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Varistor Insulation for HTS Magnets

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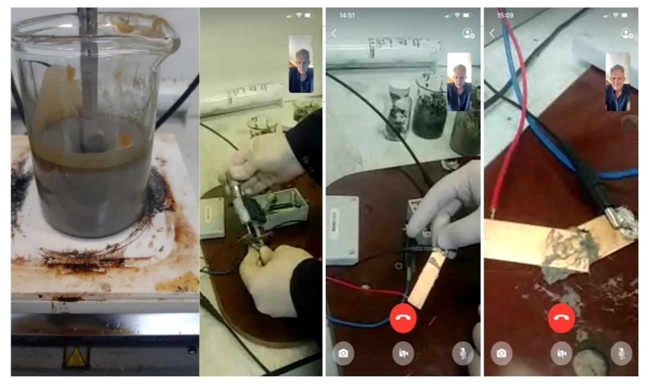
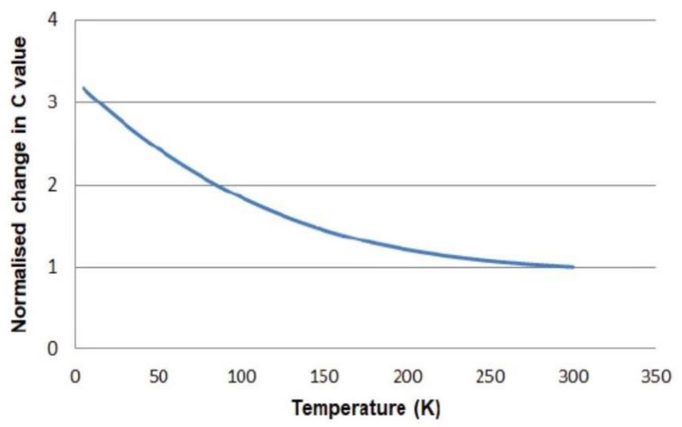
Abstract

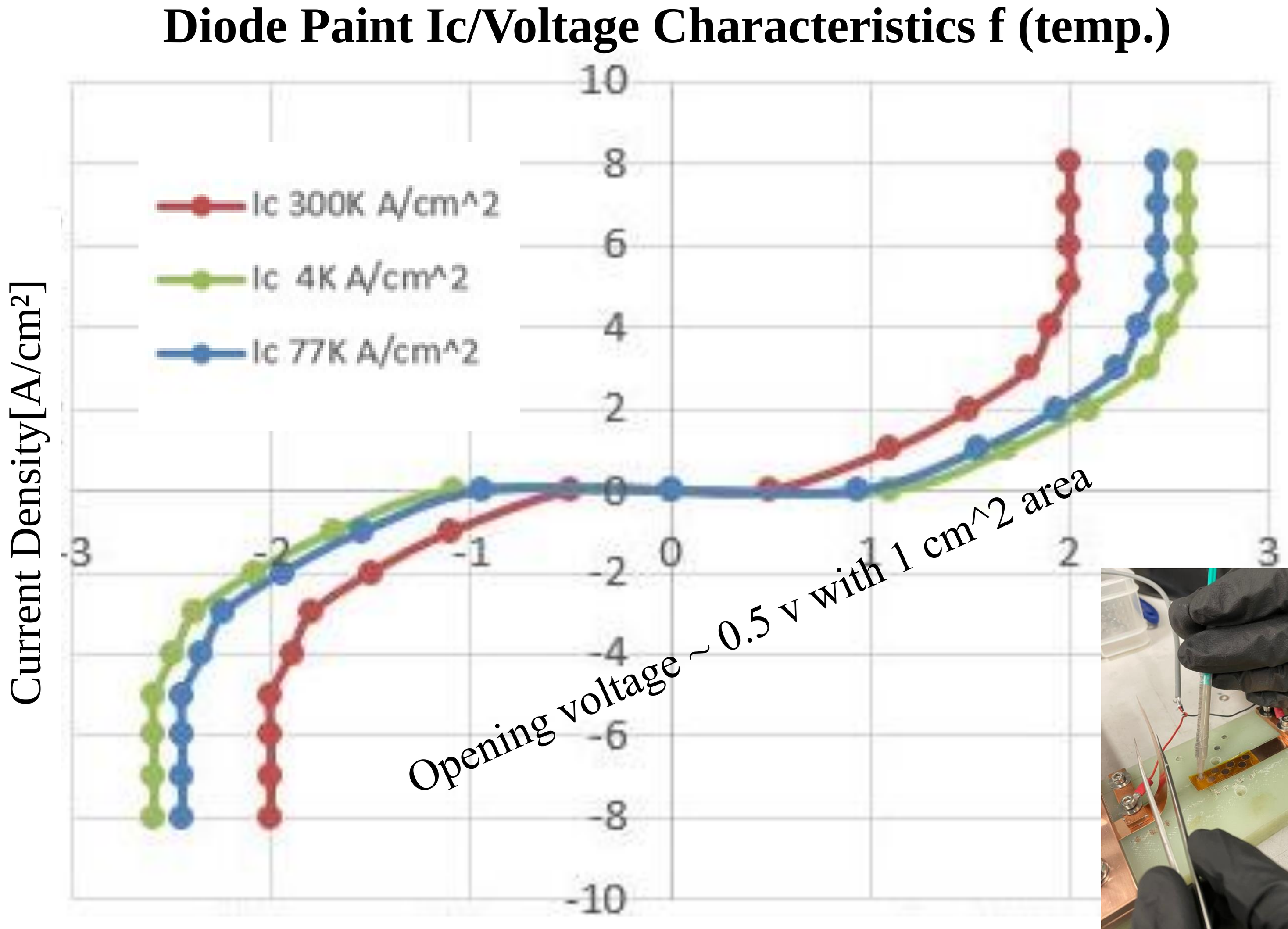
A variable resistance thin dielectric insulation coating for REBCO tape HTS coils has been developed. This new type of insulation system switches between fully insulating and conducting, after an increase in inter turn voltage. Non-Insulated (NI), fully soldered, HTS coils have proven to be very reliable; NI coils are achieving high magnetic fields above 25 Tesla and are almost impossible to quench. Over-current operation simply redirects the excess current out of the superconducting tape, to flow radially through the coil then back to the power supply. The internal coil resistance can then run the current down when the power supply is switched off. The disadvantage with NI coils is, the coil volume and inductance increases, the charging / discharging time can take many hours, even days. This is not compatible with magnet systems that need accurate and fast current to magnetic field control, such as accelerators or other systems. With the Varistor Insulation (VI) we aim to achieve both robust performances as seen in NI coils and fast ramping with controlled current to field transfer functions. In this paper we present the electrical characterization of the insulation at room temperature and cryogenic temperatures, along with simulated magnet operation during ramping, normal operation and failure modes. We discuss other features of the VI insulation such as, application methods to provide thin layers, and alternative formulations to tune its properties. Its ability to act as a distributed quench heater when the voltage threshold is exceeded is also discussed.



