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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Methods for response stabilization in bolometers for rare decays

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Abstract

Massive bolometric detectors operated at very low temperatures ($\simeq 10\,\mathrm{mK}$) can be used to search for rare events, such as Double Beta Decay and interactions of Dark Matter candidates. In experiments of this type it is important to keep the detector response steady within 0.1% level over periods of the order of one year or more, often in conflict with the intrinsic instabilities of the cryogenic setups. Here, a powerful method to stabilize detector response is described: using calibrated amounts of energy, injected by means of alpha particles or resistive heaters, a correlation between pulse amplitude and detector bias can be established. This correlation can be used to correct off-line the amplitudes of every pulse. The satisfactory results achieved with this technique are reported and discussed. For this purpose heavily doped Si heaters with steady resistances at cryogenic temperatures were designed and succesfully tested. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction to response stability in bolometers

Typical applications of low temperature massive detectors are searches for Double Beta Decay and Dark Matter [1,2]. A common point in these experiments is the necessity to operate the detectors in stable conditions for periods of the order of one year or more. Unfortunately, the complicated cryogenic setup required for the detector operation shows intrinsic instabilities (like temperature fluctuations) which can spoil the detector energy resolution, one of the *atouts* of the bolometric technique. It is therefore mandatory to develop a specific method to stabilize the detector response or at least to correct its instabilities effectively.

In the last few years our group has played a pioneering role in the development of a real physics experiment with bolometers [3] and therefore had to cope up with the stabilization problem before other collaborations. Our typical detecting element [4] consists of a 340 g single TeO_2 (paratellurite)

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crystal, thermally coupled to a 10 mg Neutron Transmutation Doped Ge crystal, serving as a phonon sensor. The detector is operated at about 10 mK in a low radioactivity dilution refrigerator installed underground in the *INFN Laboratori Nazionali del Gran Sasso* (LNGS), in order to search for Neutrinoless Double Beta Decay of ^{130}Te. Runs lasting up to 10 000 h have been performed with devices of this type [3].

In this paper, we focus our discussion on the instabilities originated by changes in the detector operation parameters, without considering possible drifts due to the electronic chain elements or to some critical components, like load resistors. In order to evaluate exactly at which level the cryogenic apparatus instabilities can affect the detector performance, one should develop a complete thermal model, able to determine the temperatures of the various parts of the detector as a function of the refrigerator temperature and of the parasitic powers (of electromagnetic and microphonic origin) dissipated in the detector elements. We are still working on a model of this type. However, a rough quantitative estimation of the effects of the refrigerator temperature fluctuations can be done, assuming naively that the detector consists of a single thermal stage weakly connected to the heat bath. In this frame, one has to take into account that the detector operation temperature T_b (about 10 mK) is significantly different from the heat sink temperature T_0 (about 5 mK), the two temperatures being connected by the relationship

$$w = \frac{g}{\alpha + 1}\,(T_b^{\alpha+1} - T_0^{\alpha+1}), \tag{1}$$

where w is the power injected into the detector (due both to bias current and to spurious effects like vibrational heating and perhaps to energy transfers caused by residual helium atoms present in the experimental vacuum), while $G = gT^{\alpha}$ is the temperature dependance of the thermal conductance of the detector to the bath. In ad hoc measurements [4] we have found that α is close to two, from which one can deduce that

$$\frac{\mathrm{d}T_b}{T_b} = \frac{\mathrm{d}T_0}{T_0}\left(\frac{T_0}{T_b}\right)^{\alpha+1} \simeq \frac{\mathrm{d}T_0}{T_0}\left(\frac{5}{10}\right)^{3} = \frac{\mathrm{d}T_0}{T_0}0.125, \tag{2}$$

which links relative variations of bath temperature to relative variations of detector operation temperature, fortunately attenuated by detector/bath thermal decoupling. Nevertheless, since thermistor resistance R has a temperature dependance law that, close to the operation point, leads to the approximate relationship $\mathrm{d}R/R = -A\mathrm{d}T/T$ (A being a dimensionless constant which for our thermistor is around 10), and since the bias applied to the detector V_b is equal to IR where I is the constant bias current, one has that

$$\left|\frac{\mathrm{d}V_b}{V_b}\right| = \left|\frac{\mathrm{d}R}{R}\right| = \left|A\frac{\mathrm{d}T_b}{T_b}\right| \simeq 1.25\left|\frac{\mathrm{d}T_0}{T_0}\right|, \tag{3}$$

showing that the relative changes of the detector bias are of the same order of magnitude of the relative changes of the base temperature.

