Large Area ?-thermal Phonon TES Detector Mediated by the quasi-particle Diffusion Signal for Space Application

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Large Area A-thermal Phonon TES Detector Mediated by the quasi-particle Diffusion Signal for Space Application

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Abstract. Low temperature detectors operated at about 0.1K have achieved excellent spectral performances in the soft X-rays, becoming appealing for new challenging measurements with space missions in Astrophysics. In order to exploit their full sensitivity, it is necessary to minimize the background signals generated by the cosmic rays, i.e., high energy protons and light nuclei, that leave sizable amounts of energy in the same spectral window of the astrophysics signals. Detectors for GeV protons and nuclei operating few millimeters from the X-ray detector at 0.1K can act as anti-coincidence to disentangle the fake signal of cosmics. Fast and large detectors are designed and fabricated. These operate by mixing the fast a-thermal phonon signal with the slow diffusive thermal ones. A greater uniformity in the response should be obtained using large shaped superconducting aluminium films that acts as phonon collectors: the quasi-particles created by high energy phonons diffuse along the film toward a small Ir TES sensor giving out to a fast rise time. Here we present the measurement of an operating prototype of a superconducting anticoincidence detector for the proposed space mission ATHENA+.

1. Introduction

To the present state-of-the-art, superconducting Transition Edge Sensors (TES) allow very accurate measurements of X-rays from several kind of sources. The proposed next x-ray observatory, ATHENA+, includes a high resolution X-ray micro-calorimeter spectrometer, based on the TES-technology [1], with a working temperature around 50mK. In order to achieve the science requirements it is necessary to reduce the cosmic background. High energy protons passing through the microcalorimeters release an energy comparable to the one of an X-ray. The rejection of these fake events is possible with a second detector, the so-called Cryogenic Anti-Coincidence (Cryo-AC), just few millimeters beneath the former; in this way the cosmic ray hits both detectors and a signature to reject this event is produced. It has been demonstrated that the Cryo-AC can reduce the background up to a factor of 20 [2]. M. Loidl et al investigated the properties of quasi-particles diffusion over several mm in cryogenic detectors finding good performances using Ir [3], we therefore decided to use this element, as its critical temperature is near that of the main micro-calorimeter.

2. A-thermal phonon physics

The Cryo-AC must fulfil two main requirements: fast response, for the prompt time coincidence of false events, and energy linearity to fix the threshold and optimize the efficiency. In order to get fast signals with the Cryo-AC we need to operate out of the equilibrium, then it is necessary to absorb the high energy phonons before they thermalize. In the most general case, the primary radiation will produce a highly ionized track in the detector, actually a silicon chip. The process of the primary energy thermalization goes as described in the following [4]. In silicon the primary energy produces energetic electron-hole pairs and phonons. Phonons anharmonicaly decay in lower energy pairs of acoustic ones. These propagate balistically reaching the surface of the absorbing crystal being the life time of few microseconds [5]. If an event in the absorber occurs near a TES we have a fast rise time pulse due to the shorter travelling path of the phonons. The low energy diffusive phonon gives out to the slow thermal signal in the whole crystal. The Cryo-AC returns to the equilibrium temperature via the thermal link to the heat sink. Due to the radiative transport of the first burst of fast phonons it is necessary to increase the collecting area as much as possible, without increase of heat capacity. If we use a low specific heat superconducting film coupled with the TES, the phonons break the Cooper pairs into quasi-particles that diffuse toward the lower gap TES film. Thus the critical parameter is the whole collection efficiency which includes also the quasiparticle transport to the TES.

