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Sensitivity to Cosmic Rays of Cold Electron Bolometers for Space Applications

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Abstract An important phenomenon limiting the sensitivity of bolometric detectors for future space missions is the interaction with cosmic rays. We tested the sensitivity of Cold Electron Bolometers (CEBs) to ionizing radiation using gamma-rays from a radioactive source and X-rays from a X-ray tube. We describe the test setup and the results. As expected, due to the effective thermal insulation of the sensing element and its negligible volume, we find that CEBs are largely immune to this problem.

Keywords Bolometers, Cold Electrons, Cosmic Rays, Space Instrumentation

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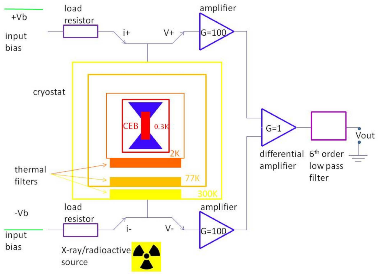

Fig. 1 (Color online) Block diagram of the experimental setup for irradiation of Cold Electron Bolometers with ionizing radiation.

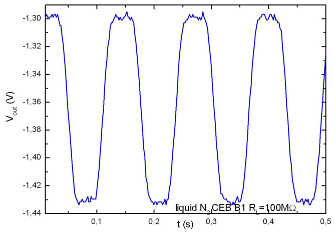

Fig. 2 (Color online) Output voltage obtained chopping black-body radiation (300K−77K) in the 350 GHz band of the detector.

1 Introduction

The sensitivity of bolometers to cosmic rays is well known (see e.g.[1]) and has been an important issue for several astronomy missions, including the recent Planck-HFI[2]. For future ultra-sensitive space-based surveys of the sky in the mm/sub-mm range, like the proposed missions COrE[3], Millimetron, PRISM[4], etc., which aim at noise performance limited by the low photon background achievable in space, this will be the main factor limiting their ultimate sensitivity (see e.g.[5]). Also in the case of missions requiring large throughput detectors, like the SWIPE instrument[6] on the LSPE balloon[7], the effect of cosmic rays on standard bolometers can be very significant, due to the large absorber area. Cold Electron Bolometers (CEBs) represent a promising mm/sub-mm detection technology, in alternative to the now common bolometers based on Transition Edge Sensors. In a CEB a nanoabsorber is coupled capacitively to the radiation collecting antenna by means of SIN tunnel junctions. The same SIN junctions provide cooling of the nanoabsorber removing hot electrons (see e.g.[8]). We have carried out a test campaign, irradiating CEBs built in Chalmers[9,10] using both radioactive sources and X-ray sources. Here we describe the experimental setup, the measurements and the results.

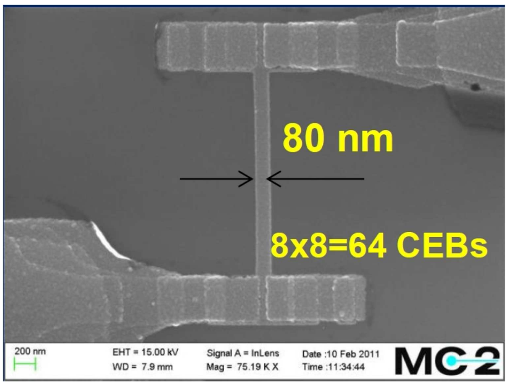

Fig. 3 (Color online) SEM picture of a typical CEB absorber.

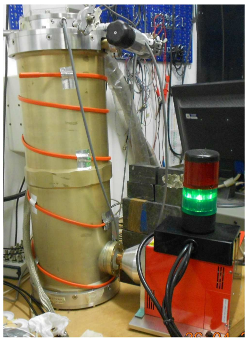

Fig. 4 (Color online) The micro-focus X-ray source in front of the CEB cryostat.