Of course, pulse amplitudes V_s change as well when the applied bias V_b changes. We observed that in most cases the signal amplitude increases as the detector bias increases. If the bias increase originated only by a decrease of the base temperature T_0, this is the expected behaviour, as in this case both factors involved in detector sensitivity (operation temperature and applied bias) move in the direction that improves detector response. Unfortunately, we seldom observe an opposite behaviour, whose explanation requires a complete, not yet available detector thermal model. In both cases however, in a small enough neighbourhood of V_b, the function $V_s(V_b)$ can be taken as linear, so that

$$\left|\frac{\mathrm{d}V_s}{V_s}\right| \simeq \left|\frac{\mathrm{d}V_b}{V_b}\right| \simeq 1.25\left|\frac{\mathrm{d}T_0}{T_0}\right|. \tag{4}$$

Now it is important to establish at which level we can tolerate fluctuations in the detector response. Since the typical intrinsic resolution of our single element ranges from 2 to 5 keV rms, we expect an rms resolution of the order of 0.1–0.2% at 2528 keV (^{130}Te Double Beta Decay transition energy): therefore, changes of the base temperature even at the 0.1% level may have a negative effect on detector performances. Our experience shows that in long measurements one has to cope with fluctuations of this order, mainly because variations of liquid bath levels (at 4.2 and 1.5 K) determine small changes in the flow rate of ^{3}He–^{4}He mixture (the working fluid in a dilution refrigerator) that influence base temperature. The problem can be minimized by directly stabilizing the main cryogenic parameters as much as possible. Therefore, we stabilize:

- the level in the 1.5 K bath, equating exactly the boil-off to the filling rate regulated by a needle valve;
- the level in the 4.2 K main bath, by means of a helium re-liquefier inserted in the bath itself;
- in some runs, the mixture flow rate, through a feedback control acting on the still power;
- in some runs, the detector holder temperature, using a heater–thermometer feedback control.

In addition, even if the holder temperature is steady within our requirements, one observes that the parasitic power included in w (see Eq. (1)) can also fluctuate (probably because the mechanical vibrations which heat the detector up depend on the liquid levels and other instable cryogenic parameters, as one can appreciate from the variations in time of the microphonic noise figure of the detector). Consequently, T_b can change even in the absence of T_0 changes and in any case the fluctuation problem survives at a relevant level: a stabilizing mechanism acting directly on the detector followed by an off-line pulse amplitude correction is therefore necessary.

2. The energy-pulser method

An obvious approach to the response stabilization consists in delivering periodically to the detector one (or more) fixed amount of energy, generating a detector response as similar as possible to the signal of interest. The energy injection can occur in the form of:

- energetic particle absorptions (naturally present or intentionally determined);
- Joule pulses delivered by a proper heating element thermally coupled to the crystal;
- light pulses transmitted through optical fibers.

We have studied all these points, even if we have discharged for the moment the last solution, since it is by far the most complicated and the least suitable for the multiplication of channels that we foresee for our experiment. The technical details of the first two solutions will be exposed in the next two sections.

Once an energy-pulser of some type is operating, there is the problem to exploit at the best the informations it gives. The most natural approach would be to register the pulse amplitudes V_p given by the pulser together with their arrival times and then to reconstruct the function $V_p(t)$, which represents the detector response as a function of time: it can be used to correct off-line the amplitudes of every pulse whose arrival time is known. Unfortunately, this method has an intrinsic limit: the function $V_p(t)$ is sampled with a certain rate, that cannot be too high for obvious reasons of dead time. Therefore, fast variation of the detector response could not be registered and pulses occurring during these variations would be erroneously corrected.

There exists a much more powerful approach to the problem. The amplitudes V_p can be correlated with the baseline level V_c preceding immediately the pulse development: V_c can be inspected for every pulse, as our ADCs register a baseline segment of about 100 ms before pulse onset. V_c is correlated to the bias level V_b across the thermistor, to which it is linked by the relationship

$$V_c = \Gamma(-V_b + V_{off}), \tag{5}$$

where Γ is the total gain and V_{off} is the offset added to null the DC output. The sign minus accounts for the fact that signals are acquired so to be positive, their polarity being opposite to the bias polarity. Consequently, a fast decrease of the bias level (i.e. a pulse) appears as a fast increase of the baseline level, while a decrease of the operation temperature, which leads to an increase of the operating resistance and of V_b, appears as a decrease of V_c. Therefore, by identifying off-line the pulses given by the energy pulser and corresponding to a constant delivered energy, a plot of V_p versus V_c will generally show a monotonically decreasing function $V_p(V_c)$, since in most of the cases amplitudes increase with V_b: the function $V_p(V_c)$, if the V_c excursion is not too big, can often be succesfully approximated with a negative slope straight line (Fig. 1); over larger V_c excursions, a phenomenological polynomial fit can be used. Of course, this procedure is possible

