Thermal characterization and noise measurement of NbSi TES for future space experiments

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Abstract— **The principal observational demonstration of the theory of the Big Bang, the cosmic microwave background (CMB), has its maximum of intensity to the millimeter-length wavelengths. Instrumental progress allowed the development of bolometric detectors adapted to these wavelengths. Superconducting transition-edge sensors (TESs) are currentlyunder heavy development to be used as ultra sensitive bolometers. In addition to good performance, the choice of material depends on long term stability (both physical and chemical) along with a good reproducibility and uniformity in fabrication. For this purpose we are investigating the properties of NbSi thin films. NbSi is a well-known alloy for use in resistive thermometers. We are co-evaporating Nb and Si simultaneously. We present a full low temperature characterization of the NbSi films. In order to tune the critical temperature of the NbSi thermometers down to the desired range, we have to adjust the concentration of niobium in the NbSi alloy. In this experiment, we set for a Niobium concentration of 15%, to be able to run tested at a convenient temperature of 300mK. Tests are made using 4He-cooled cryostats, 300mK 3He mini-fridges, resistance bridge and a commercial SQUID. Parameters being measured are: critical temperature, resistance, sharpness of the transition and noise measurements.**

I. INTRODUCTION

Future generations of space experiments will require sensitivities better by a factor of 10 to 100. The only solution is an extensive coverage of the focal plane by large contiguous detector arrays of 10 000 pixels or more, with NEPs ranging from 1.10-17 W/Hz^1/2 for mapping instruments to 1.10-19 W/Hz^1/2 and better for spectrometers at the focus of cooled telescopes [1]. These improvements of sensibility are required for the mapping of the Cosmic Microwave Background polarized emission with high signal to noise ratio, as well as for spectroscopic observations of galaxies during their formation at high red shift. We present here the development and test of TES bolometers arrays and readout for this purpose. These detectors are included in the design of coming ground based instrument such as BRAIN (Dome C). The BRAIN experiment is a bolometric interferometer for B-modes of the Comic Microwave Background [2].

Besides, they may be candidate for future ESA missions: a cosmological mission like Bpol or a spectrometer such as in SPICA [3].

II. ARRAYS FABRICATION

The fabrication of arrays is developed in the microelectronics facility IEF/MINERVE of Paris Sud-11 University at Orsay. NbSi are in co-evaporators of CSNSM. Characterization and tests were conducted at IAS.

NbSi thin films are currently used as thermometers for different devices related to detection in astrophysics, be it for bolometer arrays for submillimetric or X-ray detection. They can act as high impedance or as TES thermometers. The material is in this form Nb_xSi_{1-x} : x higher than 12 % for superconductive detectors, or lower for high impedance detectors. The critical temperature Tc can be adjusted between approximately 50 mK and 1 K [4].

Our NbSi TES have been made with 15,55 % and 15,18 % of Nb. The fabrication process is composed of four steps with three lithography.

1. Deposit of membranes material by PECVD (SiO_2+Si_3N_4 SiO2/SiN/SiO2 = 290/230/100 nm thick)
2. Level 1 – lithography of the thermometers NbSi (100 nm)
3. Level 2 - lithography of the connection circuits (Nb, 50 nm)
4. Level 3 - lithography of the contact pads (Au, 150 nm)

In this study we have worked only on the NbSi TES, without opening the membranes. The optical lithography is a process used in microfabrication to selectively remove parts of a thin film (or the bulk of a substrate). It uses light to transfer a geometric pattern from a photomask to a light-sensitive chemical (photoresist or simply "resist") on the substrate.

The NbSi is co-evaporated by irradiating two targets of Nb and Si simultaneously. In order to lower the average resistance at the superconducting transition below 1 Ω, interleaved comb geometry is used. The contact pads make the electric interface between the Nb leads and the external system. Gold is used for the contacts because it offers the advantage of a compatibility with Nb connections. The layer of gold (100-150 nm) is deposited on the ends of the Nb tracks. We can see the metal layers on the periphery of the array (Fig. 1). After the process, we have obtained an array of 23 pixels.

