R&D on transparent electrodes

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Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

This work is based on the design and realization of **different transparent electrode prototypes** for ***XLZD***. The work has been done in collaboration with the *CREO* (Centro di Ricerche Elettro-ottiche) Laboratories, in L'Aquila:

- **Transparent Conductive Electrodes** (**TCE**s): conductive layers (Indium-Tin-Oxide (**ITO**), Al_2O_3-doped Zinc-Oxide (**AZO**) and **Graphene**) deposited on a transparent UV grade fused silica **UVFS** or **CaF_2** support (**thickness *5 mm*, diameter *1 inch***);
- **Metal** (copper or silver) **nano-wires** over support;
- **Metal reticles deposited via lithography** over support.

The test facility

A **cryogenic test facility** (**STARX**) is currently installed at LNGS. It will provide a **clean liquid xenon** (**LXe**) **environment**, in which TCEs characterization will take place.

The **STARX cryogenic system** consists of a **cryostat** and a **noble gas re-circulation circuit**:

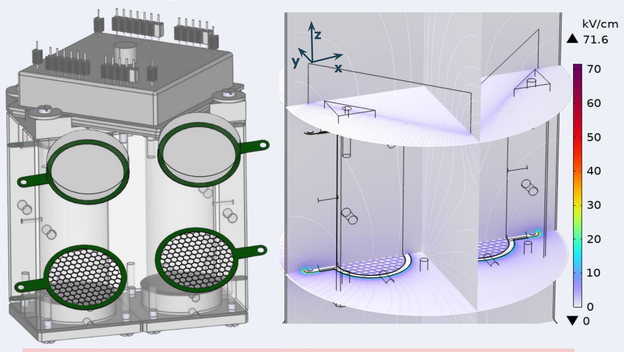
- The cryostat is equipped with a condenser cooled by a **Cryomech PT60 single-stage pulse tube cryocooler**; and pre-cooled by a **liquid nitrogen powered heat exchanger**;
- The gas flow is promoted by a **circulation pump**, regulated by a **Sierra SmartTrack 100 gas flow controller** and purified through a **SAES PS4-MT3 getter**;

And inside the cryostat..

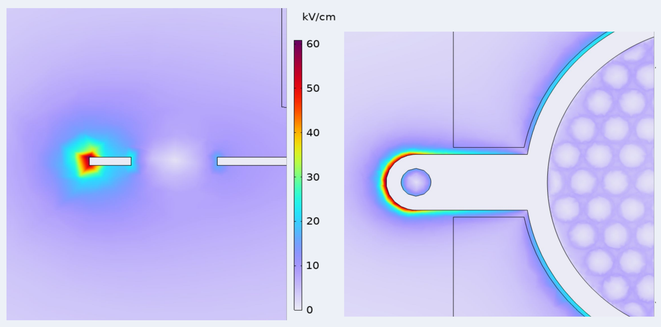
- **2 Parallel cylindrical Teflon Chambers are suspended in the external cryostat**;
- A **TCE is placed in the upper face of each chamber** acting as **anode**, and a **steel grid** with hexagonal holes **in the bottom face** as **cathode**;
- The chambers end-caps are instrumented with a **multianode Photomultiplier Tube** (PMT) R12699-406-M4;

Simulations

Several **Comsol studies** have been performed **to evaluate the maximum electric field values and the field homogeneity inside the chamber**.



3D View of the teflon chambers and **electric field** inside them.



2D view of critical planes in which we have the highest electric field values: **xz** (left) and **xy** (right) **plane** view in correspondence of the bottom steel grids.