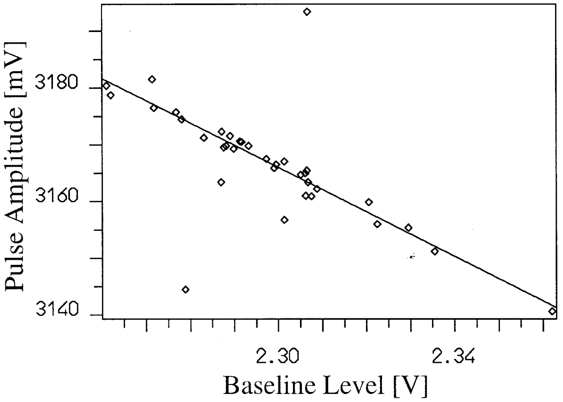

Fig. 1. Pulse amplitude as a function of the baseline level for a one day lasting measurement; the pulses are generated by 5.41 MeV α-particles (^{210}Po).

only if the electronic chain is totally DC coupled (this requires some care in matching offsets with ADC range and dynamics) and – very important technical detail – if the DC stability of the amplifiers is excellent (at the 0.1% level): the last point has required a lot of specific work for our room-temperature electronics [5]; in the past we used 4.2 K cooled electronics [6] which unfortunately exhibited large offset changes in correspondence with the 4.2 K bath liquid level changes. In this discussion we have excluded that V_b changes could be due to polarization current changes, assuming therefore that the detector load resistor is constant: in our first runs we used 4.2 K cooled, slightly temperature dependent load resistors, that showed some variations during the measurements: we have now eliminated this problem using high value room-temperature load resistors.

Once the function $V_p(V_c)$ is known, one can take a reference baseline V_{Cref} for which $V_{\mathrm{Pref}} \equiv V_p(V_{\mathrm{Cref}})$, and then construct the function

$$\alpha(V_c) \equiv \frac{V_{\mathrm{Pref}}}{V_p(V_c)}, \tag{6}$$

which constitutes the multiplicative factor which takes back to the reference level V_{Pref} an amplitude V_p of a pulse acquired when the baseline value was V_c. Of course, since the points (V_c, V_p) are noisily distributed around the fitting function $V_p(V_c)$, the corrected amplitudes will distribute around V_{Pref} essentially according to the intrinsic resolution figure of the detector. Now, the same factor $\alpha(V_c)$ can be used to correct the amplitude of every pulse (not only the ones from the energy pulser) whose corresponding baseline level is known. The correction is effective for fluctuations which take place on a time scale longer than the typical pulse time constants, since the baseline level is considered constant along the pulse development: experience shows however that dangerous instabilities occur on time scales of the order of several minutes or hours and can therefore be corrected. In this discussion, deviations from linearity of the detector energy response are not considered: one could account for them by using a set of calibration pulses with different amplitudes, spanning all the interesting dynamical range.

The power of this method lies in the fact that the relation among pulse amplitude and baseline (bias) level is an intrinsic property of the detector and of its operation point, that, once determined with sufficiently high statistics, can be generally applied for pulse correction. In principle, this method works irrespective of the time structure of the operation point variations, if they are not too fast with respect to pulse time constants. Furthermore, even when $V_p(V_c)$ is an increasing function, in contradiction with a naive interpretation of the detector behaviour, it can be used for pulse correction because it expresses in any case a physical relationship between detector operation point and pulse amplitude. This analysis could lead to the erroneous conclusion that it could be sufficient to determine this relationship just once in a single calibration: unfortunately, in a long run one observes that the function $V_p(V_c)$ itself can change, probably because V_c does not provide a unique determination of the detector working point. It is therefore necessary to monitor the baseline dependance of the pulse amplitude by means of the continuous operation of the energy-pulser: the measurement is then divided into segments of a few days and the correction is performed over each of them. As it will be shown in the next sections, this stabilization mechanism is very effective and allows in some particularly unsteady measurements to re-compact peaks in the energy spectrum that had been completely washed off by the cryogenic instabilities.