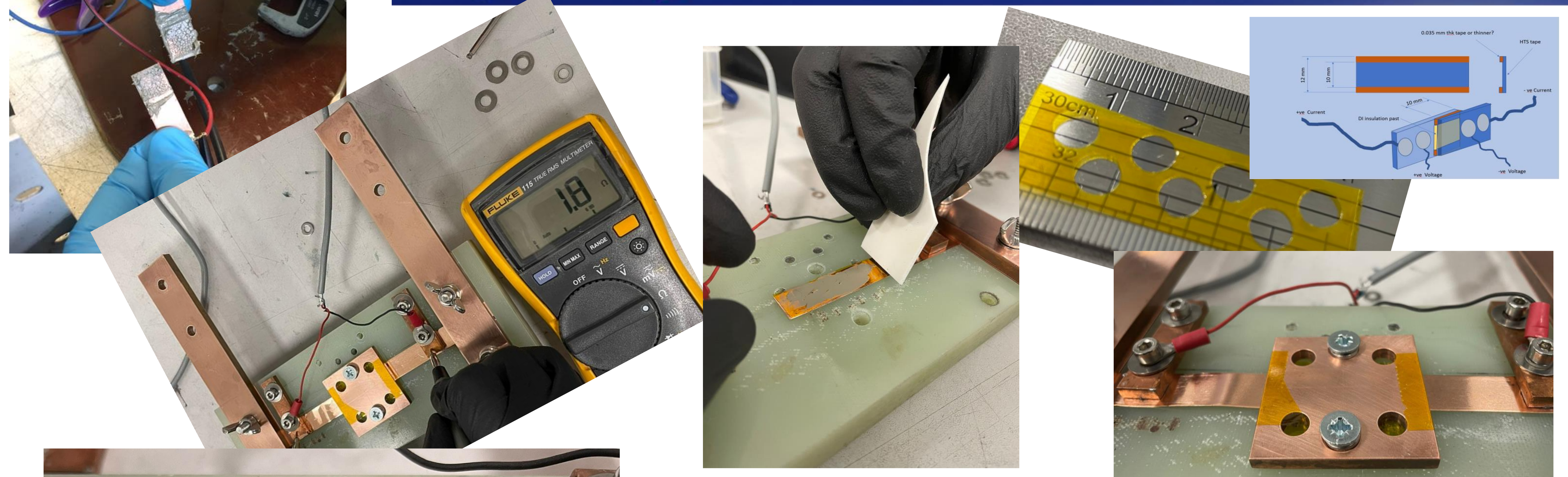
Mixing the active material with the suspension is difficult and take several stages.