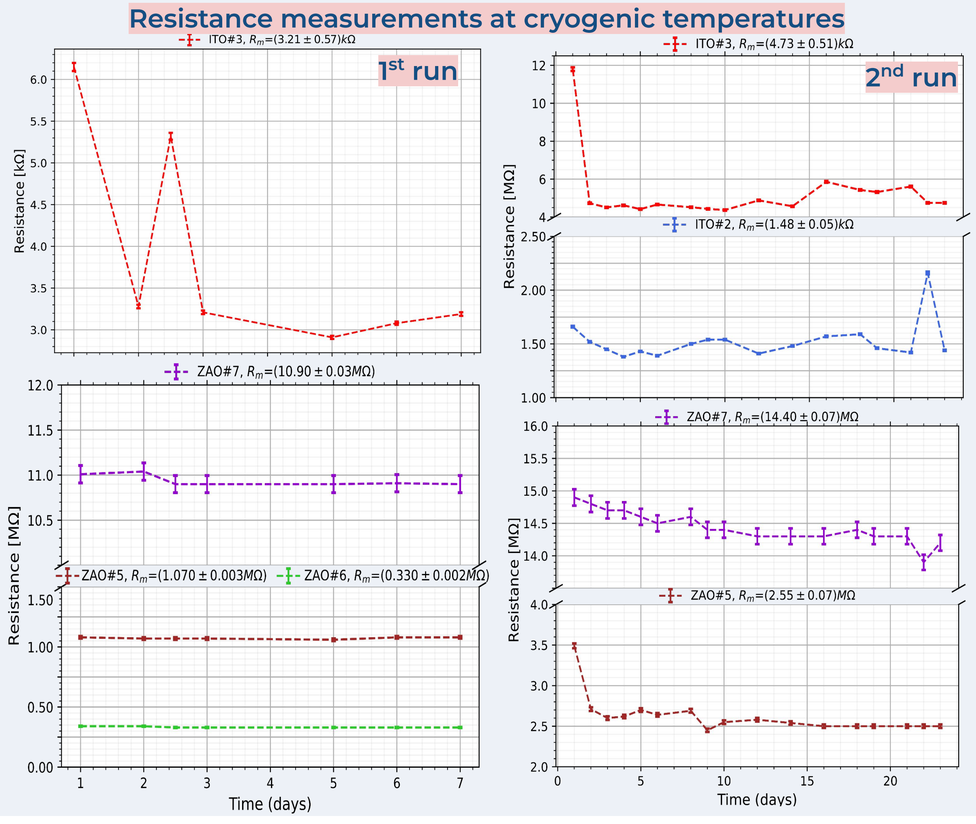
The chambers are **supplied with copper spacer rings**, placed in the upper and bottom chambers faces:

- The upper rings are grounded;
- -1kV is the exercise potential for the PMT;
- The bottom grids are taken to:
  - 5kV
  - 10kV

LXe is predicted to have a large bulk breakdown field of approximately 1 MV/cm. -> **No breakdown voltage exceeded.**

Conductivity in LN_2

Resistance measurements at cryogenic temperatures

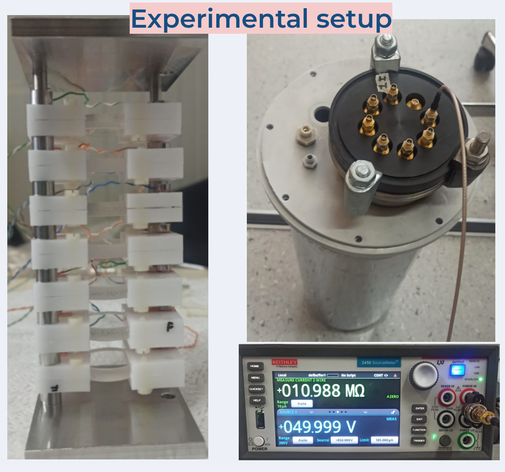


The resistance values were measured at cryogenic temperatures for the different assembled **TCE**s. They were arranged along a vertical structure, made of derlin clips electrically connected to a source meter.

- **7 TCE**s have been tested in a dewar constantly filled with liquid nitrogen LN_2:
  - **#1,3** in **CaF_2** with **ITO** deposit;
  - **#2** in **UVFS** with **ITO** deposit;
  - **#4** in **CaF_2**, virgin;
  - **#6,7** in **CaF_2** with **AZO** deposit;
  - **#5** in **UVFS** with **AZO** deposit.
- Resistance values have been measured in 2 runs:
  - a **1st run** of **7 days**: only #3,5,6,7 worked;
  - a **2nd run** of **23 days**: only #2,3,5,7 worked;
- After 1st run #3,4,6 (**CaF_2**) **cracked** due to the presence of a temperature gradient (avoided in the 2nd run). **Conductivity NOT compromised**;
- 2nd run appears more stable with respect to the 1st possibly due to losing electric contacts in the 1st run;
- **Systematic errors in the plot due to pressure variations** (±40 mbar corresponding to ±2K in temperature). The instrument uncertainty is negligible (0.8Ω).

TCEs catalogue

Experimental setup



Conclusions

- **STARX facility** already **tested and thermodynamically characterized in Ar and** also **in Xe**;
- **Stable behaviour of TCEs' conductivity at cryogenic temperatures** observed, in particular for those with AZO deposit;
- **UVFS is preferable for mechanical stability** and also purity (fluorine may contribute to the background because of α-n high cross section);
- **We are ready to characterize the TCEs in the STARX facility**.

Future outlooks

What will be possible to measure inside STARX?

- **Evaluate TCEs performances** under electric field in LXe cryogenic environment:
  - **Test the mechanical stability** in LXe;
  - **Measure the light yield** *LY* **as a function of the potential applied** between anode and cathode;
- **Measure the transmittance at *178 nm*** by scintillating LXe with ^{83m}Kr source activation.

And the future?

- Currently, **other layer materials** (like **Graphene**) **and technologies** (like metal **nano-wires** or **reticles** over transparent substrate) are under investigation in the Creo Laboratories and **will be characterize in STARX**;
- The **chambers diameter will be increased** to test bigger electrode prototypes (*2 inch*, *4 inch* already fabricated).