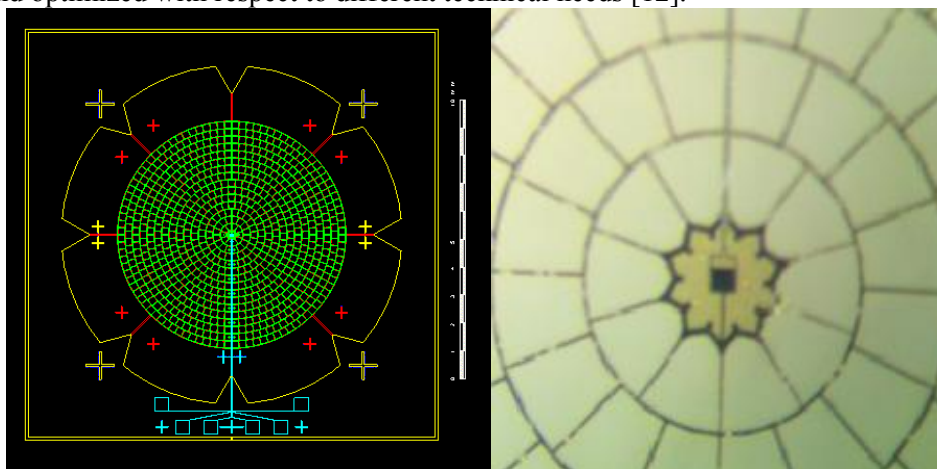


Figure 1. The full set of drawings of all photolithographic masks shown with different colours and a centre of a finished device.

In figure 1 the full set of drawings of all photolithographic masks are reported to give the overall view of the detector. The absorber has a diameter of 8 mm and 8 legs, 1 mm long, that connect the spiderweb absorber to the substrate frame.

The fabrication process make use of a commercially available silicon wafer 380 μm thick, with both sides covered by two layers of thermal silicon oxide, 300 nm thick, and CVD silicon nitride, 1 μm thick. The wafer is diced to square 15x15 mm chips and then rinsed in soap solution, deionized water and acetone.

The fabrication process is shown in figure 2: the first step is the TES film growth and patterning. This is obtained by lift-off using negative photolithography. The three-layer Ti/Au/Ti TES deposition is obtained by e-beam evaporation without breaking the vacuum. The base pressure is typically less than 10^{-6} Pa and the thickness are: 5 nm of Ti as sticking layer, 4 nm of Au and 38 nm of Ti (fig. 2a). The second step is the TES wires fabrication (fig. 2b) with e-beam evaporation of Ti/Al/Ti three-layers and lift-off lithography. Before the wire film deposition, the TES is sputtered with Ar ion beam to remove titanium oxide from its surface. The spiderweb gold absorber made by 65 nm thick Au patterned film, is grown on top of 5 nm of Ti sticking layer (fig. 2c).

A positive photolithography is then used to cut the silicon nitride and silicon oxide supporting layers. The parts uncovered by the photoresist are etched by Reactive Ion Etching (RIE) with a $\text{CF}_4 + \text{O}_2$ mixture for silicon nitride and CF_4 for silicon oxide (fig. 2d). The final step in which the spiderweb structure is suspended with deep RIE of Si chip from the back side. In this case an aluminum hard mask is deposited on the chip back side (fig. 2e). The deep RIE process is done with an $\text{SF}_6 + \text{O}_2$ mixture. The endpoint detection is performed with plasma light spectroscopy (fig. 2f). The final result is shown in figure 3 and in figure 1.

In addition to low temperature detector, a room temperature bolometer was produced in order to perform fast EM tests into the cavity. In this test version the Ti/Au multilayer of TES and the aluminum films of the wiring were substituted with platinum ones. The early results showing that we have successfully coupled the bolometer to several modes of the EM field in the cavity was reported by Lamagna together with the calculation [11].

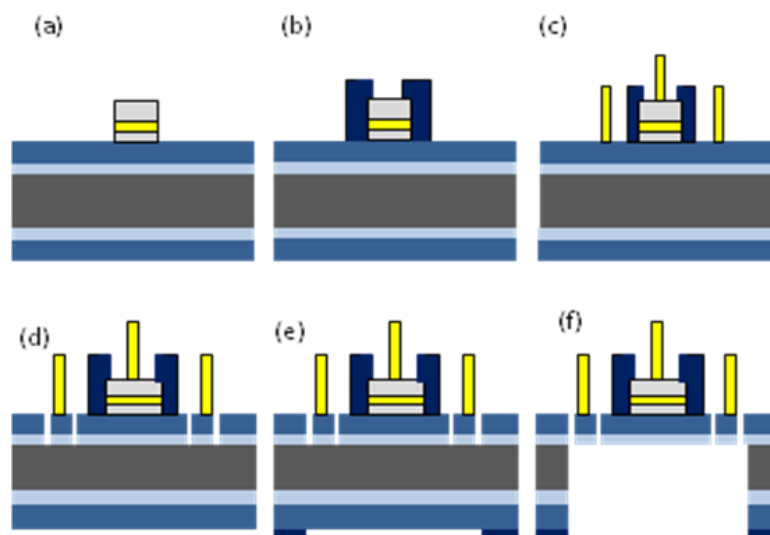


Figure 2. Scheme of spiderweb detector fabrication process. (a) TES growth; (b) wiring growth; (c) absorber growth; (d) spiderweb etch; (e) hard mask growth; (e) deep back etching.



Figure 3. Final spider web bolometer compared with a 1 Euro coin.

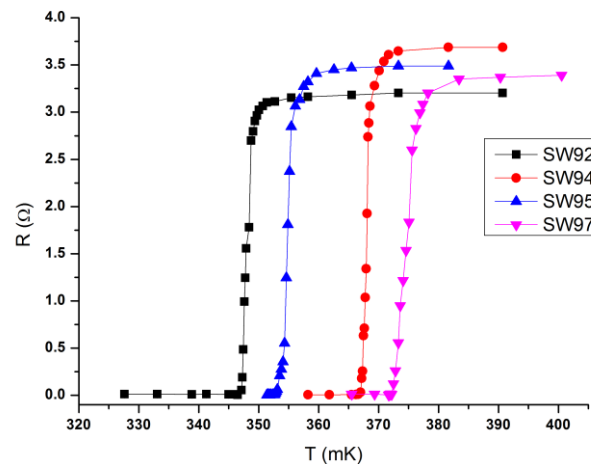


Figure 4. Superconducting to normal transitions of 4 devices reported as example.

3. Critical temperature measurements

The critical temperature of several devices were measured using a $^3\text{He}/^4\text{He}$ dilution cryostat. In figure 4 are reported the transition of few samples. All critical temperatures are grouped between 345 and 375 mK. All transitions are very narrow with a width of 2 mK or less. In tab.1 are reported the effective thicknesses of the TES layers. The correlation among thickness and critical temperature, due to the proximity effect, seems to be driven mainly by the topmost and thicker titanium layer and weakly by the gold thickness. Further measurements of TES parameters are on the way.

Table 1 Effective TES layers thickness of the devices considered in fig 4, the layers are reported as the deposition order: the last row is related to the topmost layer.

| | SW92 | SW94 | SW95 | SW97 |
|-----------|------|------|------|------|
| Ti | 5.0 | 5.0 | 5.0 | 5.0 |
| Au | 4.4 | 4.4 | 3.8 | 3.8 |
| Ti | 37.2 | 38.0 | 37.2 | 38.0 |

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