Large bolometers arrays with NbSi sensors for future space experiments

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The submillimeter and millimeter space astronomy will require higher sensitivity instrument for the future missions. Large bolometer arrays filling the telescopes focal planes are a promising solution to this sensitivity increase.

New techniques in microelectronics allow to build such arrays of detectors using collective processes. We present here the developments led in France of bolometers arrays using NbSi alloy thermometers. NbSi films can be made either high impedance or superconducting. We describe the manufacturing process of the array and the tests perspectives.

1. Introduction

The submillimeter and millimeter wavelength range is entering a new era with the launch to come of the Planck and Hershel space missions. The observations from above the atmosphere, opaque excepted for a few windows of the spectrum, will give unprecedented access to the studies of the interstellar medium, the galaxies, the large structures of the universe and the cosmic microwave background (CMB).

The design of present 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. The advantage of well defined beams is therefore counter-balanced by the loss of a large fraction of the collected photons. This is the case in the HFI/Planck and SPIRE/Herschel instruments.

Among the topics that will need further observations following these two missions, the study of the inflation phase of the universe will require large improvements of sensitivity in the measurement of the CMB polarized emission. The ESA Cosmic Vision and NASA Beyond Einstein programs includes missions dedicated to these measurements.

An increase factor of 10 to 100 is required in sensitivity with respect to current instruments. It 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, with individual pixel NEPs below 10^{-17} $WHz^{-1/2}$.

We present here a french collaborative effort in the developpement 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. Two types of thermometers are beeing studied, based on Niobium Silicon alloys: high impedance (Anderson isolator) or superconducting [1].

2. Arrays manufacturing

2.1 Thermal architecture

The thermal architectures is developped in common for both types of thermometers in the microelectronics facility IEF/MINERVE of Paris Sud-11 University at Orsay. Two architectures have been designed, a 204 pixels array and an 23 pixels array. The former (fig. 1) will be used in a millimeter camera for the 30m IRAM telescope on Pico Veleta (Spain).

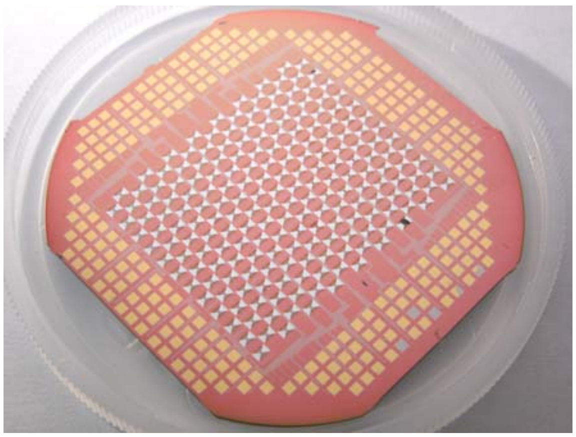

Figure 1: 204 pixels array architecture

The later (fig. 2) is designed to be used in the Olimpo balloon program with a feedhorn array in front of the detctors.

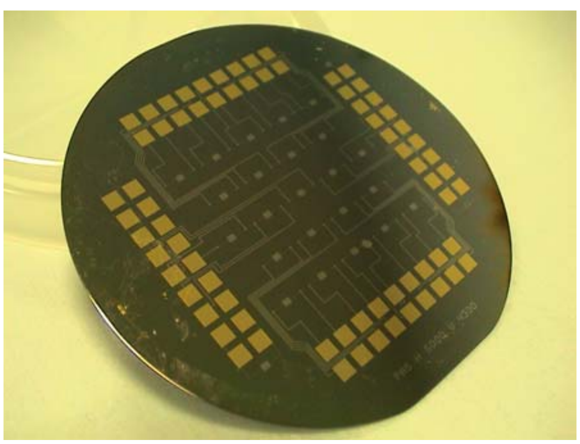

Figure 2: 23 pixels array architecture (thermometers only)

2.2 Thermometers

The two types of thermometers studied are based on Niobium Silicon alloys. These are high impedance (Anderson isolator) [2] or superconducting (Nb fraction larger than 0.13). The thermometric sensor is composed of a film of NbSi co-evaporated by irradiating two targets of Nb and Si simultaneously.

In the case of the superconducting sensor, the mixing ratio *x* of the 100 nm thick Nb_xSi_{x-1} thermometer is adjusted in order to obtain the goal transition temperature. In order to lower (below 1 Ω) the average resistance of the film at the middle of the superconducting transition, an interleaved comb geometry is used for the Nb electrodes (fig. 3). A typical NbSi thermometer (10 mm x 10 mm) transition curve was previously measured [3]. The design is scaled down to 0.8 mm x 0.8 mm for the 23 pixels array (fig. 2).

Nb and NbSi are deposited in dedicated evaporators and co-evaporators of CSNSM/Orsay.

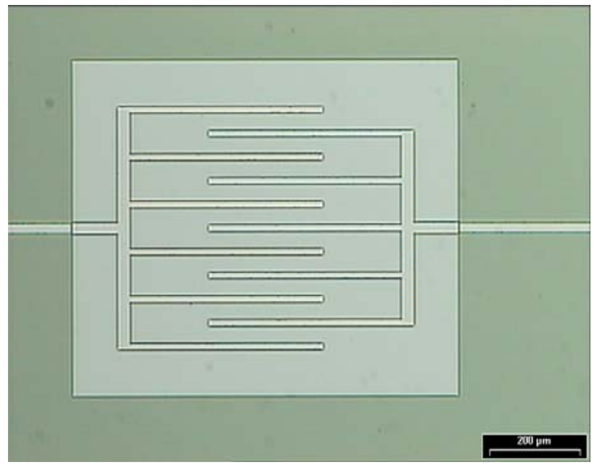

Figure 3: NbSi superconducting thermometer. The leads comb structure is Nb, and the square NbSi.

2.3 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

2.4 Readout

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

2.5 Coupling with radiation

The 204 pixels array includes an antenna pattern associated to a dissipator for the coupling with the incoming radiation [4]. For the first realisation of the superconducting array, 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 [5].

3. Test perspectives

Tests and characterisation of the high impedance arrays are described in [1]. The test setup for the superconducting array is under development. 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 will be measured on a 23 pixels array for which only the thermometers are built (fig. 3). In parallel, we will characterize the noise properties of a single NbSi superconducting thermometer. The test setup 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.

4. Conclusion

While the high impedance arrays are mostly validated and characterized, the development of superconducting arrays is starting and its testing phase is only beginning Once this phase is passed, we will be able to continue the integration of a complete array of superconducting bolometers with optical coupling.

References

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