Snowmass2021 - Letter of Interest

BULLKID: Low-threshold Kinetic Inductance Detectors for neutrino and dark matter searches

NF Topical Groups: (NF10) Neutrino detectors
(Other) *(CF1) Dark Matter: Particle Like*

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Abstract: Cryogenic sensors are used in experiments to detect low-energy nuclear recoils from dark matter or neutrino interactions. Besides the record energy thresholds, the limit of current technologies resides mainly in the scale-up capabilities. BULLKID is developing a new detector concept to reach relatively high target masses with high granularity, by exploiting the multiplexing capability of Kinetic Inductance Detectors.

Introduction. BULLKID[2] is an R&D in view of new cryogenic experiments on GeV/sub-GeV dark matter and coherent elastic neutrino-nucleus scattering (CEνNS). The ultimate goal is to build a detector with energy threshold on nuclear recoils below 100 eV and target mass above 1 kg, leveraging the sensitivity and multiplexing capability of superconducting Kinetic Inductance Detectors (KIDs)[1]. These features would enable the detection of elastic and spin-independent Dark Matter interactions in the 0.2-2 GeV mass region close to the so called "neutrino floor", and the measurement of the CEνNS cross-section with percent precision.

Current cryogenic experiments in the field (CRESST[3], NUCLEUS[4], SuperCDMS[5], MINER [6] or EDELWEISS[7;8]), are based on transition edge sensors (TES, superconductors) or neutron transmutation doped thermistors (NTD, semiconductors), both featuring excellent energy threshold (down to 20 eVnr in the case of NUCLEUS). The target mass ranges from 10 g for NUCLEUS to few kg for other experiments, but the number of readout channels and thus the granularity is limited to few tens, due the fact that the multiplexing is complicated (TES) or even impossible (NTD) to implement. Achieving at the same time high mass, low-energy threshold, and high number of readout channels would increase the sensitivity and capability of background identification in experiments.

Detector concept. The BULLKID detector is based on the phonon-mediated KIDs developed by the CALDER R&D on cryogenic light detectors[9]: particles interact in a silicon substrate and generate athermal phonons that in turn scatter trough the substrate until they are absorbed in aluminium[10] or aluminium-titanium[11] KIDs deposited on the surface.

While CALDER developed 2x2 cm^2 or 5x5 cm^2, 300 or 600 μm thick, silicon substrates as particle absorbers, the Dark Matter or neutrino target unit of BULLKID consists in a 5x5x5 mm^3 silicon dice. Several dices are obtained from a single 5 mm thick silicon "wafer" with a diameter of 3": one side of the wafer hosts the chip, with a single feedline running through all the KIDs to enable their multiplexing; the opposite side is grooved into a square grid of 5 mm pitch, with a groove depth of 4.5 mm or larger, so as to obtain almost cubic dices and leave the surface hosting the KIDs intact. Up to 100 dices, each sensed by a single KID, can be obtained from a wafer, for a total active mass of 31 g. In a future experiment, several identical diced wafers would be stacked to reach the target mass. Besides the scale-up capability, the proposed geometry is expected to be efficient in background reduction: multiple-dice events can only be induced by cosmic rays or natural radioactivity, while neutrinos or dark matter particles generate single-dice events.

Status and prospects. We successfully grooved 60 dices in a 5 mm thick wafer (see Fig. 1, right) and we are currently working on the optical polishing of the surfaces, which is necessary to ensure good phonon reflection at the dice surfaces and eventually good signal transmission to the KID. In parallel we are testing on standard 300 μm wafers different layouts of the KID array (see Fig. 1, left), to optimize the uniformity of the sensors and to reduce the electrical cross-talk. Finally we are working on the KID sensitivity: based on the experience of CALDER, we expect an energy threshold between 100 and 200 eV. To further improve it, we are currently testing alternative designs of the KIDs and studying new configurations of the superconductor, in particular the titanium-aluminum multilayers which provide better sensitivity than aluminum films. The first test of a grooved wafer sensed by the KID array is expected by the end of 2020.

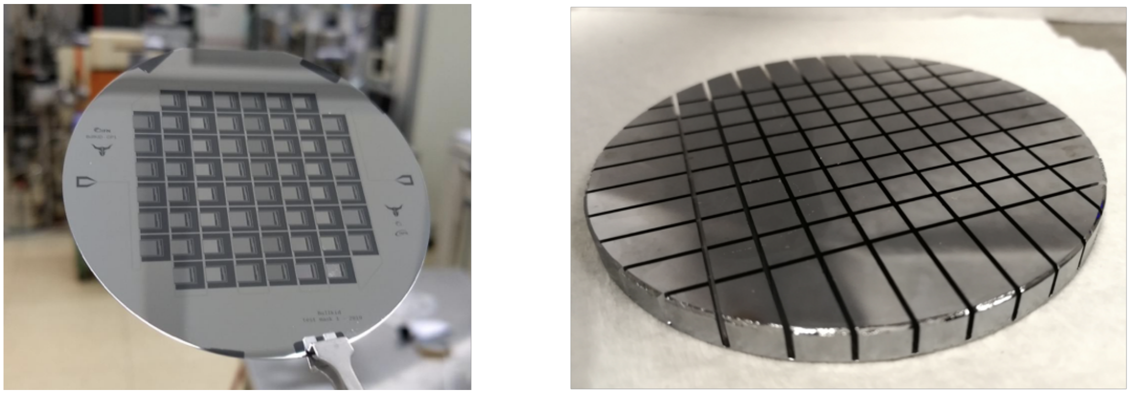

Figure 1: Array of 60 KIDs on a 300 μm test wafer (left) and grooved 5 mm thick wafer (right). The collaboration is currently working on realizing the first prototype of 5 mm wafer with the KID lithography on the side opposite to the grooves.

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