ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Genova

INFN/TC-96/01
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SIS-Pubblicazioni
dei Laboratori Nazionali di Frascati

INFN - Istituto Nazionale di Fisica Nucleare
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A 3.9 K TRANSITION EDGE PARTICLE DETECTOR WITH Dc-SQUID READ-OUT AND TEMPERATURE STABILIZATION

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Abstract

The response of a Tin transition edge micro-calorimeter, operated at 3.9 K, with an alpha particle source, was investigated.
A SQUID read-out electronics was used in order to minimize the electronic noise, and a new way to use SQUID in order to stabilize the working temperature of the detector was tested.
These preliminary results can be of interest in the application of this kind of low temperature detectors to heavy ions nuclear physics.

1 Introduction

The energy sensitive detection of heavy ions may be an interesting application for low temperature micro-calorimeters. This application has been discussed in several publications [2] [3], and the first devices have been tested [4] with heavy ions (Ne, Ar, Xe, Bi) in the energy range 3.6 MeV/u $<$ E $<$ 12.5 MeV/u. The advantage of a micro-calorimeter transition edge detector with respect to conventional detector is the possibility to have an energy resolution of approximately $\Delta E/E= 10^{-3}$-10^{-5} which is the resolution currently aimed for in a variety of applications in nuclear physics with heavy ions.

Moreover in theory the radiation damage of this type of detector would not compromise too much its performance, and there would be the possibility to use a detector composed of only superconducting material, which removes almost completely the problem of radiation damage. Nevertheless the first results obtained with heavy ions [4] show that the theoretical limit of the micro-calorimeter energy resolution has not yet been reached because of the noise of readout electronics and the temperature instability.

The aim of this present study is to show that a relatively simple calorimetric detector which is able to work at 3.9 K , temperature of a pumped helium bath, can provide good energy resolution for the detection of heavy ions. We have studied and built a test device, with commercially SQUID read-out in order to minimize electronic noise, which is described in the following Section.

In the last Section we propose also a new way to use a SQUID in order to stabilize the working temperature of the detector.

2 Detector Characteristics

A superconducting phase transition micro-calorimeter is composed by a small film of superconducting material evaporated onto an absorber crystal. The basic idea is to mesure the temperature rise of the film after energy is deposited by a particle interaction in the absorber. The detector is operated near the critical temperature T_c of the thin film because the strong temperature dependence of the film's electrical resistance makes it a very sensitive thermometer.

The ultimate energy resolution of the particle detector is limited by the thermal noise, and the expression of the minimum detectable energy is [1] :

$$E_{min} = 2.36\sqrt{kT^2C} \qquad (1)$$

where C is the heat capacity of the detector and T is the working temperature. A unique feature of cryogenic detectors is the extensive choice available for the material of the detector.

A detector composed of a transition edge tungsten film with an area of $1mm^2$ and a thickness of 1 μm, and of a superconducting absorber with similar dimensions and a higher critical temperature, has a limit on energy resolution of few eV FWHM.

The prototype detector developed here was realized in order to test the SQUID readout and a new thermal feedback system, not to achieve a high energy resolution. The test device was composed of an absorber of Silicon (4x5x0.1 mm) and a thin film of Tin used as phase transition thermometer

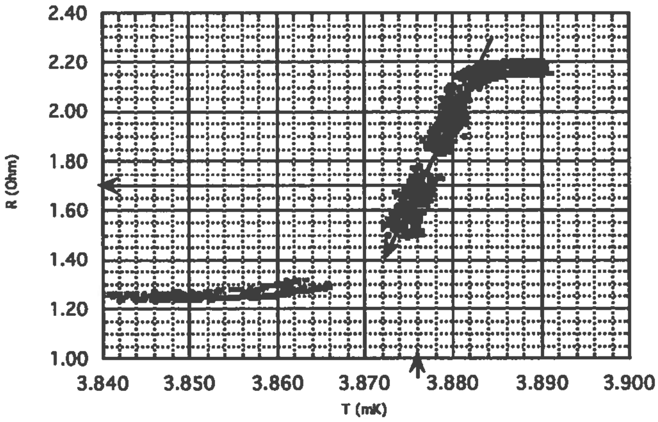

Figure 1: Total resistance of Tin film plus electrical contacts versus the temperature of the detector.

for the micro-calorimetric detector. The Tin film thickness was $0.1 \mu m$, it had a meander shape and a resistance of 14 Ohm at room temperature; the width of the scribed sections of the film was 0.75 - 1 mm. The electrical contacts of the thin film thermometer were made using silver paste, and the resistance of the film plus the resistance of the contacts was of about 2.2 Ohm at the temperature of the helium bath. The resistance in the transition region is shown in Figure 1.

