Cryogenic light detectors for the search of neutrinoless double beta decay

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Abstract

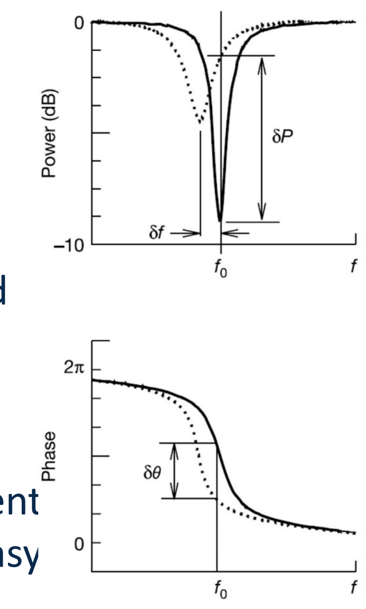
CALDER (Cryogenic wide-Area Light Detectors with Excellent Resolution) is a project for the development of large area phonon mediated KIDs (Kinetic Inductance Detectors), for the detection of Cherenkov radiation emitted from βs in 0vDBD decay in TeO2.
The KIDs are superconducting detectors made of high quality factor superconducting resonators, which are coupled to a transmission line for signal readout.
We designed and fabricated KIDs using aluminum. The Al thin films (40 nm) were evaporated on Si(100) high resistivity silicon wafers using an electron beam evaporator in a HV chamber.
In this work we report the steps of the fabrication process. All devices are made in direct-write using Electron Beam Lithography (EBL), positive tone resist poly-methyl methacrylate (PMMA) and lift off process.
In order to improve the sensitivity of the detectors we have started recently to use sub-stoichiometric TiN deposited by means of DC magnetron sputtering and we will optimize a different fabrication process.

KID working principle

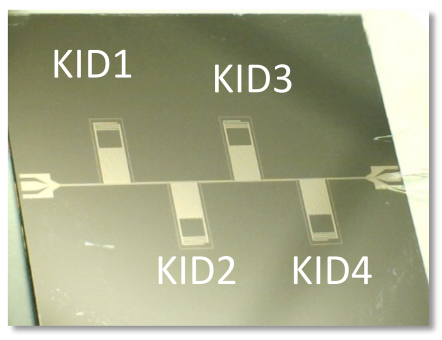
Kinetic Inductance Detectors are superconducting microresonator devices with very high Q factors (10^4-10^6) and resonant frequency typically between 1-10 GHz

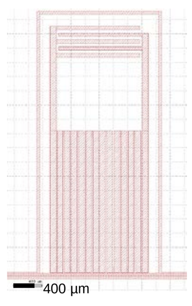
The interaction of a photon or a phonon with the detector breaks Cooper pairs, modifying the inductance and therefore amplitude and phase of resonator transmission (S_{21}) when coupled to transmission line

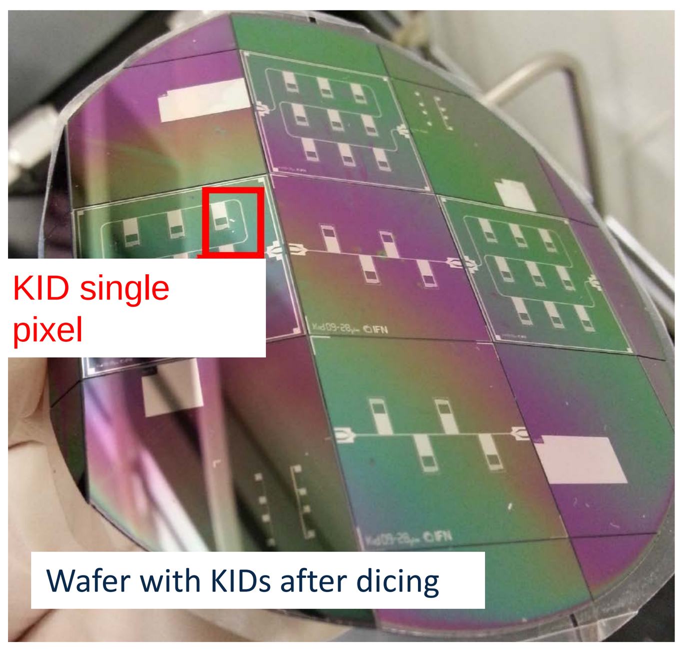
Main advantages of this technology are represented by: excellent intrinsic energy resolution, relatively simple signal readout and easy scalability by a frequency multiplexing, excellent reliability