3. Particle-based stabilization

A continuous calibration realized by means of particle absorption is a possible way to realize an energy pulser. The advantage of this method is that the detector response to the pulser is identical (or very similar) to the response to the events of interest. There are however some disadvantages:

- if the calibration is performed with a gamma source and, as in case of Double Beta Decay experiment, calibration signals of the order of a few MeV are preferable, a fully contained gamma event of that energy is accompanied by a large number of lower energy events which would increase excessively the rate and the background;
- the calibration could be performed with an alpha source; this is in any case difficult, as the source must be very thin in order to avoid excessive straggling, and simultaneous emission of photons could lead to the same problems as in the first point;
- the Poissonian time distribution of events of a natural source, limits the calibration rate;
- the calibration pulses cannot be flagged and their off-line identification is based only on their amplitude.

However, our group has obtained interesting results by using a natural ^{210}Po contamination of paratellurite crystals. This isotope belongs to the ^{238}U chain and is often present in many materials, in equilibrium with its possible long living progenitors in the chain: ^{238}U itself (unlikely), ^{226}Ra or ^{210}Pb, which is often spread out by its progenitor ^{222}Rn. The chemical affinity of polonium with both tellurium and oxygen is probably responsible for the incorporation of ^{210}Po in paratellurite. Its uniform diffusion in the bulk and its radioactive properties make ^{210}Po an ideal energy pulser for TeO$_2$ detectors: it decays to ^{206}Pb emitting a 5.304 MeV alpha particle with more than 99% probability; there is a small irrelevant chance (0.00107%) of emitting a 803.1 keV photon through an excited state of ^{206}Pb. Therefore, all our background spectra are dominated in the alpha energy region by a huge peak at 5.408 Mev (the total transition energy, since also nuclear recoil is detected [7]) that can be used for stabilization purposes.

A typical time behaviour of ^{210}Po pulse amplitude before correction is shown in Fig. 2a; as explained in Section 1, exploiting baseline-amplitude correlation for ^{210}Po pulses, selected by their amplitude, it is possible to convert pulser amplitudes to a reference amplitude. In Fig. 2b the time behaviour of ^{210}Po pulse amplitude after this correction is shown. Of course, the effectiveness of the correction can be proved only by its effect on another energy peak. In Fig. 3, a not-corrected ~ 3000 h background spectrum is reported in the region

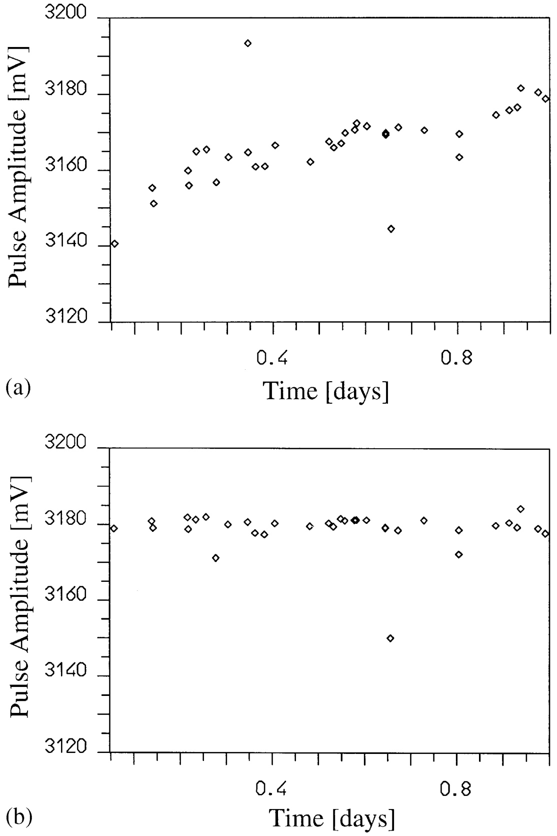

Fig. 2. Time behaviour of the pulse amplitude before (a) and after (b) correction; the pulses correspond to 5.41 MeV (^{210}Po) α-particle absorption.

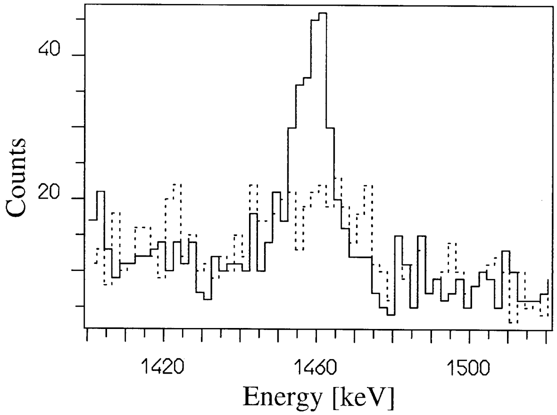

Fig. 3. Not-corrected ∼ 3000 h background spectrum (dotted line) compared with the same spectrum after correction (solid line): the ^{40}K 1460 keV background peak appears.

where one expects a peak due to ^{40}K (a typical contamination which gives 1460 keV photons); the same spectrum after correction is superimposed, showing the dramatic improvement in the energy resolution.