2 Experimental setup

Due to the extremely small volume of the CEB absorber and to the relative decoupling of electron and phonon systems at low temperatures, we expect that the CEB cross-section for ionizing particles is very small. We prepared our experimental setup to check this hypothesis. The CEB is cooled down to about 304 mK with a ^{3}He fridge pre-cooled by a pulse tube refrigerator. A window and a stack of filters defines the sensitive bandwidth of the detector (10% wide centered on 340 GHz). The chip we have tested lacks of lenses, so its coupling to mm-wave photons is through a small cross-slot antenna. The optical responsivity has been checked repeatedly during the measurement campaign and found to be very stable. With optimal DC bias, the electrical responsivity is around 1.2×10^{10} V/W. The detector signal is amplified by a factor 1000 and filtered with a 6th order low-pass filter (200 Hz cut-off). See Fig. 1,2 for the setup and the response to mm waves. A source of ionizing photons is placed in front of the HDPE window of the cryostat. The (negligible) absorption of ionizing photons by the window and the stack of filters is computed from literature data.

3 Measurements with a radioactive source

The radionuclide ^{137}Cs emits at (85.10 ± 0.20)% photons with energy of (661.657 ± 0.003) keV [11]. Given the geometry of our detector, the activity and distance of the source, and the intervening absorption, if the entire CEB chip ($4\,mm^2$) is sensitive to ionizing particles we should observe one event about every 50 s; if only the Al absorbers (total area $5\,\mu m^2$) are sensitive the events rate should be as low as about 1 event per month.

During this test the output signal from the CEB is filtered by a band-pass filter (LF cut-off=0.1 Hz, HF cut-off=300 Hz). The noise power spectrum of V_{out} does not change in presence of the radioactive source, nor its offset. For 662 keV photons the dominant interaction with the CEB is Compton scattering. Assuming that all the energy acquired by a target electron is converted into a detectable signal, and taking into account the time response of our detection chain (~ 1.1 ms), the signal produced by each hit should be ~ 100 mV at the detector; given the amplification of the readout electronics, it should saturate the dynamic range of the amplifier. We collected more than 16 hours of measurements finding none of such events. We conclude that either the only part of the CEB chip sensitive to gamma-rays is the tiny CEB absorber (Fig. 3), or the energy acquired by target electrons is not converted into a detectable signal. Both cases indicate that these detectors are very promising to be used in space.

4 Measurements with a X-ray source

Having failed to detect ionizing particles with the radioactive source, we wanted to further check our hypothesis using a source of ionizing particles producing a much higher flux, so that even if the sensitive volume is extremely small we should detect some effect. We used a Microfocus X-ray source (model L10101 Hamamatsu). We sent different fluxes of X-photons [12] (Fig. 4) in the energy range ($10 \div 100$) keV. Spillover of X-rays was monitored by a Geiger counter 1m away from the X-ray source (Fig. 5, top). For large fluxes (high current in the source) and high energy (large accelerating voltage) ($V \times i > 2W$) we observed a shift in the detector signal offset (Fig. 5, center) and a heating of the ^{3}He evaporator (Fig. 5, bottom). Both the heating of the evaporator and the offset shift are proportional to the integral of the Kramers′ law over the X-ray energies (Fig. 6).

From the data of Fig. 5 it is evident that the arrival of a large number of X-ray photons per unit time results in a shift of the detector signal offset, without any