KIDs



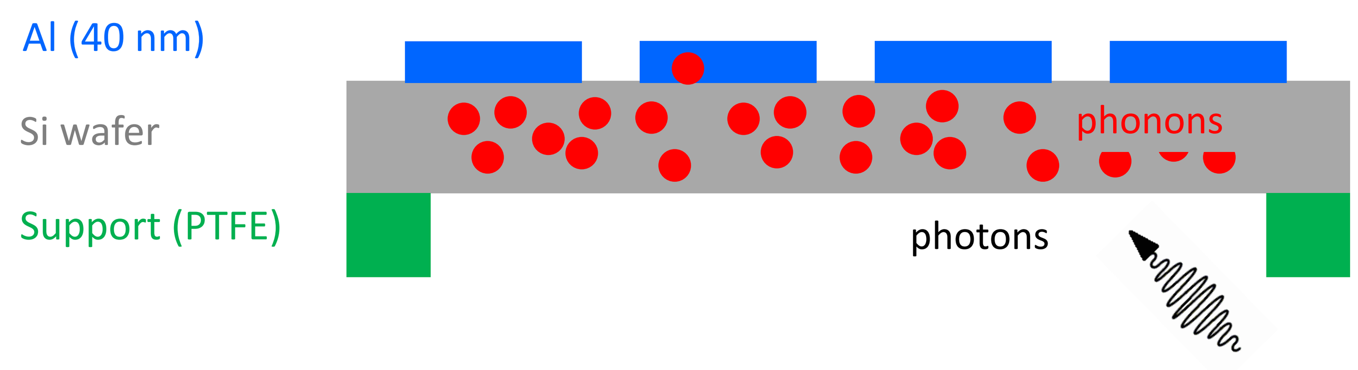




high-resistivity Si substrate
2x2 cm² chip-size sampled by 9 or 4 pixels
Single pixel active area ~ 2 mm²
Resonant frequency: ~ 2.5 GHz

CALDER project

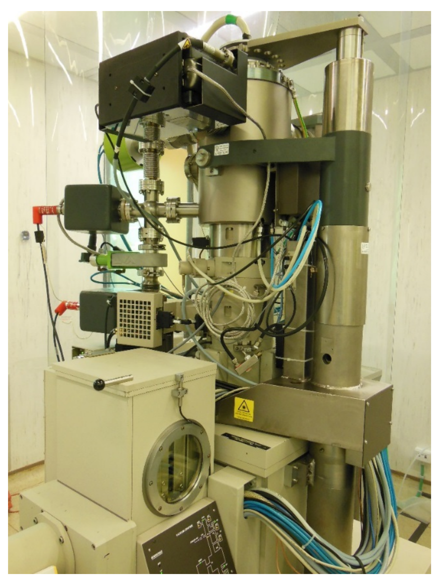
Only limit of KIDs: poor active surface → indirect detection of phonons produced by photons interactions in the substrate



Incident photons converted into athermal phonons

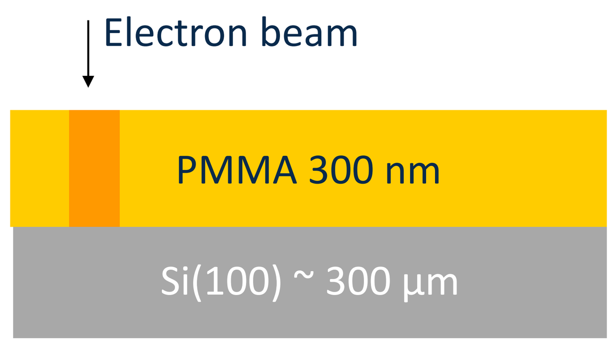
Diffused phonons can be absorbed by KIDs

