# Thermal Detector Model for Cryogenic Composite Detectors for the Dark Matter Experiments CRESST and EURECA

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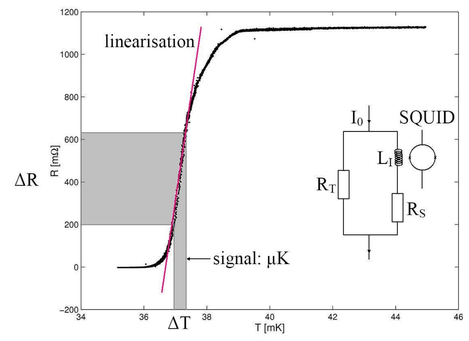
## CRESST (Cryogenic Rare Event Search with Superconducting Thermometers)

*detector module of the CRESST experiment*

- direct detection of well motivated cold dark matter particles: WIMPs (= Weakly Interacting Massive Particles)
- detection via coherent WIMP-nucleus scattering
- detector modules consisting of two cryodetectors equipped with tungsten transition edge sensors (W-TES)
- phonon channel: scintillating $CaWO_4$-crystal (300g, height, ⌀=40mm) as target with W-TES (directly evaporated)
- light channel: SOS (Silicon on Sapphire) or Silicon crystal (⌀=40mm) with W-TES (directly evaporated)
- suppression of $\gamma$- and $\beta$-background by phonon-light-technique




*TES working principle*

## Why cryogenic composite detectors?

**Requirements for a dark matter experiment like EURECA (European Underground Rare Event Calorimeter Array):**

- huge target mass (ton scale)
  → large-scale production of the detector modules
- detectors with very similar properties
  → reproducible production
- possibility to employ multi-material targets
  → introduce a detector design that allows the use of different absorber materials
- detailed understanding of the detector response
  → thermal model for the chosen detector design

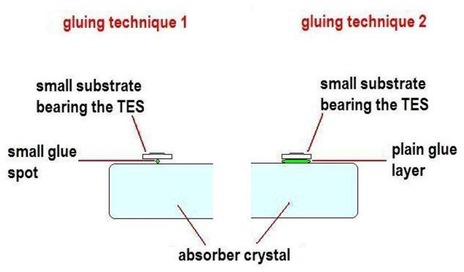
⇒ *Composite Detector Design*

## Composite detector design (CDD)

- decouple the W-TES production from the choice of the target material and thus avoid heating cycles of the absorber crystal
- fabrication of the TES on a separate substrate
- use small $Al_2O_3$ substrates ($3\times5\times1mm^3$) for the deposition of the W-TES
- production of several TESs in one step with similar properties


*shadow mask for production of several TESs*

- attaching of this separate TES to a massive absorber crystal by gluing



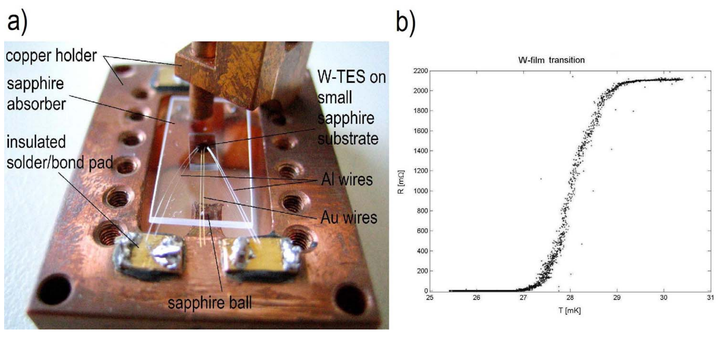

*two different gluing techniques*

**⇒ allows pretesting of the TESs**
**⇒ avoids heating cycles of the absorber (no oxygen loss of the crystal → no scintillation-light reduction)**
**⇒ enables large-scale production**

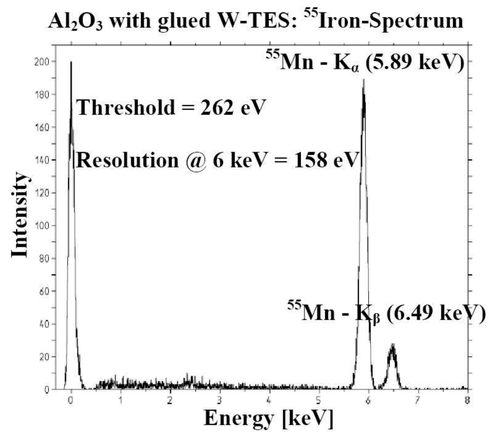
### Example: Composite detector with sapphire absorber

Sapphire substrate ($5\times3\times1mm^3$) with deposited W-TES (⌀=2mm) is glued on absorber substrate (sapphire, ($10\times20\times1mm^3$)):

- electric (Al-wire) and thermal (Au-wire) contacts directly bonded
- glue: epoxy resin (Epotek 301-2), small glue spot (⌀ ≈0.5mm)
- $^{55}$Fe-source positioned below the detector




*a) Composite detector with sapphire absorber; b) Transition of the utilised W-TES*




*$^{55}$Fe-spectrum recorded with glued sapphire detector (see left picture). Separation of the Mn-$K_\alpha$ and Mn-$K_\beta$ line can clearly be seen. Threshold: 262eV, resolution @ 6keV: 158eV*

