Multiplex readout of high energy resolution γ-ray calorimeters.

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Abstract

We succeeded in frequency domain multiplex readout of two γ-ray microcalorimeters with 60eV energy resolutions at 60keV, the same as we obtained with conventional DC biases and readout individually .

Key words: Microcalorimeter; transition-edge sensor; multiplex readout; frequency domain

1. Introduction

Cryogenic microcalorimeters are promising detectors to achieve high energy resolutions. Large format microcalorimeter arrays can realize spectrometers with imaging ability or higher count-rate in various wavelength. Multiplex readout of microcalorimeters is essential for microcalorimeter arrays. Two ways are proposed for microcalorimeter readout. First way is to multiplex detector signals in time domain[1]. Second way is to multiplex signals in frequency domain[2][3].

In this paper, we describe development of frequency domain multiplex readout of γ-ray TES(Transition-Edge Sensor) microcalorimeters in our group.

2. Theory

Microcalorimeters are biased by DC voltage or current and by the Joule heating, their temperatures are kept slightly (10∼20%) higher than bath temperature. And we can measure the energy of small heat input as changes in device resistance. For example, we consider a device is biased by constant voltage V_0 (TES microcalorimeters) and has resistance R_0 in steady state. When the device has heat input, we can describe the change of current through device in time domain as:

$$I(t) = I_0\{1 - \Delta r(t)\}, \tag{1}$$

where $I_0 \equiv V_0/R_0$ is current through device at steady state and $\Delta r(t) \equiv \Delta R/R_0$ is normalized resistance change caused by heat input. In frequency domain, (1) is:

$$I(\omega) = I_0\{2\pi\delta(\omega) - \Delta r(\omega)\}, \tag{2}$$

where $\delta(\omega)$ is Dirac's delta function.

If we bias the device by sinusoidal wave $\sqrt{2}V_0\cos(\omega_M t)$ (modulation frequency ω_M is much faster than device time constant), current through device becomes:

$$\begin{aligned} I(\omega) =& \sqrt{2}\pi I_0\{\delta(\omega_M) + \delta(-\omega_M)\} \\ &- \frac{\sqrt{2}}{2} I_0\{\Delta r(\omega_M + \omega) + \Delta r(-\omega_M + \omega)\}. \end{aligned} \tag{3}$$

This means, we can shift the frequency of device signal by $\pm\omega_M$. By choosing bias modulation frequencies properly, we can readout signals from multiple microcalorimeters without confusion.

In the same manner, noise originates in the device thermal property(phonon noise) is shifted in frequency domain. And we can remove noises which do not shift in frequency domain(Johnson noise of device, bias circuit) applying LC filter circuit before adding signals from devices. Thus, we can add signals from multiple microcalorimeters without loosing S/N ratios(i.e. without degrading energy resolutions).

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3. Experiment

We used TES microcalorimeters which consist of a superconducting Sn absorber (1mm×1mm× 250μm) glued to a Mo/Cu TES thermometer (500μm × 500μm × 0.2nm). The critical temperature of the devices is near 120 mK. Further details of the device can be found in [4] and [5] And we used an array SQUID to readout device signals.

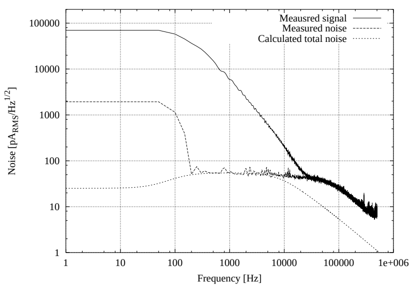

Fig. 1. Signal and noise power spectra of γ-ray TES calorimeter under DC bias. Lines represent measured signal, noise, and calculated noise spectrum. Measured spectra has large error at lower frequencies due to small DC offset.

Fig. 1 shows the measured signal, noise and calculated noise power spectrum density of these microcalorimeters with DC bias measurements. From this plot, we can see that the signal time constant of the device is about 200Hz and signal to noise ratio falls to unity around 20kHz. With DC bias operation, we obtained energy resolution $\Delta E_{FWHM} = 60$ eV with 59.54keV peak of ^{241}Am.

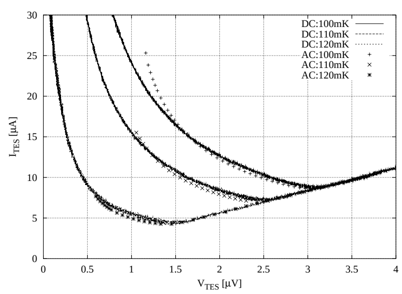

Fig. 2. I-V properties of device under DC(lines) and AC(dots) bias at bath temperatures = 100, 110, and 120mK

Fig. 2 shows I-V properties of our device under DC and AC bias. To plot this, we include the effect of the inductance (10 nH) of the bias shunt resistor which provides twice as much impedance as its resistance (5mΩ) at the bias frequency of this measurement($\sim$180kHz). We observed a discrepancy between DC and AC measurement at lower device resistance region at 100mK bath temperature measurements. The reason of this is not clear, but this might be caused by nonideal device bias voltage caused by inductance in bias circuit.

Other than this discrepancy, DC and AC I-V curves agree well. This means, device properties are not affected by AC bias current.

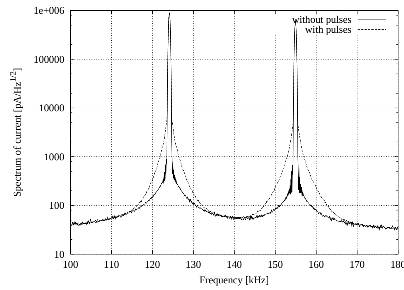

Fig. 3. Output spectrum of two channel multiplex microcalorimeters with(broken line) and without(solid line) γ-ray pulses.

We used a summing loop made by U.C.Berkeley[3] to sum the signals from two γ-ray devices in multiplex experiment. In this experiment, we biased these two devices by two sinusoidal waves of modulation frequencies 124kHz and 154kHz respectively. We also used LC bandpass filters connected directly to the device to eliminate the offband Johnson noises.

Fig. 3 shows the output power spectrum of two devices with(broken line) or without(solid line) γ-ray pulses. From this plot, it can be seen that signals from two sensors are well isolated in the frequency domain so that cross-talk is eliminated . And after demodulating these signals, energy resolutions of both devices are just the same as when operated individually under DC bias.

4. Conclusions

We demonstrated that frequency domain multiplex is a promising way to readout multiple microcalorimeters.

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