Fabrication



EBL Leica/Vistec EBPG 5000

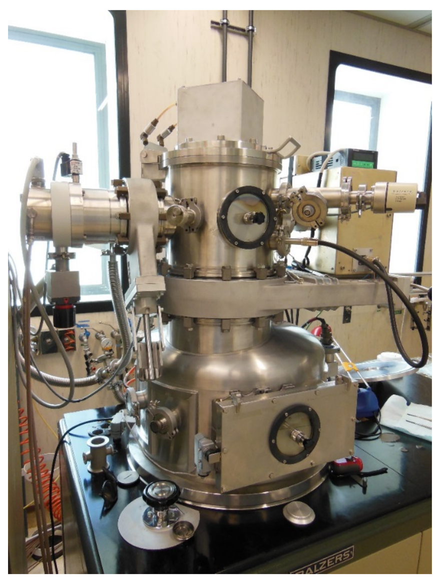
PMMA is patterned by EBL at 100 keV beam energy and 90 nA gun current, with a typical exposure dose ranging from 450 to 550 µC/cm² depending on the extension of the area to be exposed



Exposed PMMA is removed by developer solution of MIBK:IPA 1:1 for 90 sec

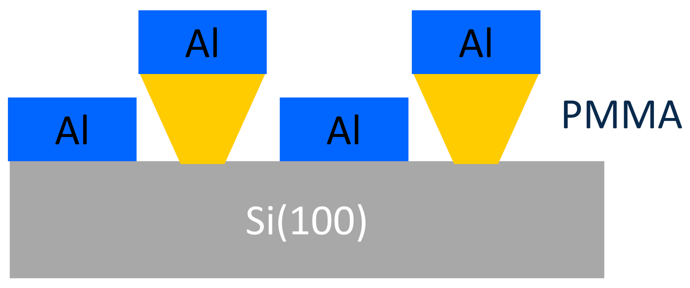
Oxford RIE

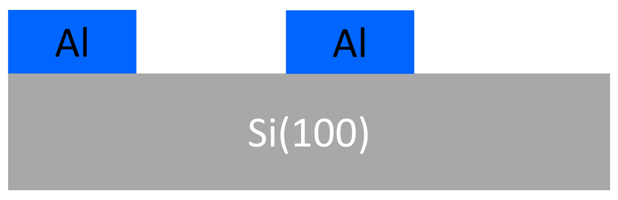
Cleaning using RIE with oxygen plasma to obtain an undercut in the PMMA profile



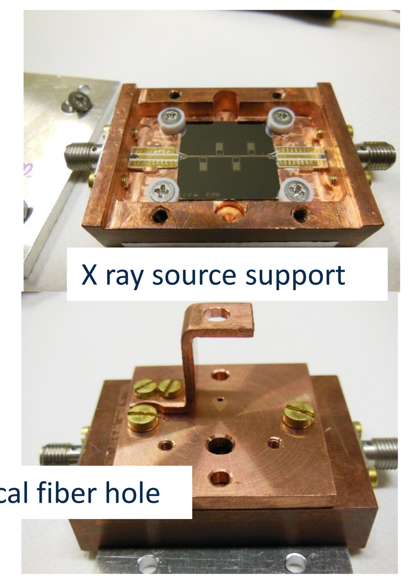
Electron beam evaporator

To remove native oxide from the silicon areas to be covered with Al the silicon substrate is dipped in dilute HF at 2% for 10 sec, then the sample is covered with a 40 nm Aluminum layer using electron gun evaporation in HV chamber





After the Al deposition, the wafer is immersed in hot acetone to achieve lift-off: the e-resist under the Al lm is dissolved and takes the Al film with it



Detector in its holder and electrically connected to the SMA read out

Back side of detectors is illuminated with sources (x-ray and light)

