



Low-temperature relative reflectivity measurements of reflective and scintillating foils used in rare event searches



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ABSTRACT

In this work we investigate the reflectivity of highly reflective multilayer polymer foils used in the CRESST experiment. The CRESST experiment searches directly for dark matter via operating scintillating CaWO_4 crystals as targets for elastic dark matter–nucleon scattering. In order to suppress background events, the experiment employs the so-called phonon–light technique which is based on the simultaneous measurement of the heat signal in the main CaWO_4 target crystal and of the emitted scintillation light with a separate cryogenic light detector. Both detectors are surrounded by a highly reflective and scintillating multilayer polymer foil to increase the light collection efficiency and to veto surface backgrounds. While this study is motivated by the CRESST experiment, the results are also relevant for other rare event searches using scintillating cryogenic bolometers in the field of the search of dark matter and neutrinoless double beta decay ($0\nu\beta\beta$). In this work a dedicated experiment has been set up to determine the relative reflectivity at 300 K and 20 K of three multilayer foils (“VM2000”, “VM2002”, “Vikuiti”) produced by the company 3M. The intensity of a light beam reflected off the foil is measured with a CCD camera. The ratio of the intensities at 300 K and 20 K corresponds to the relative reflectivity change. The measurements performed in this work show no variation of the reflectivity with temperature at a level of $\sim 1\%$.

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1. Introduction

The direct dark matter search experiment CRESST¹ aims at the detection of dark matter particles elastically scattering off target nuclei in scintillating CaWO_4 single crystals which are operated as cryogenic detectors at mK temperatures [1–4].

For active background discrimination CRESST is using the so-called phonon–light technique based on the simultaneous measurement of the heat signal in a cryogenic phonon detector (CaWO_4 crystal [5,6] equipped with a thermometer) and a light signal with a separate cryogenic light detector (Silicon-on-Sapphire plate equipped with thermometer) [4]. A particle interaction in the crystal leads to an energy deposition. This energy is primarily transformed into phonons (heat) and a few percent into photons, depending on the type of particle interaction [1]. Both detectors are enclosed in a reflective and scintillating housing which consists of a highly reflecting multilayer polymer foil to increase the light collection and veto surface backgrounds.

In the CRESST experiment, only a fraction of the emitted scintillation light is detected due to a limited transparency of the target crystal as well as the size and absorptivity of the light detector. Furthermore, a decreased light collection could be explained due to the possible limitations of the reflecting and scintillating foil since the reflectivity is only measured at room temperature [7–10]. The foils used in CRESST are multilayer polymer mirrors and have a high reflectivity of $> 98\%$ in the wavelength range from 400 to 800 nm at 300 K [11]. Due to the layered structure of the foils under investigation [12], a potential contraction of the layers could lead to a change in the interference between the different layers and therefore, a decreased reflectivity at low temperatures cannot be excluded. To investigate the temperature dependence, relative measurements of the reflectivity at temperatures of $T = 300$ K and $T = 20$ K have been performed. The temperature of 20 K represents the lowest temperature accessible with the cryocooler used. The 20 K missing to the mK base temperature of [1–4] represent only $\sim 8\%$ of the range from room- to the base temperature and a potential

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¹ Cryogenic rare event search with superconducting thermometers.

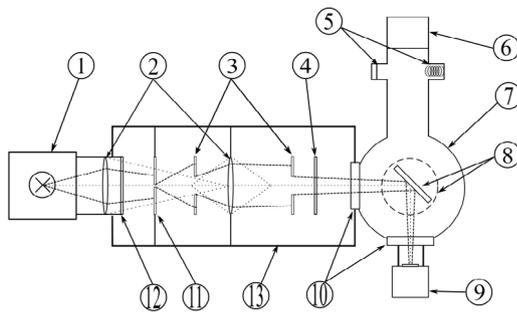


Fig. 1. Schematic drawing of the setup. 1: Halogen lamp, 2: Lenses, 3: Apertures, 4: Filter, 5: Pressure sensors, 6: Turbo molecular pumping system, 7: Vacuum chamber, 8: Foils on cold finger, 9: Detector (CCD camera), 10: Quartz glass windows, 11: Pinhole, 12: Diffusion disc, 13: Dark box.

change of the reflectivity should appear up to the temperature of 20 K. For this purpose, a dedicated setup was built in the framework of this study to investigate three foils (“Vikuiti”, “VM2000” and “VM2002” (3 M)).

2. Experimental setup

The concept of the experiments is based on a comparison of the measured intensities of a light beam which is reflected off a foil sample at 300 K and at 20 K. From the ratio of these intensities the relative change in reflectivity can be derived. The advantage of this setup is that it is not sensitive to changes of the reflection due to thermal contraction of the holder and the foil and therefore, is not sensitive to any image distortion up to the size of the 2D sensor used. By integrating the signal over the whole area of the sensor it is possible to compare the results of the measurements at 300 K and 20 K.

A schematic drawing of the setup is presented in Fig. 1. The light source used in the experiment is a 100 W halogen lamp (1) manufactured by LOT Quantum Design [13] which is cooled by convection. With halogen lamps nearly constant light intensities can be achieved over a long time whereas the intensity of, e.g., LEDs can vary within a few percent.