The width of the transition from normal to superconducting state, defined as $\Delta T = T(90\%) - T(10\%)$ is 15 mK, and the transition slope near Tc is approximately 0.15 Ohm/mK. This curve could be reproduced during a single helium transfer. However the characteristics of the thermometer were not stable if the device was exposed to air between transfers.

In order to test the calorimeter at temperatures between 2 K and 4.2 K, a ^{4}He cryostat has been used. The cryostat was connected to a roots pump in series to a rotary pump, and the temperature was stabilized by mechanical pressure regulation. The fluctuation of the bath temperature was of approximately 10 mK at a fixed bath pressure.

The calorimeter bias circuit is shown in Figure 2.

The superconducting film is current biased. The resistance bridge is in

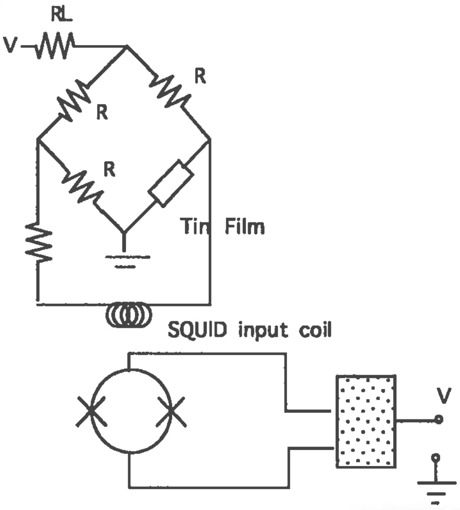

Figure 2: Bias circuit of the Tin thin film thermometer.

equilibrium when the temperature of the film is Tc, the critical temperature of Tin defined as the temperature where the film resistance has decreased to 50% of its normal-conducting value. The critical temperature of the film has to be chosen as the working temperature of the detector. The Tin film acts as a thermometer: when a particle interacts in the pure Silicon absorber, it is rapidly thermalized, causing an increase in the temperature of the detector and consequently of the Tin film resistance. The unbalance of the bridge changes the current in the SQUID input coil, and the output of the SQUID, enhanced by a low noise amplifier, is proportional to the energy released by the particles.

The device was irradiated with an alpha particle source of ^{241}Am, of energy 5.5 MeV. In Figure 3 the pulse shape of a single 5.5 MeV event is illustrated, which is obtained with the circuit of Figure 2. The SQUID output is enhanced using a low noise amplifier with a bandwidth of 100-3000 Hz.

The baseline noise in the frequency range typical of the phonon spectrum was consistent with the expected magnitude from (2). The rise time of the signal is about 25 μs and the decay time, which is determined by the thermal properties of the calorimeter, is about 300 μs.

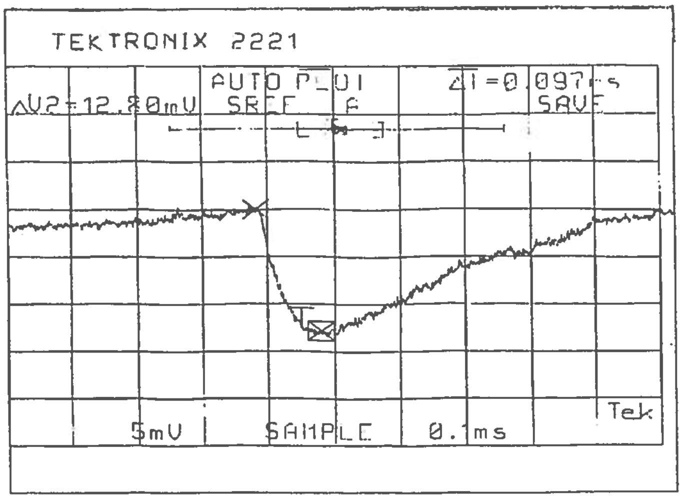

Figure 3: Pulse shape of a single 5.5 MeV event. The baseline slope is due to 50 Hz power supply interference.