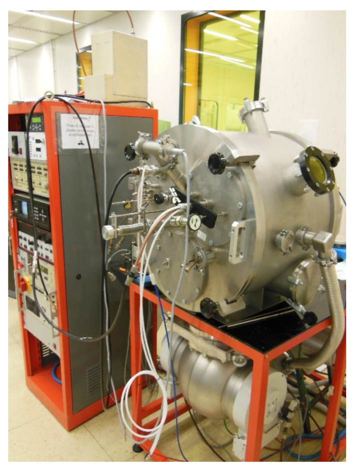
Titanium nitride

	Al	TiN_x	Ti+TiN	Hf
Tc (K)	1,20	0,50*	0,40*	0,12
L (pH/sq)	0,05	3	30	3

*tunable

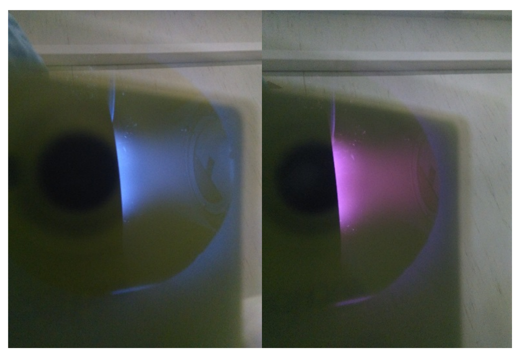
$$\Delta E \propto \frac{T_C}{\varepsilon\sqrt{QL}}$$

Materials with lower T_c (better ΔE)



Sputtering HV chamber with Titanium target

TiN will be deposited with reactive nitrogen in plasma



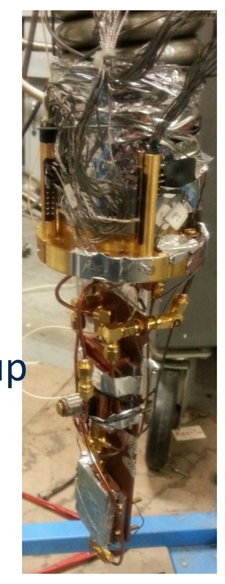
Ti deposition light blue plasma

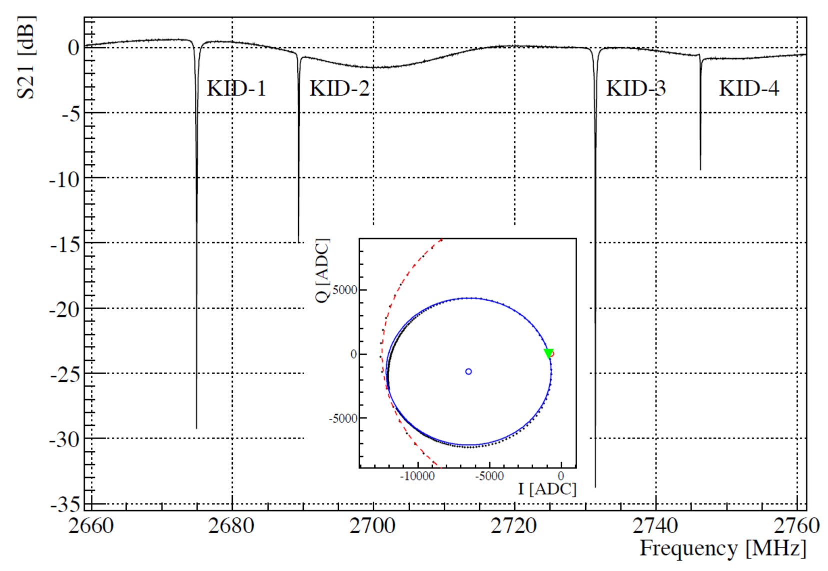
TiN deposition pink plasma

Results

Cryogenic setup 15 mK dilution refrigerator

Readout electronics up to 12 resonator @ 2 MHz bandwidth





Amplitude of the S_{21} around the resonances
Fit of the resonance circle of KID-3, the green marker indicates the resonant frequency (inset)

	f_0 [GHz]	Q $*10^3$	P_{in} [dBm]
KID1	2,675	6	-63
KID2	2,689	18	-64
KID3	2,731	8	-66
KID4	2,746	35	-72

References
http://arxiv.org/abs/1505.01318
http://arxiv.org/abs/1505.04666

13th Pisa Meeting on Advanced Detectors La Biodola, Isola d'Elba (Italy) May 24 - 30, 2015