With a collimating lens the source is imaged into a second lens (2). A diffusion disc (12) is mounted to homogenize the light. After the diffusion disc a pinhole (11) is mounted as well as two apertures (3) which prevent stray light from reaching the sample and reduce the diameter of the beam. With the second aperture the cross-section of the resulting beam is further reduced to a diameter of approximately 10 mm. This beam passes an interchangeable filter (14) and is then reflected off the foil sample (8) under an angle of 90° to a CCD detector (9). The diameter of the beam is chosen in such a way that the full spot size is projected onto the CCD detector. This setup essentially projects an image of the pinhole onto the detector. The tungsten halogen lamp acts together with the collimating lens and the diffusion disc as a light source for the pinhole.

The detector (9) used is a monochrome CCD camera (ATIK 3831+ [14]) with a spatial resolution of (3362 \times 2504) pixel of the 8.4 Megapixel Kodak KAF 8300 sensor. Each pixel has a size of (5.4 \times 5.4) μm^2 resulting in a sensor size of (17.6 \times 13.5) mm^2 . The camera is using a 16 bit Analog to Digital Converter (ADC). To reduce thermal noise the sensor can be cooled to a temperature which is $\sim \Delta T = -40^\circ$ lower than the ambient air temperature by means of a Peltier cooler.

A mechanical shutter is fitted to the camera. This, however, requires a minimum advisable exposure time due to the time in which the shutter is opening and closing. For the ATIK this minimum exposure time is 200 ms. The camera is linear in pixel value as a function of the exposure time over its full range. Therefore, it is necessary to limit the exposure time to guarantee pixel values below the maximum of around 65 000 channels.

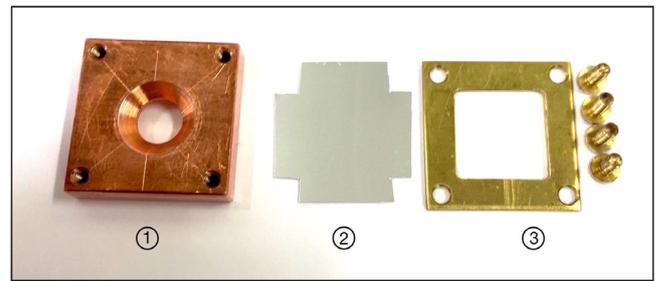


Fig. 2. Holder for the foil samples. A small amount of vacuum grease is put onto the upper surface of a $[2 \times 2]$ cm^2 copper plate (1) as well as onto the brass frame (3) to allow movements of the foil. The foil (2) is fixed in between these two parts which are screwed together.

All optical components are enclosed in a dark box (13). To reduce reflections from scattered light, all walls of this box are coated with an anti-reflective paint (Nextel Velvet-Coating 811-21, produced by 3 M).

The foil of interest is mounted in a vacuum chamber (7) on a cold finger of a cryocooler (“Cryodrive 3.0” manufactured by Edwards, UK). The vacuum chamber is needed in order to avoid conductive heat transfer between the wall of the chamber and the cold finger of the cryocooler since this would lead to a high thermal load and therefore, a increased base temperature. Furthermore, it is needed to prevent the condensation of water on the sample. Due to expansion of helium gas in the coldhead it is possible to cool the coldhead down to ~ 20 K. The chamber is evacuated to a residual pressure $\lesssim 10^{-6}$ mbar by means of a turbomolecular pump (6). This avoids water condensing on the foil and reduces convective heat transfer with the chamber walls.

The temperature of the cold finger is measured using a PT 100 resistive thermometer. The resistance is read out via a four-point measurement (AVS 47A resistance bridge by Picowatt, Finland). Because PT100 thermometers are not calibrated for temperatures below 100 K, the resistance of the PT 100 was calibrated against a known reference resistance.² During the measurements a temperature of less than 20 K was achieved.

In Fig. 2 the unmounted holder for the foil is shown. A small amount of vacuum grease is put onto a copper plate (1). This allows for a movement of the foil during the cool-down process due to the different coefficients of thermal expansion of copper and the dielectric foil. The foil sample (2) is fixed in between the copper plate and a brass frame (3) which is also prepared with vacuum grease. Four screws fix all the parts.

3. Data analysis and results

3.1. Measurements and data analysis

Two types of measurements were performed:

(1) To study the stability of the halogen lamp, a series of single images with a frequency of 12 images/h was recorded. In order to suppress the influence of disturbing stray light and electronic noise a dark image (i.e., an image without light) is subtracted pixel wise from all subsequent images. The mean value over all pixels is then determined to monitor changes in intensity as a function of time. This method has been used with a fixed exposure time of 7 s to check the stability of the measurement over a longer period.

(2) The relative reflectivity measurements were performed with so-called multi-images where a series of images is combined to one picture. The mean intensities over all pixels at 300 K and at 20 K are compared. The exposure time is set to a fixed value between 7 s and 15 s. An

² The temperature-calibrated reference resistor was obtained from Walther-Meissner-Institut für Low Temperature Research, Garching, Germany.

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