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Glued $CaWO_4$ detectors for the CRESST-II experiment

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The Cryogenic Rare Event Search with Superconducting Thermometers Phase II (CRESST-II) at the L.N.G.S in Italy is searching for Dark Matter using low-temperature calorimeters. These detectors allow to discriminate different particles by simultaneous measurement of phonons and scintillation light. The sensors used consist of superconducting tungsten thin-film thermometers, which measure the thermal effect of the phonons created in an attached absorber crystal. It has been observed that the scintillation of the $CaWO_4$ absorber degrades during the process of depositing the tungsten film. In order to prevent this, a new technique for producing the detectors was investigated. This technique might also be valuable by expanding the range of scintillator materials suitable for producing a Dark Matter detector.

1. Dark Matter search with CRESST-II

1.1. Introduction

Since the observations of Zwicky in the 1930's the nature of Dark Matter remains unknown. Experiments like WMAP [1] could only deliver more evidence on its existence but could not clarify its nature. The weakly interacting massive particle (WIMP) is a well-motivated candidate for Dark Matter [2].

1.2. CRESST-II

The CRESST-II experiment aims for direct detection of WIMPs scattering off nuclei in a scintillating absorber crystal [3]. The target material is chosen in order to optimize the cross section for spin-independent coherent WIMP-nucleus scattering, whose cross section scales quadratically with the atomic mass *A*.

The energy transferred by a scattering is typically only in the order of 10 keV. This, together with an extremely low interaction rate of less than 10 events per kilogram of absorber material and year of exposure requires very sensitive detectors, which allow the rejection of background events [2].

In order to reject the background radiation, CRESST-II uses scintillating crystals as target material. A schematic view of the detector can be seen in Fig. 1. The energy deposited in a scintillating absorber crystal by a particle interaction excites both phonons and scintillation light. The relative amount of light depends on the nature of the detected particle. As WIMPS, in comparison to highly ionizing particles, cause a relatively low light output, the optimization of detection of the scintillation light is of utmost importance.

The scintillation light is absorbed by a silicon coated sapphire crystal, exciting phonons in the crystal lattice. Each of the two crystals of a detector module, $CaWO_4$ and sapphire, is connected to a superconducting phase transition thermometer for measurement of the phonon signals.

Such a thermometer consists of a thin-film of superconducting material (tungsten) which is deposited on the crystal. Phonons are absorbed in the film and increase the temperature of its electron system. The film is thermally stabilized in its phase transition from the superconducting to normal conducting state, therefore its resistance is extremely sensitive to variations in temperature. Phonons that are absorbed in the film increase the temperature of its

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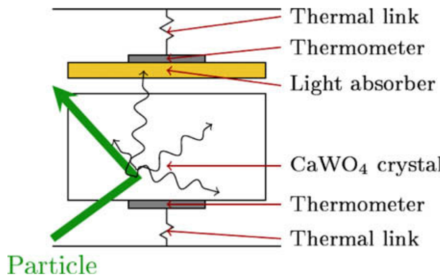

Fig. 1. Schematic view of the detector.

electron system and thus its resistance. The change in resistance is read out by a sensitive SQUID circuit [3–5].

The upcoming EURECA experiment is going to use particle detection and discrimination techniques developed and studied in the CRESST-II experiment [6].

2. Glued detectors

The idea behind the use of glued detectors is to produce the superconducting phase transition thermometers on small substrates that later on are glued onto the scintillating absorber crystals. This has several advantages:

Light yield: For the evaporation of a tungsten film, the scintillating absorber crystal is heated up. Heat, however, degrades the light output of the scintillator [7], resulting in a decreased particle discrimination capability.

New materials: Other attractive scintillator materials may suffer even more from the W-deposition and etching. Producing the thermometer on a small substrate avoids the exposition of most of the scintillator material to these treatments. In this way, the gluing technique already allowed the use of a $ZnWO_4$ scintillating absorber crystal in the current run [8].

Mass production: Producing several thermometers at once on a single substrate increases the overall speed of detector production. The substrate can be cut and the thermometers then can be glued onto several absorber crystals. For the upcoming EURECA experiment which aims at increasing the target mass, many more detector modules are needed than the 33 foreseen for CRESST-II.

