# Microcalorimeters for application in heavy ion and nuclear physics experiments

S. Kraft-Bermuth[1]*
[1]Institute of Atomic and Molecular Physics, Justus-Liebig-University, 35392 Giessen, Germany
. * email: saskia.kraft-bermuth@iamp.physik.uni-giessen.de

## Introduction

The precise determination of the energy of a particle is an important aspect in many experiments, independent of the experimental aim. To improve the precision, a novel detector concept, namely microcalorimeters, has been introduced and is now applied in many fields of experimental physics [1]. The detection principle is displayed in Fig.1: Whereas conventional energy detectors use the conversion of energy into charge or light, microcalorimeters use the creation of phonons, i.e. the detection of a temperature rise after the incoming particle has deposited its energy in an absorber of heat capacity C. The temperature rise $\Delta T$ is then detected with a temperature-dependent resistance R(T). To keep the heat capacity of the absorber small to obtain a large temperature signal, such detectors are operated at very low temperatures. A large temperature dependence dR/dT for high sensitivity is achieved with compensated-doped semiconductors or superconductors stabilized at the transition temperature (Transition Edge Sensors, TES). As the detection concept is relatively independent of the detector material, it allows a perfect adaption of the detector setup to different experimental needs.

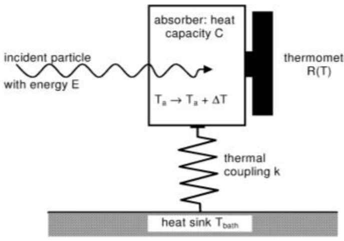

**Fig. 1** Detection principle of a microcalorimeter.

## X-ray spectroscopy

Considering experiments in nuclear physics, one application is the investigation of x-ray photons emitted by highly-charged heavy ions [2,3,4], which is one method to access fundamental interactions like quantum electrodynamics [5]. Due to the large binding energies, typical x-ray energies are of the order of 50–100 keV. Therefore, superconducting high-Z materials are used as absorbers to combine low heat capacity with high quantum efficiency. As the heat capacity also limits the active area of one single microcalorimeter to about 1 mm², arrays are mandatory to cover large solid angles.

Our group uses arrays of silicon thermistors, designed and produced by Stahle et al. [6], and adapted to high x-ray energies by Bleile et al. [7]: Sn or Pb absorbers are glued onto the thermistors with an epoxy varnish (Fig. 2, left). For x-ray energies of 50–100 keV, a relative energy resolution of $\Delta E/E \leq 10^{-3}$ has been obtained, which means an improvement of one order of magnitude as compared to conventional x-ray detectors.

These microcalorimeters have been applied in two experiments at the GSI Helmholtz Center for Heavy Ion Research in Germany to determine the 1s Lamb Shift in hydrogen-like lead [8] and gold [9] with excellent results. In the future, the application of microcalorimeters will considerably improve the precision of such experiments. The precise determination of the 1s Lamb Shift will then allow the determination of nuclear charge radii, which will be of particular interest for rare or unstable nuclides.

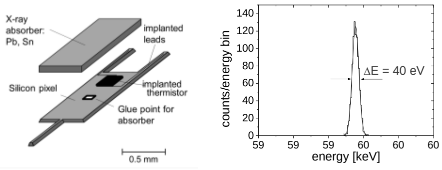

**Fig. 2** Microcalorimeter for x-rays (left) and example spectrum of a $^{241}$Am source (right).

## Spectroscopy of heavy ions

Another very important application is the energy-sensitive detection of heavy nuclides which are produced in nuclear reactions as fusion of fission products. Up to now, the determination of the energy of these reaction products is suffering from the low energy resolution, the degradation as well as the pulse height defect in charge-sensitive devices.

A lot of experiments have shown that microcalorimeters are not subject to any of the above-mentioned limitations [3,10,11]: As in principle almost the whole deposited energy is finally converted into heat after the decay of the initial electronic excitations, a more complete energy detection is achieved, which considerably improves the energy resolution as well as the energy linearity. Furthermore, microcalorimeters do not necessarily need entrance foils or dead layers. This fact considerably reduces the detection threshold and the energy straggling, thus providing improved detection efficiency and energy resolution for low-energetic heavy ions.

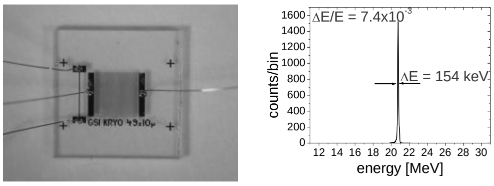

**Fig. 3** Microcalorimeter for heavy ions (left) and example spectrum of $^{235}$U at low ion energy (right).

To obtain a large sensitivity for low ion energies and avoid entrance foils, our microcalorimeters for heavy ion detection consist of sapphire absorbers of 3x3x0.33 mm³ and a thin superconducting aluminum film as TES [10,11,12] (see Fig. 3). These detectors have been tested for a broad range of nuclide masses and energies. An energy resolution of $\Delta E/E \leq 10^{-3}$ has been reached in all experiments. Neither a degradation of detector performance over time nor any pulse height defect has been observed.

Accordingly, several applications of such microcalorimeters have been demonstrated: In accelerator mass spectrometry of uranium isotopes, the sensitivity of determining the $^{236}$U/$^{238}$U isotope ratio has been improved by one order of magnitude [13]. While investigating the stopping power of heavy ions in solids, experimental data have been improved in precision considerably, and new experimental data for the energy range below 0.3 MeV/u have been obtained [14]. Mass identification of heavy nuclides by means of a combined energy/time-of-flight measurement has been demonstrated to reach a sensitivity of 1 u [11,12]. This method will allow the identification of super-heavy elements or other nuclear reaction products in the next-generation experiments.

This contribution introduces the detection principle and gives an overview on its application in heavy ion physics.

## References

[1] Ch. Enss (ed.), Topics in Applied Physics **99** (2005)

[2] P. Egelhof et al., Nucl. Instrum. Meth. A **370**, 263 (1996)

[3] P. Egelhof and S. Kraft-Bermuth, Topics in Applied Physics **99**, 471 (2005)

[4] S. Kraft-Bermuth et al., Phys. Scr. **T156**, 014022 (2013)

[5] Th. Stöhlker et al., Lecture Notes in Physics **745**, 157 (2008)

[6] C. Stahle et al., Nucl. Instrum. Meth. A **310**, 173 (1996)

[7] A. Bleile et al., AIP Conf. Proc. **605**, 409 (2002)

[8] V. Andrianov et al., AIP Conf. Proc. **1185**, 99 (2009)

[9] S. Kraft-Bermuth et al., J. Low Temp. Phys. **176**, 1002 (2014)

[10] P. Egelhof, Adv. Solid State Phys. **39**, 61 (1999)

[11] S. Kraft et al., AIP Conf. Proc. **605**, 405 (2002)

[12] A. Echler et al., J. Low Temp. Phys. **167**, 949 (2012)

[13] S. Kraft-Bermuth et al., Rev. Sc. Inst. **80**, 103304 (2009)

[14] A. Echler et al., J. Low Temp. Phys. **176**, 1033 (2014)