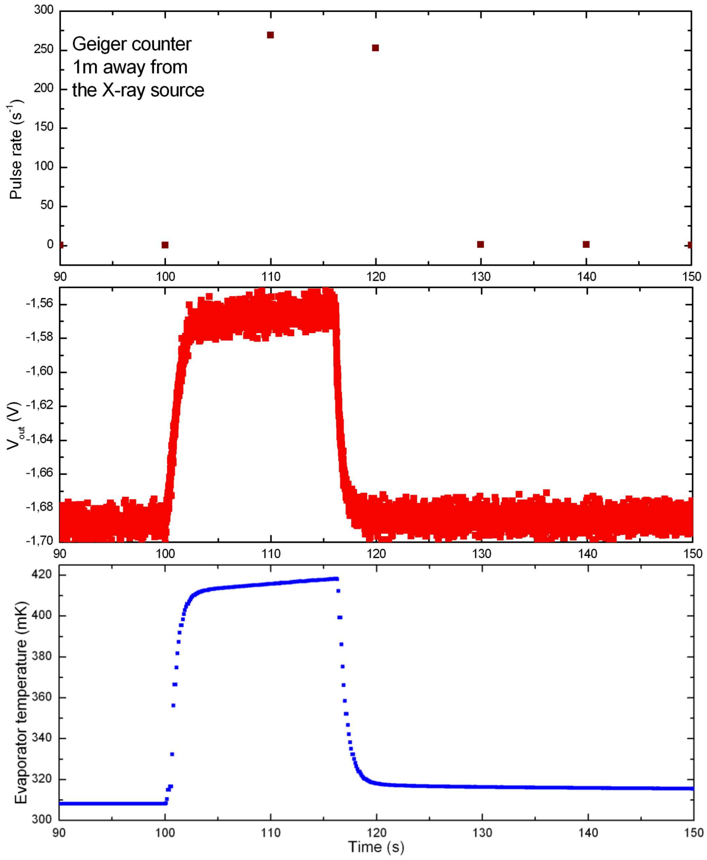

Fig. 5 (Color online) The effect of a large flux of X-ray photons on a CEB. **Top:** Record of a Geiger counter 1m away from the X-ray source during the tests; the increase in the count rate corresponds to source activity. **Center:** Voltage at the output of the CEB readout (V_{out}) in the same period, under maximum source power (10 W). **Bottom:** Warm-up (!) of the ^{3}He evaporator in the same period. The recovery to the initial temperature takes much longer than the recovery of the CEB offset.

significant change of its noise level. Either the temperature change of the evaporator produces the change in the offset, or each single X-ray hit produces a spike smaller than the instantaneous noise and the offset change results as an integrated effect of many small spikes. A combination of both effects is also possible. We note, however, that the rms of the signal, both before and after irradiation (detector and electronics noise only), and during the irradiation (detector and electronic noise plus X-rays hits), is very similar, with standard deviation around 3 mV. We

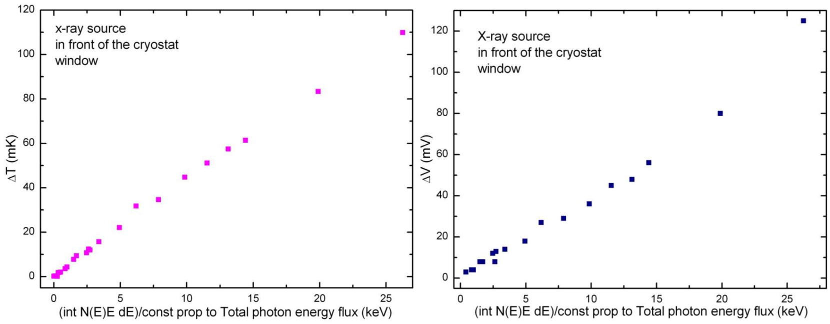

Fig. 6 (Color online) **Left:** Cryostat evaporator temperature increase versus integrated continuum energy spectrum of X-rays emitted by the X-ray source. **Right:** V_{out} offset shift versus the integrated continuum energy spectrum of X-rays emitted by the X-ray source.

can estimate an upper limit for the average amplitude $< A >$ of the individual spikes associated to X-rays hits as follows:

$$\int_0^T V(t)dt \simeq \sum_{N_{hits}} < A > \tau, \tag{1}$$

where T is the duration of irradiation, $V(t)$ is the signal level during irradiation, N_{hits} is the total number of hits during irradiation, t is the response time of the detection system. If ΔV is the shift of the offset of the signal, we have

$$\Delta V T \approx \sum_{N_{hits}} < A > \tau = T\dot{N} < A > \tau, \tag{2}$$

where $\dot{N}$ is the hit rate (hits/s). Using the properties of Poisson statistics for the number of hits, we get

$$< A >= \frac{\sigma_{irr}^2 - \sigma_{no-irr}^2}{\Delta V}. \tag{3}$$

From this we get $< A >< 0.1\,\mathrm{mV}$, i.e. well within the instantaneous noise. This means that the $(20 \div 100)\,\mathrm{keV}$ energy of each X-ray photon does not produce any significant effect in the CEB, producing only very small spikes. In operating conditions, the flux of ionizing particles will be many orders of magnitude lower than in this experiment, which means that these detectors in space will be effectively immune from cosmic rays hits.

5 Conclusions

We have tested the sensitivity of CEBs to ionizing radiation using radioactive and X-ray sources. We have confirmed that the sensitive area is only the CEB absorber and not the entire detector. We have also demonstrated that if signal spikes are produced by X-rays, these are much smaller than the rms noise of the detector. These experimental results confirm CEBs as very promising detectors to be used in future space missions requiring ultra-sensitive mm to IR detectors.

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