2.1. Proof-of-principle experiment

For the investigation of glued detectors, a proof-of-principle experiment was performed. This experiment was not shielded from background radiation. In order to cope with the relatively high count rates, a setup smaller than the one used at Gran Sasso was chosen: Instead of a cylindrical crystal of 40 mm height and 40 mm diameter, a cuboid of $20 \times 10 \times 5\,\mathrm{mm}^3$, named C14 was used (see Fig. 2).

The experiment consisted of two parts: First, the whole cuboid $CaWO_4$ crystal carrying a superconducting phase transition thermometer was exposed to 60 keV-gamma radiation from an ^{241}Am source.

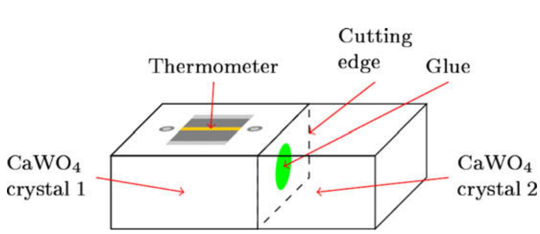

Fig. 2. Schematic view of the proof-of-principle experimental setup.

Then, the crystal was cut into two halves, one of them carrying the thermometer.These two halves were glued together with Araldite 2011®[1], a two-component epoxy resin. Signals from a 60 keV gamma source were measured, once with the radiation collimated to the half without thermometer and secondly with both halves uniformly irradiated.

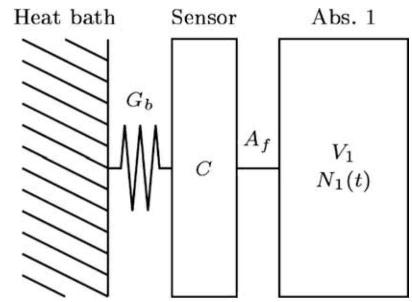

Fig. 3. Schematic view of a one-crystal-setup: V_1, N_1: volume and Phonon population in the crystal; A_f: parameter for transition of phonons between crystal and thermometer; C, G_b: heat capacity of the thermometer and coupling to the heat bath.

2.2. Theoretical model

A theoretical model [9] of the behaviour of a one-crystal-setup with a superconducting phase transition thermometer was extended in order to describe the more complex case of a glued detector.

The detection of phonons works by the following principle: Absorption of radiation in the scintillating absorber crystal creates high-frequency phonons that do not thermalize on the millisecond time scale. The phonons travel through the crystal ballistically before being collected in the thermometer. There, the phonon energy is transferred into the electron system of the superconducting phase transition thermometer, changing its electrical resistance by a measurable amount.

2.2.1. Single absorber crystal

The model makes the following assumptions: The crystal has a volume V_1 and a high-frequency phonon population $N_1(t)$. The transfer of non-thermal phonons into the superconducting phase transition thermometer is described by the transition parameter A_f. The superconducting phase transition thermometer itself has a heat capacity C and is linked with a conductance G_b to a heat bath of constant temperature (see Fig. 3). Neglecting other losses, this means that the phonon population N_1 in the absorber crystal is determined by the deposited energy E, the energy per phonon ε and the rate $\mathrm{d}N_1/\mathrm{d}t$ at which the phonons flow into the thermometer.

$$\frac{\mathrm{d}}{\mathrm{d}t}N_1(t) = -A_f\frac{N_1(t)}{V_1}. \tag{1}$$

The phonons enter the thermometer from the absorber crystal and leave through the thermal link. This raises the temperature of the thermometer by an amount of ΔT above its equilibrium temperature:

$$\frac{\mathrm{d}}{\mathrm{d}t}\Delta T(t)C = -\frac{\mathrm{d}}{\mathrm{d}t}N_1(t)\mathscr{E} - G_b\Delta T(t) \tag{2}$$

$$= A_f\frac{N_1(t)}{V_1}\mathscr{E} - G_b\Delta T(t) \tag{3}$$

[1] Araldite is a registered trademark of Huntsman Corporation or an affiliate thereof.