Calorimetric Low-temperature Detectors for Precise Lamb Shift Measurements on Hydrogen-like Heavy Ions

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The precise determination of the Lamb shift in heavy hydrogen-like ions provides a sensitive test of quantum electrodynamics in very strong Coulomb fields. For the investigation of the 1s Lamb shift in $^{208}Pb^{81+}$ or $^{238}U^{91+}$ at the ESR a high resolving x-ray detector for hard x-rays ($E \leq 100$ keV) is needed to measure the Lyman-α transitions with sufficient accuracy. For this purpose a calorimetric low-temperature x-ray detector is presently developed. Such a detector measures the temperature rise of an absorber due to the energy deposited by the incident x-ray. The potential advantage of this detection concept over conventional semiconductor detectors is due to a more complete detection of the deposited energy and a better counting statistics of the detected quanta (phonons). Thus a considerable improvement of the energy resolution in combination with a still reasonable detector efficiency may be obtained.

For reaching a high sensitivity the calorimetric detectors are operated at temperatures below 100 mK, where - due to the Debye law - the heat capacity becomes small. Therefore the detectors are housed in a specially designed $^3He/^4He$ dilution refrigerator. It consists of a standard Oxford Instruments cryostat and a side arm which allows to position the detector samples close to the interaction region of the ESR gas jet target. The cryostat reaches a base temperature of 11.5 mK and provides a cooling power of 400 µW at 100 mK.

The detector modules consist of silicon thermistors, which are used as thermometers and of x-ray absorbers glued on the top of the thermistors by means of an epoxy varnish. A schematic view of a detector pixel is displayed in fig.1. The pixel is made from a wafer of silicon containing an implanted thermistor, the implanted leads and the support beam. Thermistor arrays consisting of 36 pixels each are provided from the collaborating groups from Madison and Goddard. The final detector concept foresees three calorimeter arrays, the active area of 1 pixel being about 1 mm^2. In 1998 a fraction of 1/4 of one array (9 pixels) were supplied with absorbers, mounted in the cryostat and connected to the readout electronics. In order to suppress low-frequency microphonics the first amplifier stage was positioned very close to the detectors inside the side arm of the cryostat. It consists of cooled FET's, operated at a temperature of about 125 K, which have the purpose to reduce the relatively high impedance of the detectors. It turned out that special care had to be taken to select low-noise FET's and

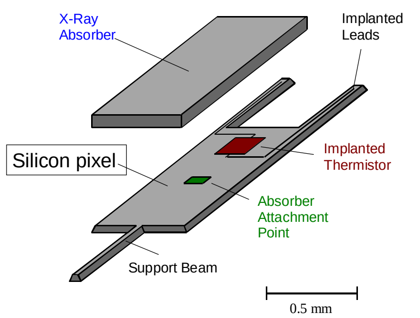

Fig. 1: Schematic view of one pixel of the calorimetric low-temperature detector.

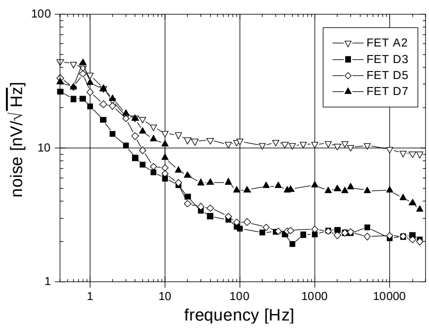

Fig. 2: Noise spectra measured at T = 125 K for different samples of two modifications (A,D) of FET's of the type INTERFET NJ14AL.

to determine their optimum operating temperature. Therefore many samples of various modifications of the type INTERFET NJ14AL were systematically tested using a specially designed test setup. As illustrated in fig. 2 pronounced differences in the noise spectra were obtained. Finally a reasonable number of FET's with sufficiently small noise at low frequencies could be selected.

After installation in the cryostat first detector tests with 59.6 keV photons, provided by a ^{241}Am-source, were performed using Sn and Re as absorber materials, which both are expected to fulfill the conditions of high absorption efficiency, low heat capacity and rapid and complete thermalization. It was found that the new cryostat and the concept for setting up the detectors are well suited for the demands of the planned experiment. All sources of noise, microphonics and external HF pickup could be kept at a sufficiently low level to obtain excellent energy resolution. The energy spectrum observed for a detector with a 0.3 mm^2 × 66 µm Sn absorber is displayed in fig. 3. For the photopeak at 59.6 keV an energy resolution of $\Delta E_{FWHM} = 121$ eV is obtained, whereas for the K_α escape lines around 34 keV, which may also be used for an accurate energy measurement of higher energy x-rays, a resolution of $\Delta E_{FWHM} = 72$ eV was measured. These results may be compared to the theoretical limit of the energy resolution for a conventional semiconductor detector which is for 60 keV photons about $\Delta E \approx 380$ eV.

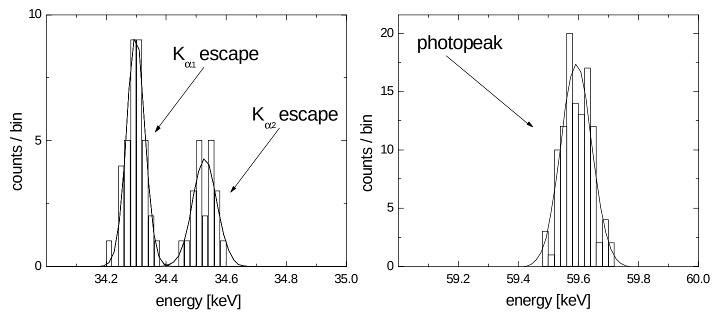

Fig. 3: Energy spectrum measured with a calorimetric detector at an operating temperature of 60 mK with a 0.3 mm^2 × 66 µm Sn absorber for 59.6 keV photons. An energy resolution of $\Delta E_{FWHM} = 121$ eV for the photopeak (right side) and of $\Delta E_{FWHM} = 72$ eV for the K_α escape lines (left side) is obtained.