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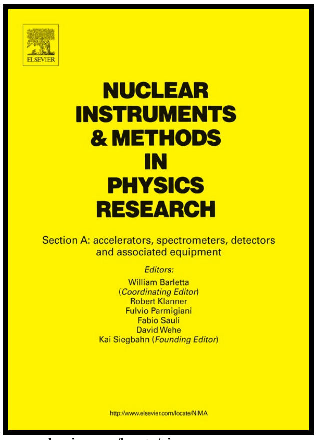

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New application of superconductors: high sensitivity cryogenic light detectors

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Abstract

In this paper we describe the current status of the CALDER project, which is developing ultra-sensitive light detectors based on superconductors for cryogenic applications. When we apply an AC current to a superconductor, the Cooper pairs oscillate and acquire kinetic inductance, that can be measured by inserting the superconductor in a LC circuit with high merit factor. Interactions in the superconductor can break the Cooper pairs, causing sizable variations in the kinetic inductance and, thus, in the response of the LC circuit. The continuous monitoring of the amplitude and frequency modulation allows to reconstruct the incident energy with excellent sensitivity. This concept is at the basis of Kinetic Inductance Detectors (KIDs), that are characterized by natural aptitude to multiplexed read-out (several sensors can be tuned to different resonant frequencies and coupled to the same line), resolution of few eV, stable behavior over a wide temperature range, and ease in fabrication. We present the results obtained by the CALDER collaboration with 2×2 cm^2 substrates sampled by 1 or 4 Aluminum KIDs. We show that the performances of the first prototypes are already competitive with those of other commonly used light detectors, and we discuss the strategies for a further improvement.

Keywords: Kinetic Inductance Detectors, light detector, background reduction, Dark Matter, Neutrinoless Double Beta Decay

1. Why new cryogenic light detectors?

Background reduction is becoming more and more important for all the experiments looking for rare events, such as dark matter interactions, neutrino-less double beta decay (0νDBD), or rare α decays. Among the several technological approaches proposed for these searches, cryogenic calorimeters (or bolometers) stand out for their excellent energy resolution (of the order of 0.1%) and for the possibility of probing different compounds; the crystals operated as bolometers can be grown starting from most of the possible 0νDBD candidates or rare-α emitters, and from several interesting targets for dark matter search.

Bolometers can be equally sensitive to α's, electrons and, if the threshold is low enough, also to nuclear recoils. This could be an advantage, as experiments designed for a specific purpose could be competitive also in other physics sectors. On the other hand, the lack of tools to identify the nature of the interacting particles prevents an efficient background suppression. A possible solution consists in equipping the bolometer with a light detector, that enables particle identification exploiting the different light emission of α's, electrons and nuclear recoils. This technique has been successfully exploited for bolometers emitting scintillation light, like ZnSe [1], $ZnMoO_4$ [2], $LiMoO_4$ [3] and many others. The scintillation crystals were coupled to light detectors made by thin Germanium disks equipped with Neutron Transmutation Doped Germanium sensors, that show a typical intrinsic energy resolution of about 80 eV RMS [4]. This sensitivity is high enough to enable an efficient particle identification with scintillation bolometers, but may be not sufficient for next generation experiments. A possible application of new light detectors with these characteristics could be the upgrade of the CUORE experiment. The TeO_2 bolometers used by this experiment do not scintillate. On the other hand, coupling a sensitive light detector to a TeO_2 would allow to measure the tiny amount of Cherenkov light emitted by electrons (about 100 eV at 0νDBD energy) and not by α's, enabling the rejection of the dominant α background [5, 6].

The CUPID interest group [7, 8], that is defining the roadmap for a 0νDBD next-generation project based on bolometers, identified the features of the desired light detector: a noise RMS resolution lower than 20 eV, high radio-purity, large active area (5×5 cm^2) and ease in fabricating/operating up to 1000 channels.

The growing interest in developing sensitive light detectors (that would be important also for other applications [1]) gave birth to several R&D activities exploiting different technologies [9, 10, 11]. None of these technological approaches is (yet) able to fulfill all the requirements for next generation projects.

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