Large bolometer arrays with superconducting NbSi sensors for future space experiments

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New techniques in microelectronics allow to build large arrays of bolometers filling the focal plane of submillimeter and millimeter telescopes. The expected sensitivity increase is the key for the next generation of space experiments in this wavelength range. Superconducting bolometers offer currently the best prospects in terms of sensitivity and multiplexed readout. We present here the developments led in France based on NbSi alloy thermometers. The manufacturing process of a 23 pixel array and the test setup are described.

1. INTRODUCTION

The design of current space missions dedicated to submillimeter and millimeter broadband or low spectral resolution observations is based on direct detectors limited by the photon noise of the incoming radiation in a diffraction limited beam. Bolometers are the most sensitive detectors for this purpose. They are associated to feedhorns and arranged in groups covering a fraction only of the focal plane area. It is the case in the HFI/Planck and SPIRE/Herschel instruments.

The study of the inflation phase of the universe requires large improvements of sensitivity in the measurement of the Cosmic Microwave Background polarized emission. The ESA Cosmic Vision and NASA Beyond Einstein programs includes such missions.

An increase factor of 10 to 100 is required in sensitivity with respect to current missions. This cannot be obtained by increasing the integration time, already counted in years for a whole sky survey. The only solution is a full coverage of the focal plane by large contiguous detector arrays of 10 000 pixels or more.

We present here a french collaborative effort in the development of such arrays. The DCMB (Développement Concerté de Matrices de Bolomètres) R&D program is supported by CNES (Centre National d'Etudes Spatiales), the CNRS (Centre National de la Recherche Scientifique) and the participating Universities. The subsystems concerned by the R&D program are: the thermal architectures of the bolometers arrays, the thermometers, the coupling with the optical radiation and the readout electronics (1). Two types of thermometers are being studied, based on Niobium Silicon alloys: high impedance (Anderson isolator) or superconducting alloys. We will develop here the superconducting case (Nb fraction larger than 0.13). Superconducting bolometers technology provides sensitive detectors (below 10^{-17} $WHz^{-1/2}$) and allows the use of a convenient multiplexed readout based on SQUIDs (2).

2. ARRAYS MANUFACTURING

The thermal architecture (figure 1) and thermometers are developped in common for both types of thermometers in the microelectronics facility IEF/MINERVE of Paris Sud-11 University at Orsay. Nb and NbSi are deposited in dedicated evaporators and co-evaporators of CSNSM/Orsay.

1.1 Thermometers

The thermometric sensor (figure 2) is composed of a film of NbSi (Niobium Silicon) 100 nm thick. It is co-evaporated by irradiating two targets of Nb and Si simultaneously. The mixing ratio *x* of the Nb_xSi_{x-1} thermometer is adjusted in order to obtain the goal transition temperature (3). In order to lower (below 1 Ω) the average resistance at the superconducting transition, an interleaved comb geometry is used.

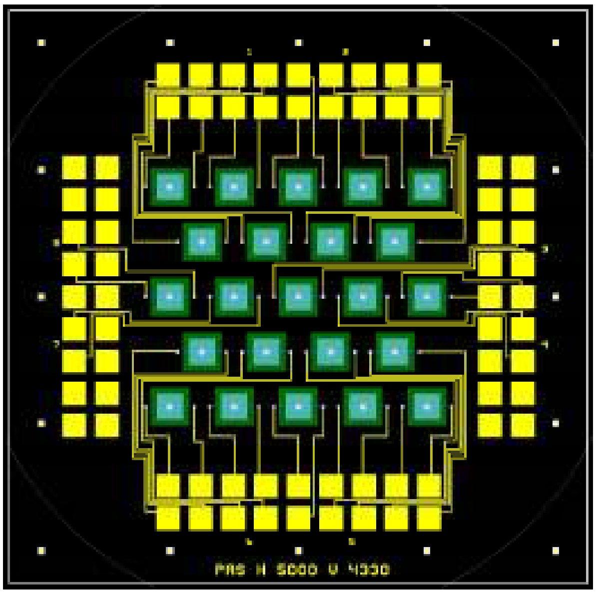

Fig. 1(color online) 23 pixels array architecture

The superconducting thermometer is voltage biased at the normal-superconducting transition. This transition is very steep, so the total power and consequently the temperature remains quasi-constant when the input radiation varies. This effect is the well know "strong negative electro-thermal feedback" (4) (5). This negative feedback also strongly decreases the time constant of the system. A typical NbSi thermometer (10 mm x 10 mm) transition curve was previously measured (6). The design is scaled down to 0.8 mm x 0.8 mm for the 23 pixels array.