In spite of the interesting results obtained (without ^{210}Po contamination our preliminary experiments on Double Beta Decay would have been much more difficult), ^{210}Po pulser cannot be the final solution for the instability problem. The main difficulty lies in the short half-life of this isotope: only 138.38 days. In our 10 000 h run, at the end ^{210}Po pulses were so rare that instability correction was becoming impossible. The typical rate is of the order of 10 pulses/h for a "new" 340 g crystal, that reduces to about 1 pulse/h after 10 000 h. Secondly, a radioactive contamination is never welcome in a low background experiment, even though very far from the energy region of interest as in this case: indeed, surface alpha emission with only partial energy deposition in the crystal could contribute to the background at much lower energies. Therefore, other solutions must be found.

As far as particle calibration is concerned, an interesting solution that we have examined but never realized, at least for the moment, consists of the intentional use of low energy, low Z, long lifetime alpha emitters. Particularly interesting is the case of samarium. This element contains two isotopes, with $A = 147$ and 148, with natural relative abundances of 15% and 11%, respectively, which are alpha emitters at the energies 2.23 and 1.96 MeV, with half-lives of 1.06×10^{11} and 7×10^{15} yr [8]. It is a remarkable advantage to have signals close to the Double Beta Decay transition energy (2528 keV), but *below* it and so not contributing to the background in the region, of interest.

With about 20 μg of natural samarium, one would obtain a rate around 10 pulses/h (sufficient for an effective stabilization) for the alphas at 2.23 MeV (the 1.96 MeV alpha rate would be negligible). Given that samarium density is about 7.5 g/cm ^{3}, a thin film 0.1 μm thick (to minimize self-absorption in the source) and with an area of about 0.3 cm^2 (a size perfectly compatible with detector and holder arrangement and dimension) would give the desired rate, if facing directly to one detector side. It is important to stress that neither the mentioned isotopes nor the others present in natural samarium are affected by other forms of radioactivity which could disturb the measurements. The samarium method would be useful in a large array experiment, where it is important to reduce as much as possible all the connections from the detectors to the cryostat's exterior.

4. Heater-based stabilization

A resistive element thermally coupled to the crystal can be used to inject calibrated amounts of energy through Joule heating. The advantage of this solution is of course the complete control of the calibration mechanism that it would offer: the pulses would be equally spaced in time. The rate and amplitudes could be easily tuned to the necessity of the experiment. However, such a heating element must satisfy some non-obvious requirements:

- its resistance must be reasonably independent of temperature and applied voltage;
- its heat capacity must be negligible with respect to the detector one;
- the relaxation time to the crystal of the developed heat must be much shorter than all the

typical thermal time constants, in order to provide an almost instantaneous energy release;

- the mechanism of signal formation for particle interactions and for Joule heating must be similar enough to assure that the pulse amplitude dependances on time, baseline level and other operation conditions are the same for the two processes;
- the heater resistance must be much higher than the connection wire resistance through the cryostat in order to represent the main point of power dissipation, but not so high to require excessive voltage pulses to develop the required calibration energy (for our experimental configuration, reasonable values range from 1 kΩ to 10 MΩ);

Steady resistances can be realized either by means of metallic alloys or through a heavily doped semiconductor, well above the metal insulator transition (MIT), so that a low-mobility metallic behaviour is exhibited. Furthermore, the resistive structure, consisting usually of a long, narrow, thin meander necessary to achieve reasonably high resistances in spite of the relatively low resistivity of the conductive material, must be integrated in a small chip easy to handle, to bond and to connect thermally to the crystal.

The heat capacity C_h of the heating element is crucial, not particularly for its contribution to the total detector heat capacity C_d (usually the heater total mass is so small that paratellurite crystal heat capacity dominates by far), but rather because it controls the thermal coupling time τ_h through the formula

$$\tau_h = \frac{C_h C_d}{C_h + C_d} \frac{1}{G_h} \simeq \frac{C_h}{G_h}, \tag{7}$$

where G_h is the thermal conductance between the heater and detector; τ_h represents the typical time necessary to achieve thermal equilibrium between heater and detector. Since τ_h's as small as possible are required, it is important to minimize the heaters heat capacity and to realize good heater–detector thermal coupling.