3 Temperature Control of Detector System

In nuclear physics experiments using heavy ions accelerators it is important to have the possibility to measure the particle energy spectrum over long period of time in order to have good statistics. In the case of transition edge micro-calorimeter, the sharpness of the superconducting transition depends on temperature, and therefore a poor working temperature regulation can compromise the spectrum energy resolution because of long term temperature fluctuation. The stabilization of the detector temperature is very important if long acquisition must be undertaken. Mc Cammon [5] and more recently K.D.Irwin et al. [7] propose to voltage bias the thermometer in order to stabilize the detector temperature through the electrothermal feedback of the thermometer. However, because of the very low resistance of the transition edge thermometer, it is very difficult to provide a constant voltage bias and to optimize the feedback parameters.
We have tested a different feedback system to stabilize the working temperature of a transition edge thermometer. The scheme of the circuit is shown in Figure 4.

In this new configuration it is possible to use the SQUID both for the electronic readout and the stabilization of the working temperature. A fixed

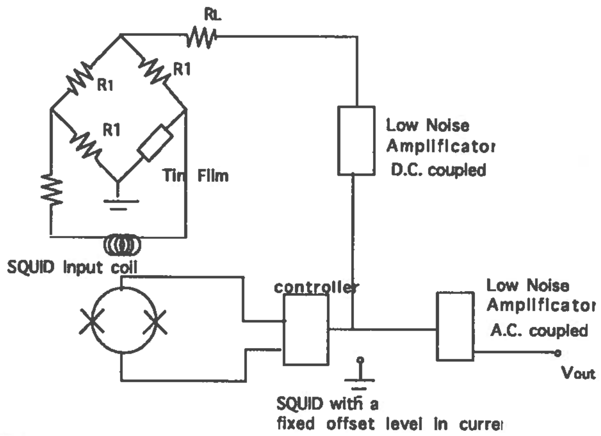

Figure 4: Scheme of the bias circuit of the transition edge with feedback.

offset level in the SQUID output, current biases the superconducting thin film. The resistance bridge is in equilibrium when the temperature of the film is the critical temperature of Tin. If the temperature of the thermometer increases, the bridge goes out of equilibrium and the SQUID output automatically adjust in order to set the previous conditions changing the joule heating of the film. The thermometer is self biasing in such a way that it is possible to change and optimize the parameters and the gain of the feedback system.

The feedback system has been successfully tested even though the Tin film was deteriorated. In fact, because of an exposure to air after a helium transfer, the resistance of the Silver paste connection had become higher so that the difference between the resistance of the normal and superconducting film was very small. Without the feedback system it was impossible to measure the pulse due to the alpha particle because of the thermal fluctuation of the helium bath. Using the SQUID output in feedback we succeeded in measuring the signal under these conditions.

4 Conclusions

A detector working at a temperature of about 3.9 K with SQUID readout electronics was successfully tested with an alpha source. The observed change in the film characteristics after long exposure in air can be avoided for example with a protective layer of Silicon oxide. Furthermore if the transition edge thermometer is built as a proximity effect bilayer [6], a wide choice of material is available and it is possible to trimmer the critical transition temperature in order to have lower operating temperature and hence better energy resolutions.

The first attempt to use the SQUID also in a feedback system in order to stabilize the working temperature shows positive results and it will be further improved in the future.

References

[1] S.H.Moseley et al. ,*Jour. Appl. Phys., 56(5), 1984, p.1257*

[2] J.Meier et al. , *Proc. of IVth Int. Workshop on Low Temperature Detectors for Neutrinos and Dark Matter, Oxford U.K., 1991, N.E.Booth and G.L.Salmon. (Eds.), Editions Frontieres, Gif-sur-Yvette, (1992) p.173*

[3] J.Meier et al. , *Jour. of Low Temperat.Physics, Vol. 93, Nos. 3/4, 1993, p.231.*

[4] A.v.Kielin et al. , *Proc. of IVth Int. Workshop on low Temperature Detectors for Neutrinos and Dark Matter, Oxford UK 1991, N.E.Booth and G.L.Salmon. (Eds.), Editions Frontieres, Gif-sur-Yvette, (1992) p.377*

[5] Mc Cammon et al. , *Nucl. Instr. and Meth. in Phys. Res., A326, 1993, p.157*

[6] U.Nagel et al. , *Jour. of Low Temperat. Physics, Vol. 93, Nos. 3/4, 1993, p.543.*

[7] K.D.Irwin et al. *Appl. Phys. Lett. Vol. 66 No. 15, 1995, p.1998*