Novel techniques for thermal detectors and applications for rare events physics

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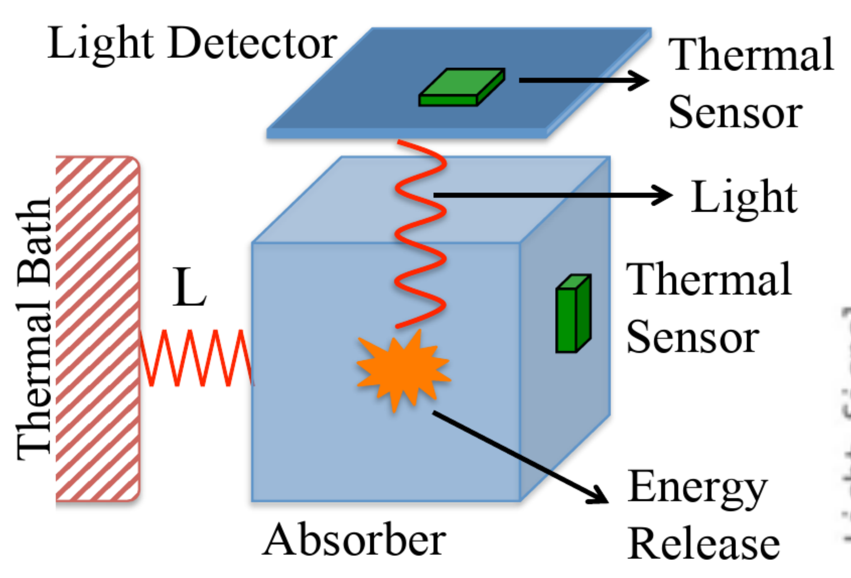
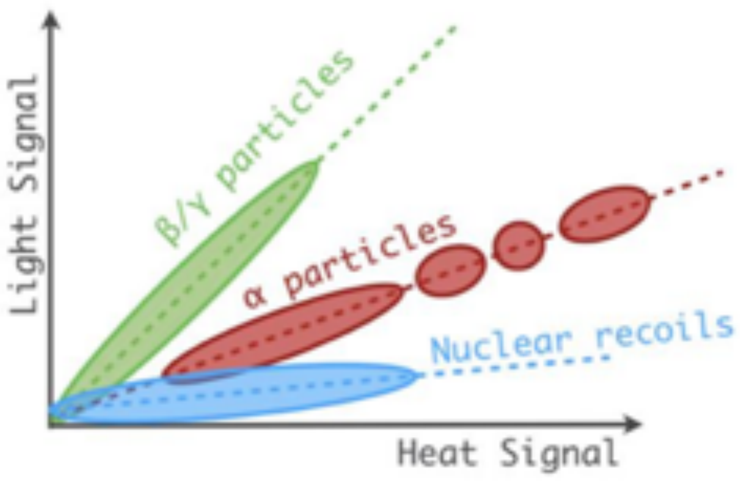
Cryogenic detectors: status and perspectives

Cryogenic detectors have been widely utilised for the last 50 years in astroparticle physics:
- Search of neutrinoless double beta decay (CUORE, CUPID-0, CUPID-Mo, AMoRE,..),
- Dark matter searches (COSINUS, CRESST-II, CDMS,..),
- Direct measurement of the neutrino mass (HOLMES, ECHo,..),
- Neutrino coherent scattering (NUCLEUS,..).

The current large scale cryogenic experiments for rare events physics (eg. CUORE, CUPID) are based on macro-calorimeters read with NTD thermistors.
A fundamental aspect for the CUPID detectors is the improvement in the collection and detection of scintillation light. Indeed, for scintillating calorimeters the light is used to obtain both the particle discrimination and a temporal information for each event.



Detectors operated at 10mK
- Optimal energy resolution in keV-MeV range
- Particle discrimination



Refs. [1-3]

Improvement of the light collection

Strategies:
- Enhance the scintillation of the crystals by doping: emission properties of the doping center, incorporation in the crystal lattice, use of stable isotopes, avoid introduction of paramagnetic centres
- **Increase the scintillation light collection**
  - **Coating of the crystal surfaces with reflective (metal) layers** (500 nm-2um)
  - Improve the light detector technology

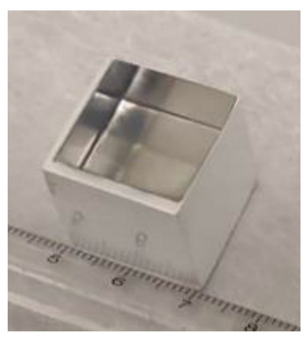
Ref. [4]