3. First detectors

Several samples of Cryo-AC have been produced and tested, which were based on Silicon absorbers and sensed by Ir TES [6][7] (Figure 1). Further, to enhance the a-thermal phonon collection, aluminium-pads were grown for increasing the detector efficiency. Roughly, the key element in the design and optimization of the Cryo-AC is the understanding of the physics processes underlying the quasi-particle and the a-thermal phonons phenomenology at short time. Figure 1 shows some preliminary results of the samples S1, S3 and S4. The so called Cryo-AC-S1 was built with a large Ir TES (with a surface of 16.5 mm^2) covering 22% of the silicon chip absorber. It showed a fast rise time of about 1 μs. The pulse shape is well fitted with a model that mix 10% of fast a-thermal response and 90% slow thermal pulse. The main disadvantage of this sample was the insufficient spectral linearity. The following others Cryo-AC-S3,S4 have similar full collecting area but made partially with 4 smaller Ir TESs (area 6 mm^2) and large Al films (area 20 mm^2). This design allows lower heat capacity from TES while keeping the same coverage. The aluminum fingers act as phonon collectors, giving rise to quasiparticles that diffuse to the TES, in order to recover additional energy. In Cryo-AC-S3 the pulse shapes split in two sets: fast energetic pulses and slower weak pulses. This behavior of the response is not well understood. Our hypothesis is that a considerable amount of quasiparticles was trapped and condensed to Cooper pairs before entering the TES. Thus fast pulses are associated to direct TES excitation, while slow pulses to indirect - via quasiparticle re-condensation [6][7]. In order to investigate this phenomena we decided to study a new geometry: 65 TES parallel connected with and without a tree shaped Al collectors; in the first configuration the total collecting area is 50%. In both chips we are interested in the global signal coming from all the sensors. In order to measure the quasi-particle diffusivity of the collectors we built, in the same fabrication process, a one millimeter long Al-strip readout by one TES at one side.

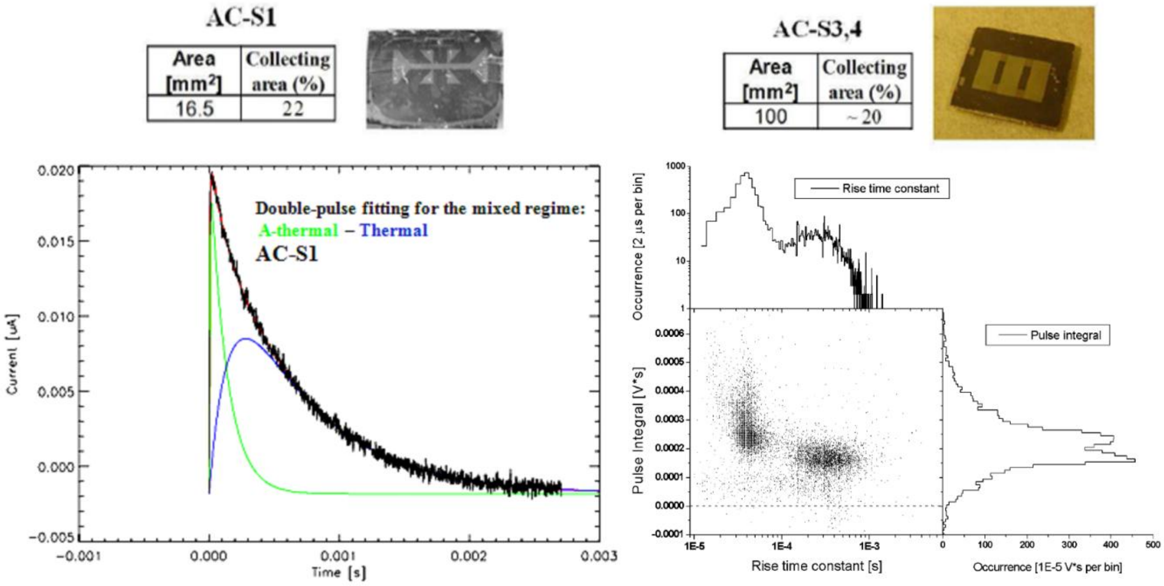

Figure 1. sketch of the preliminary results on AC-S1 and AC-S3,4 analysis; AC-S1 pulse shape with 1μs rise time constant (left) and pulse integral vs PH analysis for AC-S3 (right)

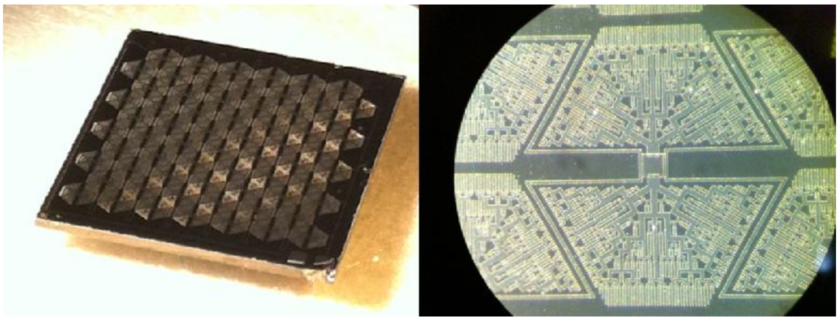

Figure 2. (left) AC-S6 detector and (right) a detail of one of the 65 Ir TES surrounded by his own Al collecting tree fins, up and down, and the wiring line.