Up to now, we have explored two different solutions for the heating element. First, we have used a commercial device developed by Mini-Systems Inc. consisting of a thin meander Nichrome film deposited on a 1 × 1 mm^2, 0.3 μm thick silicon chip, with 10 MΩ total resistance. We have employed this device as an energy pulser for a 21 g TeO_2 detector [9]. Unfortunately, the magnetic properties of Nichrome determines a huge heat capacity for this heating element, as observed also by other collaborations [10], which caused an anomalous rise time of the heater-generated pulses, much longer than the particle rise time. An efficient response stabilization was therefore impossible.

So we moved to the second possibility, consisting of the use of a doped semiconductor as a heating element. As a first test, we used a by-product of our R and D silicon microbolometer program [11] based on implanted silicon thermistors. A standard practice in silicon device micro-fabrication consists of including in the layout suitable test structures together with the actual devices of interest. The silicon wafers with the thermistors fabricated by the Istituto per la Ricerca Scientifica e Tecnologica (IRST) contain therefore also some auxiliary structures grouped in a so-called "test strip". The main function of these test devices is to allow a fabrication process control and room-temperature electrical parameter extraction. IRST has an internal standard for the contact pads of these test devices and also a small cell library of test structures. The test strip for the microcalorimeter process occupies an area of 1200 × 3000 μm^2 and contains four structures, i.e. a contact diode, a metal meander and two special resistive structures, one for the thermistor diffusion and the other for the contact diffusion: it is the last one which has been used here as a heating element. The structure itself is a narrow doped line with variable width and five contacts. This particular design allows to measure the sheet and contact resistance of the contact diffusion and also to determine the process-induced dimensional variations of the contact diffusion. The contact diffusion is obtained by opening the corresponding area in a 800 nm thick thermal oxide by lithography and etching, subsequent doping by ion implantation with 5.00 × 10^{15} ions/cm^2 of arsenic at 110 keV and activation by annealing at 975°C for 1 h in dry oxygen and 30 min in dry nitrogen. The so obtained heavily-doped diode has a junction depth of 0.5 μm and a surface concentration of 2.0 × 10^{20} atoms/cm^3, i.e. well above the MIT (8.7×10^{18} atoms/cm^3 for arsenic). At low temperatures such a heavily-doped semiconductor behaves as a quasi-metallic resistor.

We have cut a $1.5\times1.5\times0.5\,\mathrm{mm}^3$ silicon dice around the strip and have contacted the constant resistance part with two 25 μm diameter, 10 mm long, gold wires. In a preliminary checking of the voltage and temperature stability of this device down to 50 mK was found reasonable but not excellent, especially at low powers (Fig. 4). We have glued with an epoxy drop the dice at a 73 g TeO_2 detector, operated in the LNGS for a measurement of the Nuclear Quenching Factor in paratellurite bolometers [12]. The typical resistance of the heating element is around 10 kΩ at the detector operating temperature (10–15 mK). Then we injected with a programmable pulse generator square voltage pulses in the heating element, tuning the amplitude and the time width (always much shorter than the thermal pulse rise time) so as to develop a few MeV thermal energy in the pulser. The results are summarized in the following points:

- Heater-generated pulses are indistinguishable from particle pulses (Fig. 5); this is not surprising, since the heat capacity of the device should not be higher than 10^{-13} J/K (assuming that the constant resistance doped region can be described as an ideal Fermi gas) which, combined with the 10^{-10} W/K glue spot thermal conductance [4], leads to $\tau_h \simeq 1$ ms (see Eq. (7)), much shorter than the 50 ms thermal rise time of the detector; furthermore, this long thermal rise time, essentially due to heat transmission from the crystal to the sensor, washes off possible dependances of the signal shape on the initial phonon spectrum of the energy pulse.
- The nominal energy of the heater pulse is always larger (typically by a factor 2) than the one inferred from the corresponding pulse amplitude on a particle energy scale; this has a simple explanation in the inevitable partial flowing of the Joule power to the heat sink through the heater connecting wires; as long as this energy partition is not temperature dependent, the stabilization mechanism should not be affected.
- Heater pulse amplitudes scale as V^2 and as Δt, where V and Δt are respectively, the amplitude and the time width of the voltage square pulses applied at the heating element; this shows that the bolometer is really sensitive to an energy E_h given by

$$E_h = \beta \frac{V^2}{R_h} \Delta t, \tag{8}$$

where R_h is the heater resistance and β the constant partition factor mentioned at the previous