Reflective Al coating of Li_2MoO_4 crystals for CUPID and COLD*
Al Coating by sputtering (thickness 1.5-2 um) @INFN-Legnaro

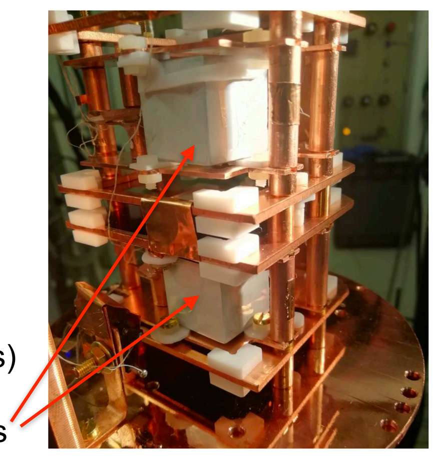
CUPID Milano cryogenic run 2023
Study of thermal sensitivity, pulse shape and light collection for Li_2MoO_4 (LMO) Al-coated vs bare.

COLD: *Coatings for Optimized Low temperature Devices - PRIN2020*

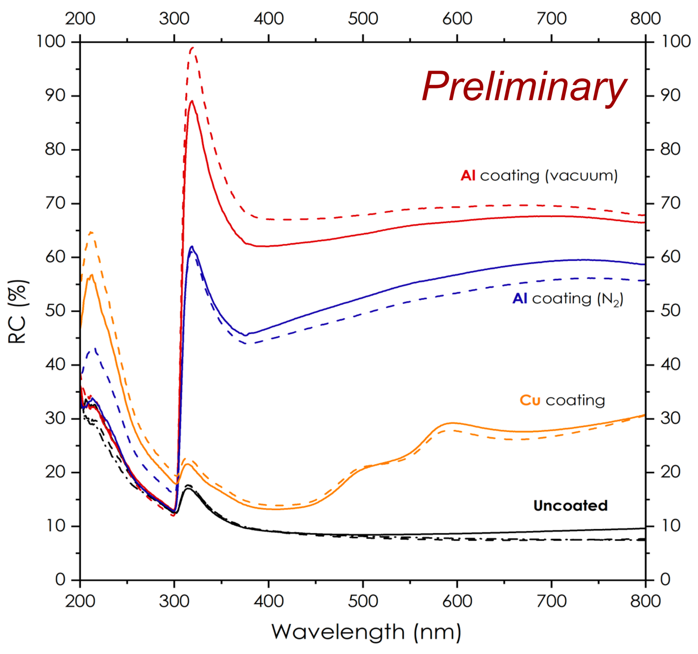
Ref. [5]



LMO Al-coated crystal (5 sides)

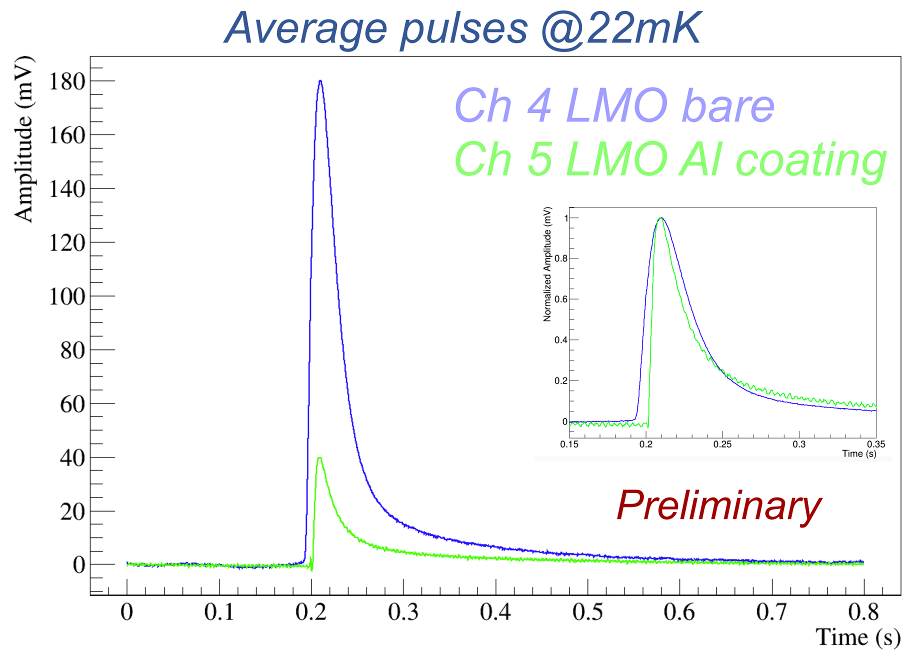


Cryogenic setup: LMO crystals



Reflectance measurement @UniMiB SciMat
- Increased reflectivity with Al-coating @300K
- To be verified for collected scintillation light @10mK