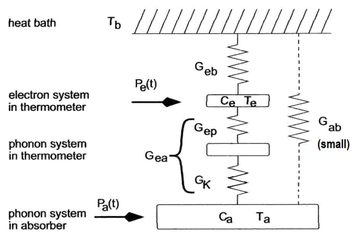
## Thermal detector model for cryogenic composite detectors

### Basic thermal detector model

Modelling of the detector response (pulse shape) dependent on basic detector components [F.Proebst et al., J. Low Temp. Phys. **100**, 69 (1995)]

cryogenic detector with the TES directly deposited on the surface

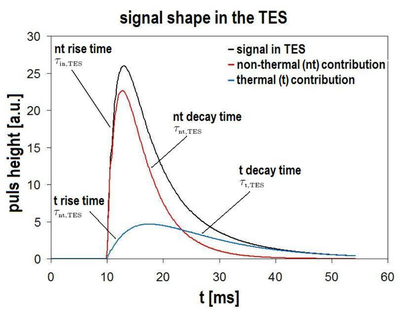
- event in the detector: energy deposition
- after very short time (∼100 ps): absorber is filled with non-thermal phonons
- absorption in the TES ⇒ thermalisation in the TES
- inelastic scattering at the absorber crystal surfaces ⇒ thermalisation in the absorber




*model of a cryogenic detector with the TES directly deposited on the surface in terms of its thermal components*

non-thermal phonons
propagation/life time $\tau_{nt,TES}$ is determined by collection time ($\propto \frac{1}{A_{TES}}$) in the TES and thermalisation in the absorber

thermal phonons
propagation/life time $\tau_{t,TES}$ is determined by the thermal conductances $G_{ij}$



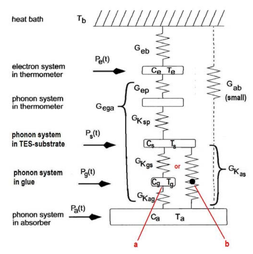

*signal shape in the TES of a cryogenic detector with the TES directly deposited on the surface*

**resulting signal shape in the TES:**

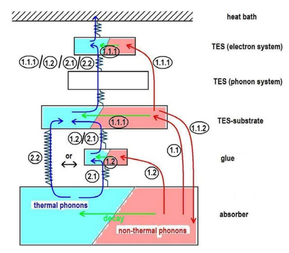
$$\Delta T(t) = \Theta(t)\left[A_{nt}(e^{-\frac{t}{\tau_{nt,TES}}} - e^{-\frac{t}{\tau_{in,TES}}}) + A_t(e^{-\frac{t}{\tau_{t,TES}}} - e^{-\frac{t}{\tau_{nt,TES}}})\right]$$

### Thermal detector model for cryogenic composite detectors

Include glue and TES-substrate into the model: ⇒ influence of these components on the pulse shape (evolution and propagation of phonons)?



*model of a composite cryogenic detector in terms of its thermal components with two different possibilities of including the glue into the model (a: as thermal component or b: as contribution to the thermal conductance)*

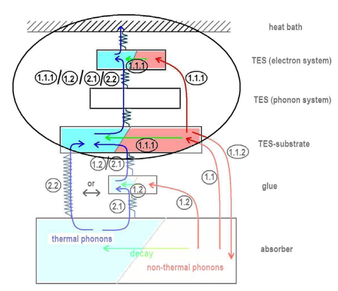



*most important propagation possibilities for the non-thermal and thermal phonons*

the (TES-substrate)-(TES) system can be treated as an individual cryogenic detector which can be described with the basic thermal detector model (see left)

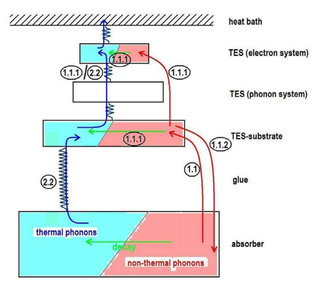
phonons from the absorber that propagate into the (TES-substrate) deliver a **slow (≫100 ps, via the glue area) energy input** into the system

⇒ convolution of power input (phonons from absorber) with signal function ($\Delta T(t)$) of "TES-detector"



*"TES-detector" can be treated as classical cryogenic detector with a slow energy input*

on the basis of the pulse shape analysis of three different composite detectors (different absorber sizes and glue areas) ⇒ **identification of dominant contributions to the signal in the TES**



*remaining non-thermal and thermal phonon propagation possibilities*

- the effective TES-to-glue-area ratio determines whether there is a significant thermal signal contribution or not
- glue is only included as a contribution to the thermal conductance in the model
- **in every detector:**
  non-thermal contribution along path 1.1 → 1.1.1 (results in one decay time $\tau_{nt,as}$)
- **depending on the effective TES-to-glue-area ratio:**
  thermal contribution along path 2.2 from thermalisation in the absorber (results in a second decay time $\tau_{t,as}$)

**⇒ compromise between nt phonon collection efficiency and, at the same time, small thermal (t) contribution**

## Future experiments and developments

### Future investigations for tailoring cryogenic composite detectors to the requirements of dark matter search experiments:

- additional tests of the developed thermal composite detector model
  - determine "TES-detector"-hits (rise and decay time)
  - inject thermal phonons *only* (via heater) into the absorber
  - build composite detectors with well defined different effective TES-to-glue-area ratios to test the predictions of the model
- optimize glue-area to TES-area ratio for CRESST-like detectors
- improve reproducibility of TES production (transition temperatures)
- add phonon collectors to the TES on the small substrate to support efficient phonon collection in the "TES-detector"