SPECTRAL BROADENING BY QUASIPARTICLES PILE-UP IN X-RAY MICROCALORIMETERS WITH SUPERCONDUCTING ABSORBERS

Marco Barbera 1, Emanuele Perinati 1, Salvatore Serio 1,2, Eric Silver 3

1 - INAF - Osservatorio Astronomico di Palermo G.S. Vaiana, Palermo, Italy
2 - Dipartimento di Scienze Fisiche ed Astronomiche, Università di Palermo, Italy
3 - Smithsonian Astrophysical Observatory, Cambridge, MA, USA

ABSTRACT

Long-living quasiparticles can pile-up in a superconducting absorber of an X-ray microcalorimeter when photons are detected at high count rates. This excess of quasiparticles can give a non negligible contribution to the total heat capacity of the absorber. In this paper we investigated the time evolution of this additional heat capacity, and evaluated the resulting spectral broadening as a function of the photon absorption rate, the line heat capacity of the absorber and the quasiparticle recombination lifetime in the absorber.

Scientific Rationale

In an X-ray microcalorimeter with superconducting absorber, a significant fraction of the energy deposited by a photon can remain undetected on the scale of the thermal pulse of the resistive sensor. When photons are detected in sequence, each photon will find in the absorber a certain number of quasiparticles left by the previous absorbed photons. These excess quasiparticles in the absorber contribute a quantity $C_{qp}$ to the heat capacity of the detector. The signal pulse produced by each photon depends on the total heat capacity of the detector at the time of the absorption and therefore on the number of excess quasiparticles present in the absorber. The presence of excess quasiparticles in the absorber is a direct consequence of the finite quasiparticle lifetime due to the increased heat capacity, and also a spatial broadening given the random nature of the arrival times of the photons.

In order to evaluate the effect of quasiparticles pile-up on the pulse height spectrum we have generated random sequences of monoenergetic \(5.9\) keV photons at given rates, and have computed for each photon the signal pulse constituting the number of quasiparticles left by the previous photons. We have assumed that each photon adds \(N_{qp}\) quasiparticles to the absorber while in between photons arrives the number of quasiparticles follows the decay law derived from our model and shown in Figure 2.

Results

Figures 3 and 6 show the pulse height spectra of monoenergetic 5.9 keV photons at various rates (1-1000 cts/s) for the two cases with the quasiparticle recombination lifetime 0.4 and 0.04 \(\mu\)sec respectively. Notice that the peak broadening shown in these figures takes into account only the pile-up effect while any other broadening, including the thermal broadening of the detector energy response due to the link with the thermal bath, is neglected.

Figure 2. Time evolution of the number of quasiparticles in the absorber for different values of the quasiparticle recombination lifetime: \(\tau_{qp}=400\mu\)sec (pure Sn) \(\tau_{qp}=100\mu\)sec (pure Sn) \(\tau_{qp}=20\mu\)sec (pure Sn)

Numerical Simulations

When photons are detected in sequence, each photon will find in the absorber a certain number of quasiparticles left by the previous absorbed photons. These excess quasiparticles in the absorber contribute a quantity $C_{qp}$ to the heat capacity of the detector. The signal pulse produced by each photon depends on the total heat capacity of the detector at the time of the absorption and therefore on the number of excess quasiparticles present in the absorber. The presence of excess quasiparticles in the absorber is a direct consequence of the finite quasiparticle lifetime due to the increased heat capacity.

SUMMARY AND OUTLOOK

We have identified, with numerical simulations, a possible effect of spectral broadening in a microcalorimeter with superconducting absorber, originating from the microscopic processes of energy thermalization inside the superconducting absorber.

In an X-ray microcalorimeter with superconducting absorber, a significant fraction of the energy deposited by a photon can remain trapped in quasiparticles for a time longer than the thermal pulse of the resistive sensor. If the rate of arrival of the photons is high with respect to the relaxation rates of the quasiparticles system in the superconducting absorber, quasiparticles pile-up can occur with a non negligible contribution to the total heat capacity of the detector, and thus on the measured pulse height spectrum of the superconducting microcalorimeter. If the rate of arrival of the photons is small, the quasiparticles recombination lifetime in the absorber is also small, and the thermal pulse of the resistive sensor can already detect the thermalized quasiparticles.

We plan to perform dedicated experimental tests on new and optimized X-ray microcalorimeters with TIn absorbers to try to achieve a better estimate of the quasiparticle recombination lifetime in this specific absorber material, and to confirm the predictions of our simulations.

This work has also stimulated a search for non superconducting absorber materials that might be more efficient and faster in thermalizing the photon energy than minimizing the CP-pile-up effect.

References


Figure 1. Schematic of the geometry of the model detector.

Figure 2. Time evolution of the number of quasiparticles in the absorber for different values of the quasiparticle recombination lifetime: \(\tau_{qp}=400\mu\)sec (pure Sn) \(\tau_{qp}=100\mu\)sec (pure Sn) \(\tau_{qp}=20\mu\)sec (pure Sn).

Figure 3. Pulse height spectra of 5.9 keV photons at various rates (1-1000 cts/s) for the two cases with the quasiparticle recombination lifetime 0.4 and 0.04 \(\mu\)sec respectively.

Figure 4. Numerical pulse height spectra of 5.9 keV photons in various cases due to the simulation with quasiparticle recombination lifetime 0.5 \(\mu\)sec (m × 7, m × 350 µm², \(T \sim 0.06\) K, number of quasiparticles 8640) and 0.05 \(\mu\)sec (m × 7, m × 350 µm², \(T \sim 0.06\) K, number of quasiparticles 8640).

Figure 5. FWHM of the 5.9 keV peak as a function of the quasiparticle recombination lifetime for the two cases with the quasiparticle recombination lifetime 0.4 and 0.04 \(\mu\)sec respectively. Notice that the peak broadening shown in these figures takes into account only the pile-up effect while any other broadening, including the thermal broadening of the detector energy response due to the link with the thermal bath, is neglected.

Figure 6. FWHM of the 5.9 keV peak as a function of the rate for the simulation with quasiparticle recombination lifetime 0.05 \(\mu\)sec (m × 1000 µm², \(T \sim 0.06\) K, number of quasiparticles 8640).