Average pulses @22mK



Preliminary:
- R_{Base}(LMO-Al) ~ 0.5 R_{base} (LMO-bare), for several temperatures (20 to 35 mK)
- Pulse ampli LMO-Al << Pulse ampli LMO-bare

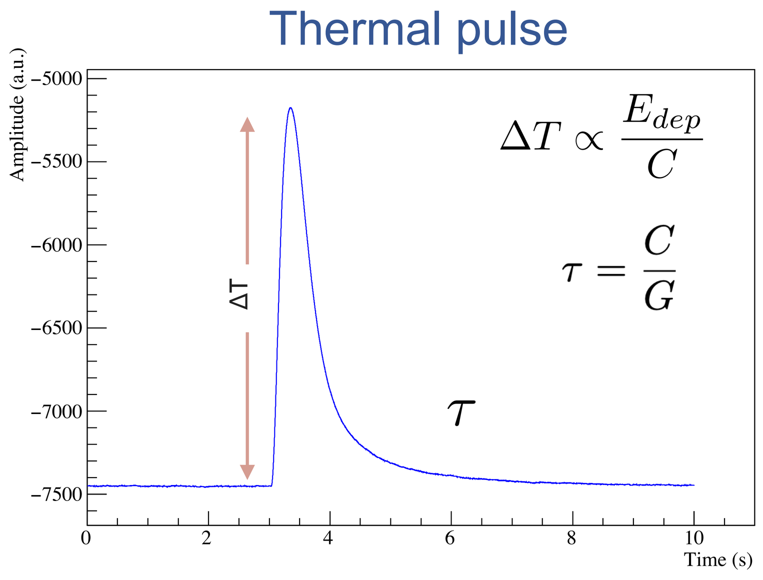
→ Hp: Introduction of Al (boundary) conductance, heat flows also LMO-to-Al, not measured; or Al acts as additional heat capacity

Analysis ongoing!

Improvement of the thermal detector sensitivity

The sensitivity of cryogenic detectors read with NTD is generally limited by the several thermal factors playing a role in the signal formation, particularly the **heat capacity of the detector (C)** and **the coupling/ bonding between the absorber and the thermistor (G)**.