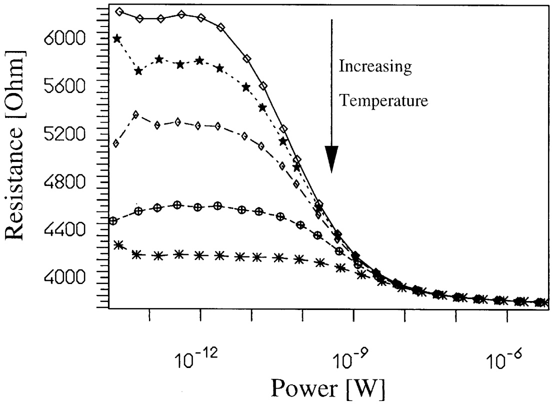

Fig. 4. Resistance versus measuring power for our strip heater; the various curves are taken at different temperatures, from 50 to 800 mK; the strip exhibits a temperature sensitive behaviour only at low power.

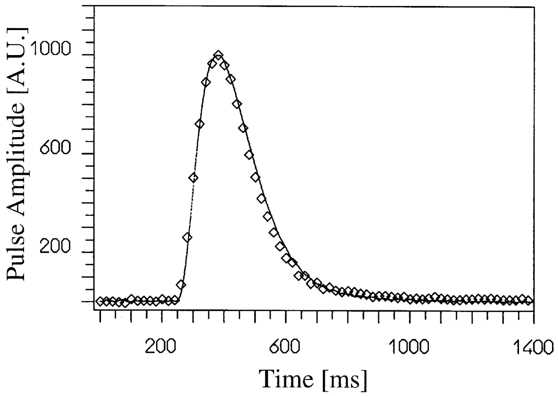

Fig. 5. Pulse generated by a particle (points) in a 340 g TeO_2 bolometer compared with a pulse generated by a strip heater (solid line); once normalized, the two pulses have the same shape.

point; the Eq. (8) shows that $dE_h/E_h = 2\,dV/V$ and $dE_h/E_h = d\Delta t/\Delta t$, imposing a stability for the pulse generator at least at the 0.1% level both in time and amplitude.

- The Crucial point is that the signals generated in the detector by the heater pulse have the same time and baseline dependance as the particle signals; this allows to perform an effective stabilization using the heater pulses, which furthermore can be easily identified and selected by software; the stabilizing effect is shown in a calibration spectrum of the 73 g TeO_2 detector, where, before stabilization the two ^{60}Co peaks at 1.17 and 1.33 MeV are hardly distinguishable, while after stabilization they appear clearly with a FWHM energy resolution of about 16 keV (Fig. 6b).
- The contemporary recording of the pulses developed on the heater itself could allow also to compensate for possible time width and amplitude drifts of the calibration signals.
- If the stabilization is performed with a particle energy-pulser, using for instance an alpha line, the FWHM energy resolution of the re-compacted peaks is the same within statistical errors as the one obtained using the heater pulses (Fig. 6a).

The last points show that a heater-based stabilization is a good candidate to be a definite solution for the instability problem. For this reason a fabrication run especially dedicated to produce diffused resistors with resistance values in the range of 100 kΩ at low temperatures has been produced at IRST. The layout of the basic resistor module consists of a 6 μm wide and about 120 000 μm long diffusion meander, that occupies an area of 1938 × 1917 μm^2 and has a geometrical resistance of 20 000 squares. During the masking step more than one of this module can be printed side by side in order to obtain larger resistors. Also the contact pads can be attached more or less freely at a lithography level (Fig. 7). In the first run eight of these modules have been added giving a total geometrical resistance of 160 000 squares. The first module was provided with eight contact pads while the others with only one. It is therefore possible to trim the resistance value by bonding the suitable pads. The basic structure of the fabrication process flow is the same as that of the contact diodes described previously. In order to have a wider span of resistance values, different doping elements and levels have been included in the run as well as a shorter annealing time (30 min dry oxygen).