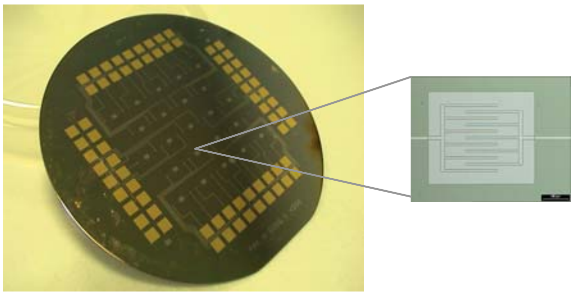

Fig. 1 23 Pixels TES array with the Nb lead comb structure

This 23 pixels array have 500 * 500 µm TES thermometers. Pixels center-to-center distance is 5.0 mm. The design of the TES is scaled down to 0.8*0.8 mm for this array. On the other hand, we also developed the complete process for the manufacture of superconductive bolometers arrays supported by membranes opened with XeF2. Tests will be made after the validation of NbSi as optimal material for bolometers

III. Thermal Characterizations

A. Test setup

Critical aspects in the fabrication of microcalorimeters are the reproducibility of the film characteristics, in particular transition temperature and their uniformity over sufficiently large areas. For that, we have fabricated two arrays with different Nb proportions for the NbSi TES. Two test benches are used in the collaboration for the measurement of the critical temperature Tc of the TES arrays (Fig. 2).

(a) (b)

Fig. 2 Test benches at APC (a) and at IAS (b)

The 3He fridge allows us to reach 300 mK. This system is integrated in a 4He cryostat. Resistance versus temperature curves were measured using this fridge, with an Air Liquide-ORPX and a Picowatt-AVS 47 resistance bridges. The array used has 23 NbSi TES. The thermometers arrays are thermally connected to the 300mK cold tip of He3 fridge.

B. First Results

Measurements are obtained during the cool down of the array down to 350 mK and then by heating the device up to 650 mK. Fig. 3 shows similar TES resistance curves during cool down and warm up on a given pixel. The thermometer is used at the transition between normal and superconducting state where sensitivity is maximum. Within the precision of the measurements, we see little hysteresis effect. Homogeneity of transitions of a set of pixels over the array is shown on Fig. 5 and Fig. 6. The pixels locations on the array are shown with the Fig. 4.

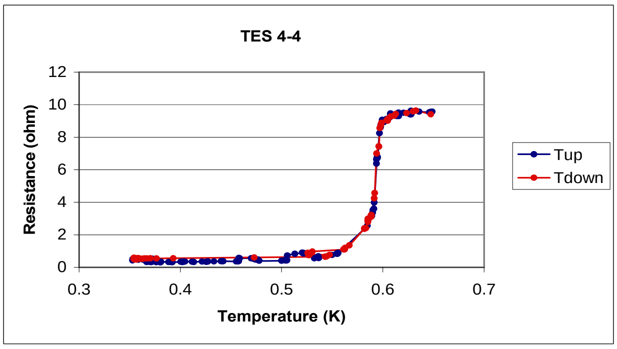

Fig. 3 Superconducting transition at the cooling (Tdown) and at the heating (Tup)

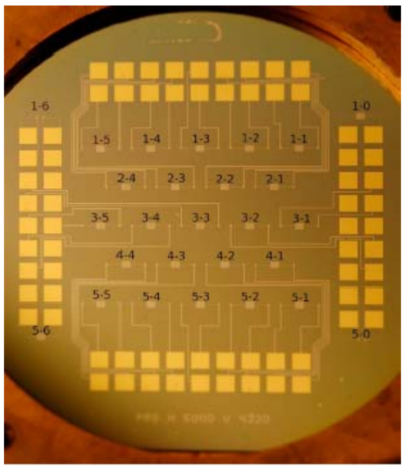

Fig. 4 Pixel numbering over the array

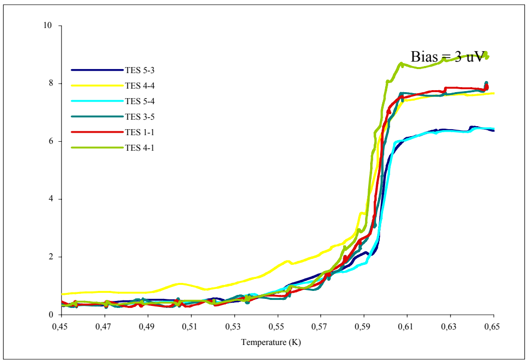

Fig. 5 Superconducting transition for different NbSi TES on 23 pixel array with 15,55% of Niobium