Thermal pulse

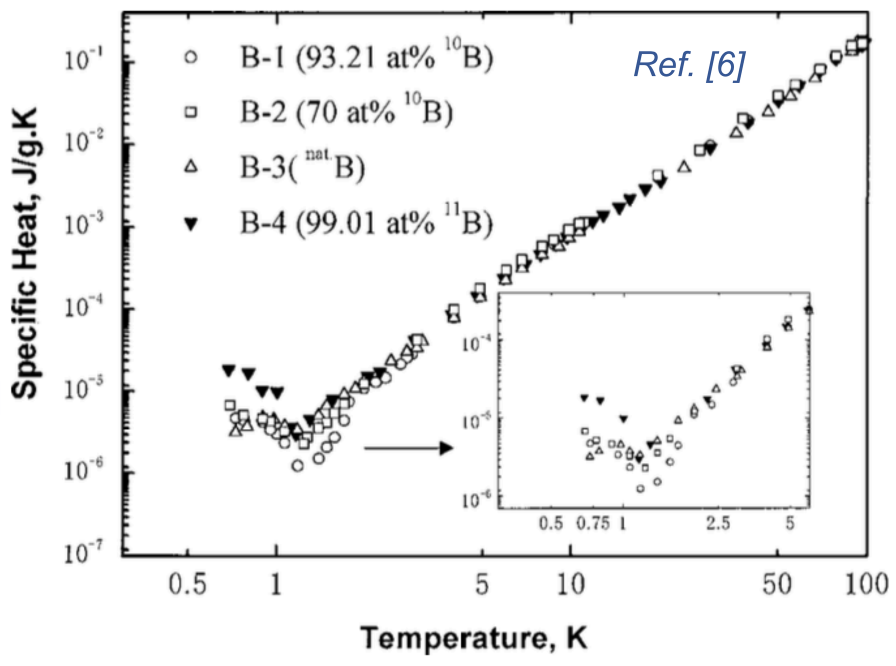


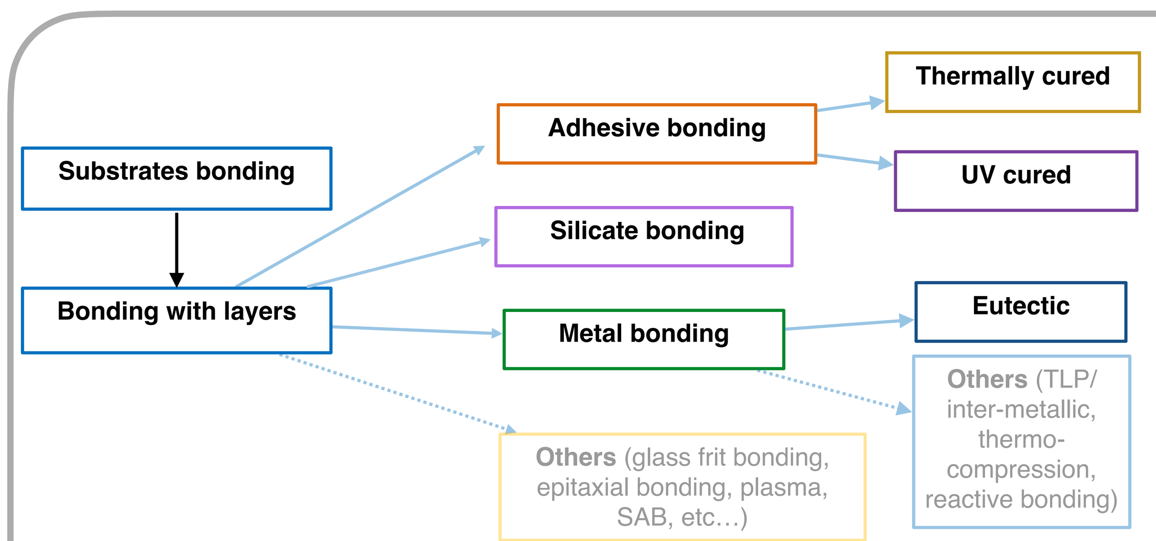
A different realisation of the NTD thermistor electrodes can affect the sensitivity of the thermal sensors; **10B/11B ion isotopes of the NTD electrode implants** have a different specific heat at low temperatures.

Specific heat $c_{s,11B}$ ~ 10 $c_{s,10B}$ @ < 500mK

For same size and doping NTDs, expected heat capacity: $C_{10B\text{-}NTD} < C_{11B\text{-}NTD}$ @10mK

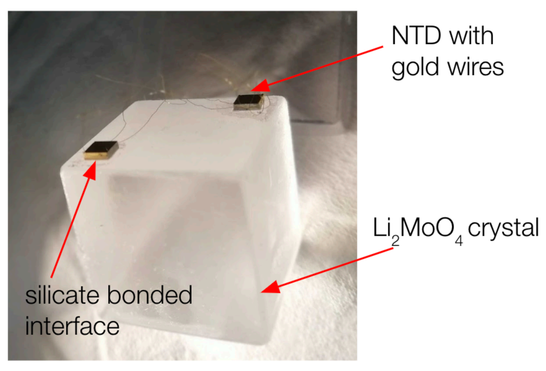
CUPID Test NTDs
- Electrodes production @IMM/CNR and INFN Bologna
- Sensor cut and polishing @INFN MiB



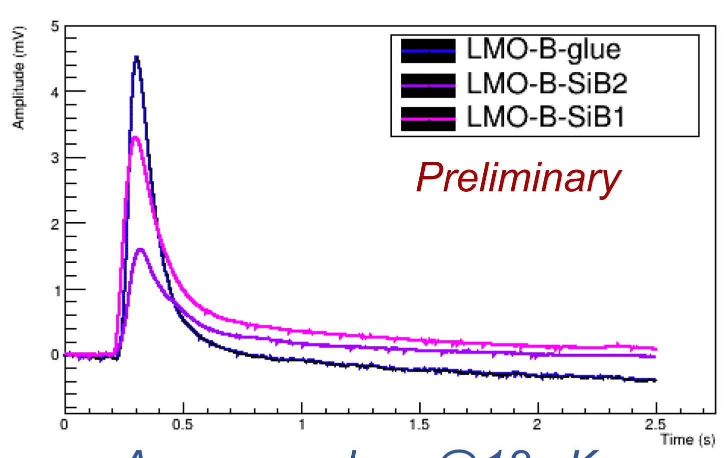


First test of silicate bonding Ge-NTD / Li_2MoO_4
(INFN MiB in collab. with INFN Ferrara)
- Tested at 300K, 77K
- Cryogenic run @10mK in 2022

First time ever of testing silicate bonding at so low T. It works!