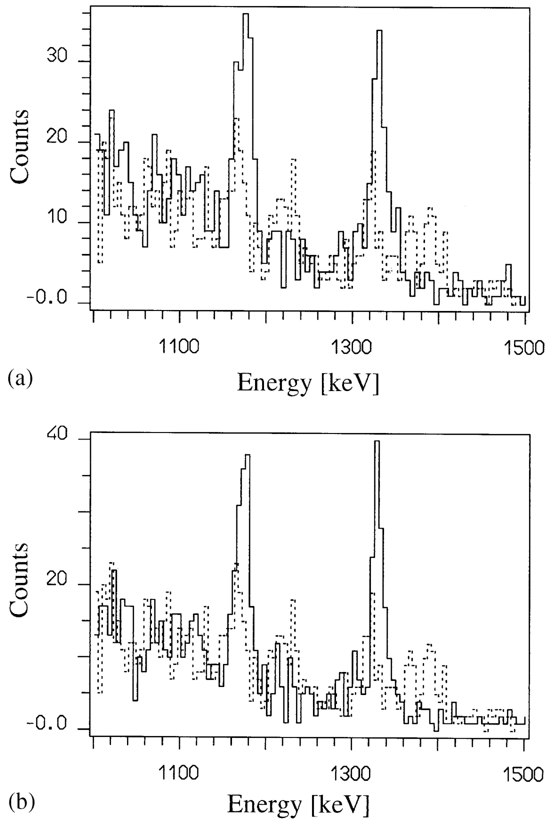

Fig. 6. Calibration spectrum of a 73 g TeO_2 bolometer before correction (dotted line) and after correction (solid line); the stabilization is performed with α-particles (a) and with heater pulses (b); in both cases the two ^{60}Co γ peaks appear after correction with equivalent resolution.

The wafers containing the resistances with the chosen doping level were cut in order to obtain 3 × 3 × 0.5 mm^3 dices, with a meander section chosen to to give 100 kΩ resistance at low temperatures. Power-resistance characteristic curves taken at different temperatures are shown in Fig. 8, showing the excellent resistance stability. These devices were successfully tested with 340 g TeO_2 detectors, and are now used to stabilize the detector responses in our 20 element array presently working at the LNGS.

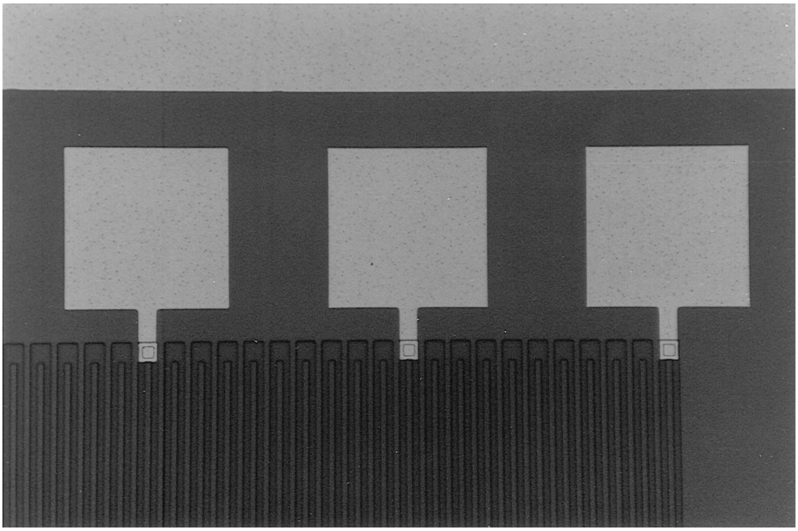

Fig. 7. Silicon implanted heater: detail of the meander structure with contact pads.

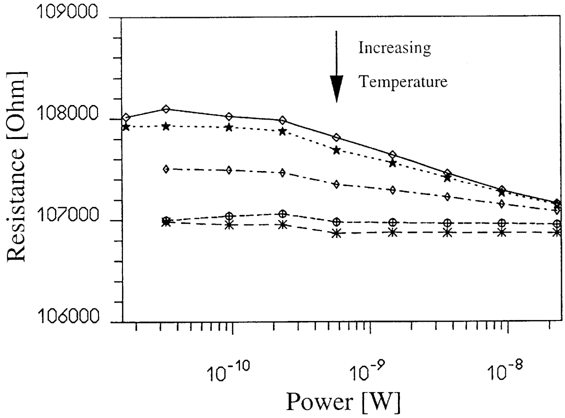

Fig. 8. Resistance versus measuring power for our meander heater; the various curves are taken at different temperatures, from 50 to 800 mK; the resistance is stable within 1%.

5. Conclusion

We have shown that the instability of the bolometer response can be successfully cured exploiting the strict correlation between the pulse and amplitude for a given deposited energy and the DC baseline level, which is determined by the bolometer operation point. Therefore, a measurement of the DC baseline level for a pulse allows to determine a correction factor for the amplitude of that pulse. The energy pulser needed to define the baseline-amplitude function can be realized not only with particle calibrations, but also with a proper heating element coupled to the bolometer: we proved that this solution works excellently and, because of its simplicity, it is going to be adopted in a large scale in the future developments of our Double Beta Decay ^{130}Te experiment.

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