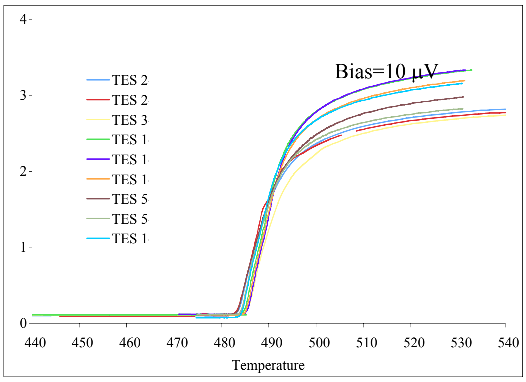

Fig. 6 Superconducting transition for different NbSi TES on 23 pixel array with 15,18% of Niobium

Results show a good homogeneity of the critical temperatures Tc accross the array. The average Tc obtained is about 595 +/- 3 mK (Fig. 5) and 486 +/- 1mK (Fig. 6). This difference in Tc dispersion can be explained by the noise of the measurements, larger for the test bench used for array showed in Fig. 6. We can notice that the normal state resistance is too high. This effect can be explained by the presence of a parasitic resistance in the setup.

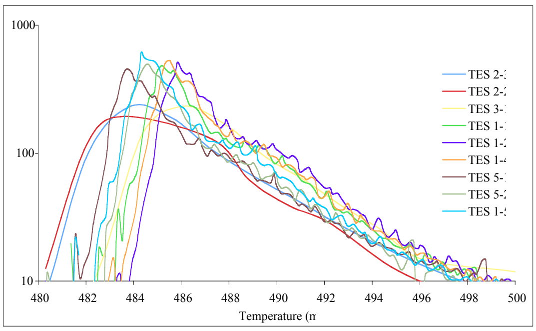

Fig. 7 Alpha parameter versus temperature with bias of 10 µV

The value of the transition remains the same for various biases applied to the resistance bridge (within +/- 2.5 mK). For all the characterized samples, the alpha parameter is larger than 100 within a 5 mK temperature interval starting from the foot of the transition (Fig. 7).

IV. NOISE MEASUREMENTS

Noise of the thermometric sensor is a key parameter in the performance of TES bolometers. For this measurement, we have developed a test bench with a commercial SQUID from Star Cryoelectronics. This test bench can characterize one pixel at a time. Fig. 8 shows a typical readout of the spectral density of the noise amplitude.

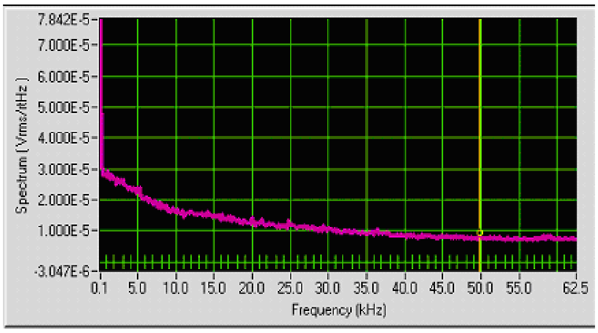

Fig. 8 Spectral density of the noise amplitude at 2 K

The noise measured at the output of the SQUID amplifier is 7.2 µV/√Hz at 50 kHz, corresponding to the specification of 3 pA/√Hz at the input. Characterisation of noise properties of a single NbSi superconducting thermometer is under progress.

V. ULTRA LOW NOISE READOUT DEVELOPED AT APC

The future use of large number of very low Tc superconducting bolometers requires the development of ultra low noise amplification and multiplexing electronics operating close to the sensors, at cryogenic temperature. The ultra low noise performances required for the TES readout are obtained by SQUIDs driven by a SiGe Integrated Circuit (ASIC) operating at 4 K. Time domain SQUID multiplexing with SiGe ASIC allows to reduce drastically the number of wires between cryogenic and room temperature. A first cryogenic ASIC was developed to read out a 2*4 SQUID array demonstrator for 8 TES This ASIC combines switching biasing for time domain SQUID multiplexing and multiplexed input SiGe amplifier. An original topology avoiding the use of two switches along the signal path allowed a voltage white noise level of 0.2 nV/√Hz at 4 K at the input of this multiplexed amplifier [5].

A second version of the ASIC allows the readout of 3 columns of 8 SQUIDs (24 pixels). It is fully differential for better noise performances [6]. Thus, it is possible to use a standard integrated technology like BiCMOS SiGe with very interesting performances at 4 K.

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