Preliminary: G_{SiB} < G_{glue}, SiB seems to introduce a longer decay constant on the pulses

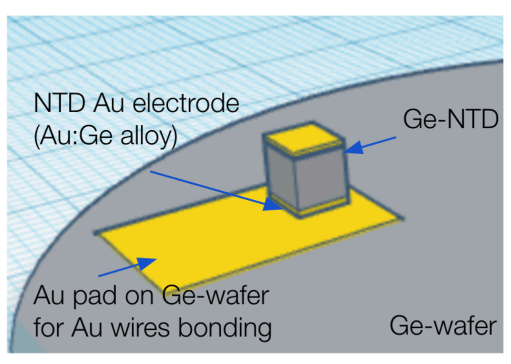


Average pulses @18mK

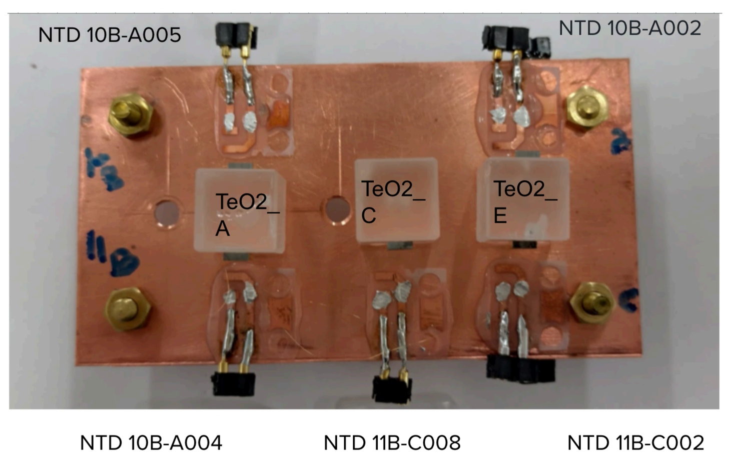
Next steps:
- Try SiB Ge-LDs / Ge-NTDs
- Other applications (eg. suspensions as in Virgo)

Design for the realisation of an eutectic bonding Ge-NTD / Ge-wafer
- Preparation of the Au-pad on the Ge wafer @INFN-LNL
- Eutectic bonding @ INFN Ferrara

Planned for fall/winter 2023



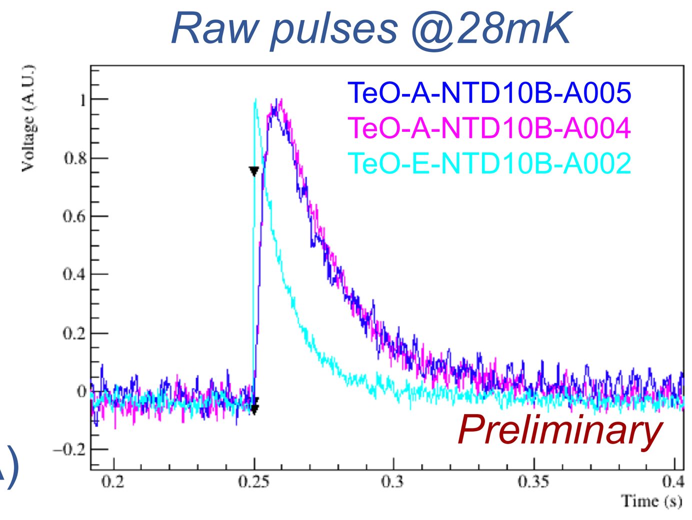
Refs. [7 - Silicate Bonding, 8 - Eutectic Bonding]



CUPID Milano cryogenic run 2023
Study of pulse amplitude and shape for 10B/11B NTDs coupled to the crystals, at different T.
$C_{det} = C_{abs} + C_{NTD}$

Preliminary:
- two NTDs of same type (10B) on same crystal (A) → same pulse shape
- two NTDs of different types on same crystal (E) → different pulse shape wrt to crystal (A)

Raw pulses @28mK



Analysis ongoing!

References

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