1.2 Contact pads

A metal layer is deposited to make the electric interface between the tracks and the contacts. Gold offers the advantage of a compatibility with niobium connections and also a good aptitude for connections with the external readout system. A layer of gold (1000Å-1500Å) is thus deposited on the ends of the Nb tracks.

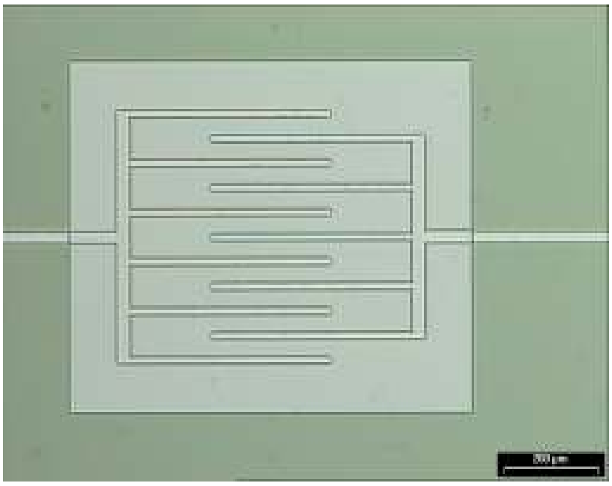

Fig. 2: (color online)NbSi superconducting thermometer. The leads comb structure is Nb, and the square NbSi.

1.3 Microfabrication process

The steps of microfabrication of the superconducting bolometers are as follows:

1. Deposition of membranes material by PECVD (SiO_2 + Si_3N_4: SiO2/SiN/SiO2 = 290/230/100 nm)
2. Nb_xSi_{1-x} co-evaporation (x=15.55%, 1000 Å)
3. Nb evaporation (500 Å)
4. Au evaporation
5. Silicon deep etching

1.4 Readout

Multiplexed readout will be performed using a 4K SiGe ASIC associated with SQUIDs. Development of the ASIC is described by D. Prele et al. (this conférence). SQUIDs mux and amplifiers procurement is currently in discussion with Supracon (Jena).

1.5 Coupling with radiation

For the first realisation, the radiation will be absorbed by a standard resistive layer or a grid adapted to the vacuum impedance. The long term goal is to couple to the incoming radiation by means of antenna (7).

3. ARRAYS TEST AND CHARACTERISATION

NbSi alloy is a new material for TES design. It requires a full characterisation and validation before using it to produce large arrays. The uniformity of the superconducting transition temperature and slope is being checked on a 23 pixels array for which only the thermometers are built (figure 3). The test bench, based on a 300 mK mini-fridge system, is being developped at IAS. In parallel, a second bench is being set up to characterize the noise properties of a single NbSi superconducting thermometer. It is based on a commercial SQUID system from Star Cryoelectronics, and a 300 mK mini-fridge and a thermal stage regulated between 300 and 500 mK. Measurements are under way.

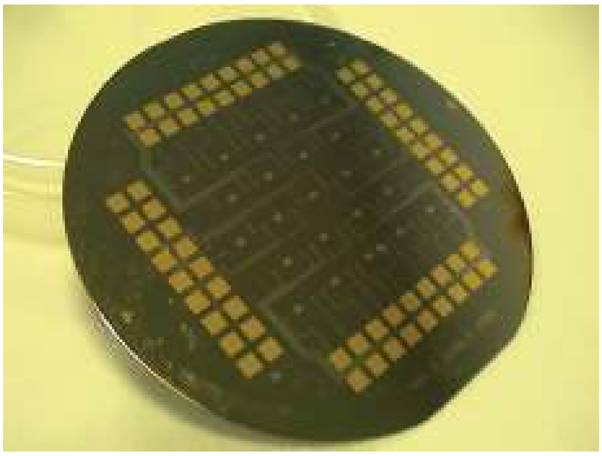

Fig. 3: (color online)23 pixels thermometers only array

4. CONCLUSION

The process required to build the thermometer array have been set up. The testing phase can now begin, for a single pixel for noise measurement on one side, and for a 23-pixels array for thermometer homogeneity measurement on the other side. Once this phase is passed, we will be able to continue the integration of a complete array with optical coupling.

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