4. Cryo-AC-S6, analysis and results

This device has the following features: on a silicon chip of 1 cm^2, 300 μm thick, we have grown 65 Ir TES (100x100 μm^2) and 2 tree-shaped Al phonon collectors for each TES. The TES area coverage was 0.65%, while the Al collector coverage was about 50%. The AC-S6 has been tested in a dilution fridge with 60 keV gamma ray from ^{241}Am. The RvsT plot shows a transition width 10%-90% of 5 mK at 114 mK. The working point was 18 mOhm with a bias voltage of 0.94 μV. The pulses corresponding to 60 keV absorption were digitized and analyzed off line. Rise times and integrals of pulses are shown in figure 3. The pulse integral histogram, which is proportional to the collected energy spectrum, shows a peak nearby zero, that is filled by very small pulses at the threshold. At higher energies there is a structure with two peaks with slight different rise times. The high energy peak can be assigned to 60 keV absorption in the whole volume, being the gamma ray attenuation length about 1.4 cm in silicon. The 10-20 keV lines of ^{237}Np should stay in the lowest peak if we assume linear the energy scale. The intermediate peak is due to events with shorter rise time that should be caused by hits in the TES neighboring volumes.

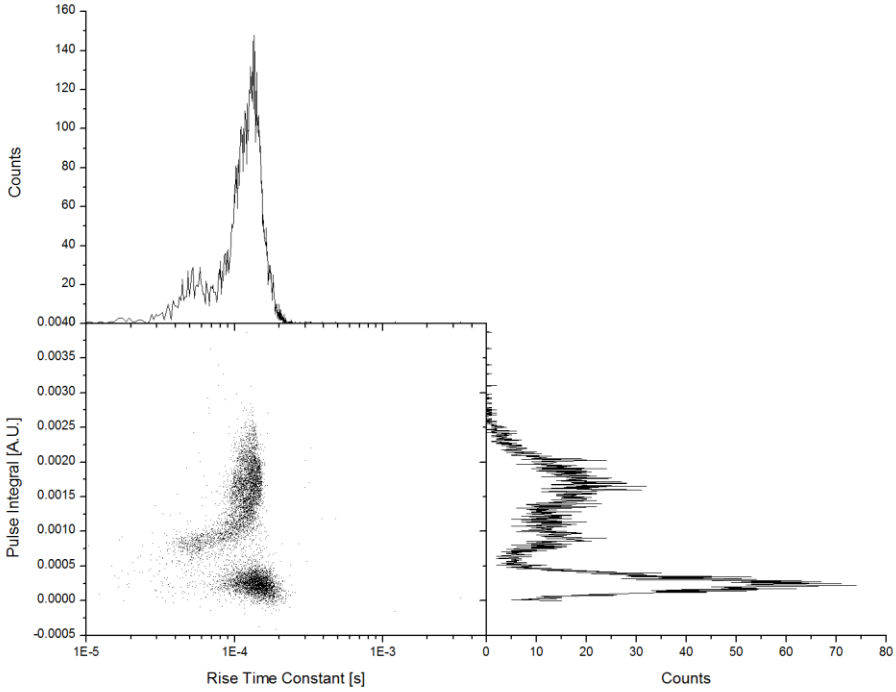

Figure 3. AC-S6 pulse integral vs pulse height analysis

5. Conclusions

With AC-S6 we fabricated a device with a larger collecting area then AC-S3, 50% in respect to the 20%. In this way we uniformed the rise time, around 100μs, obtaining only one family of pulses, unlike AC-S3. To better understand the behaviour of our new devices, in order to achieve the goal to lower the rise time down to 30μs, two other detectors have been fabricated: a version of AC-S6 without collector fins and a device to measure the quasiparticle diffusion in aluminium. These last two are currently under study.

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