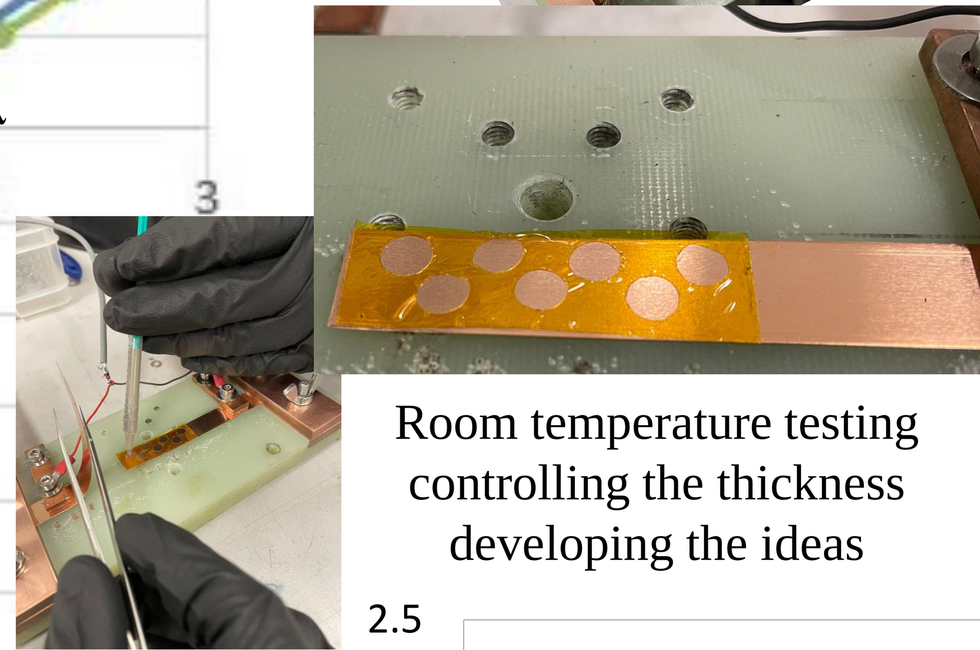


Opening Voltage v temperatures. Factor 3! Room temp to 4K



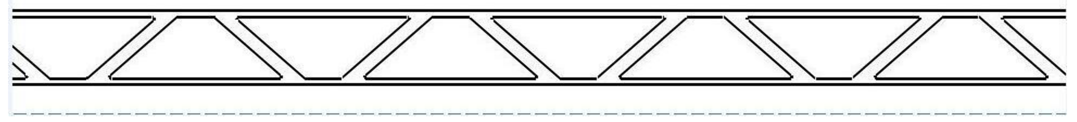
Voltage difference across coating [Volts]

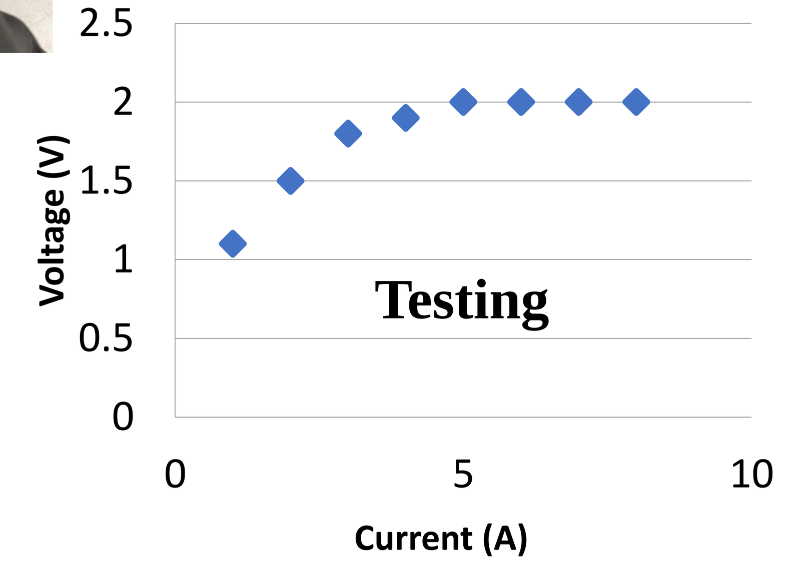


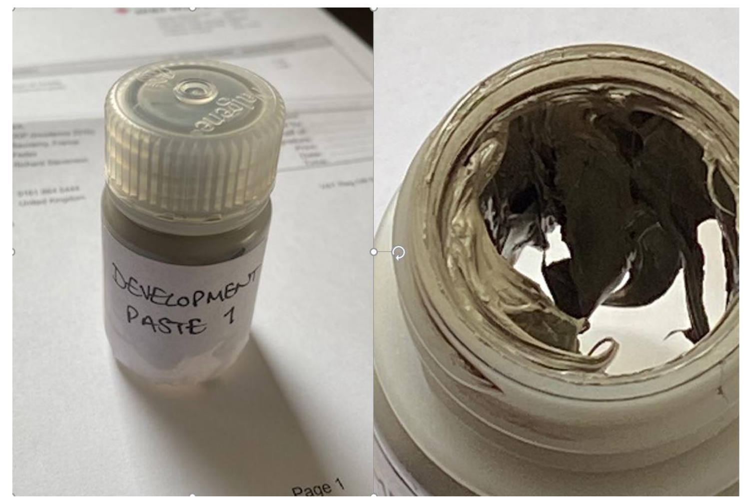


Room temperature testing controlling the thickness developing the ideas

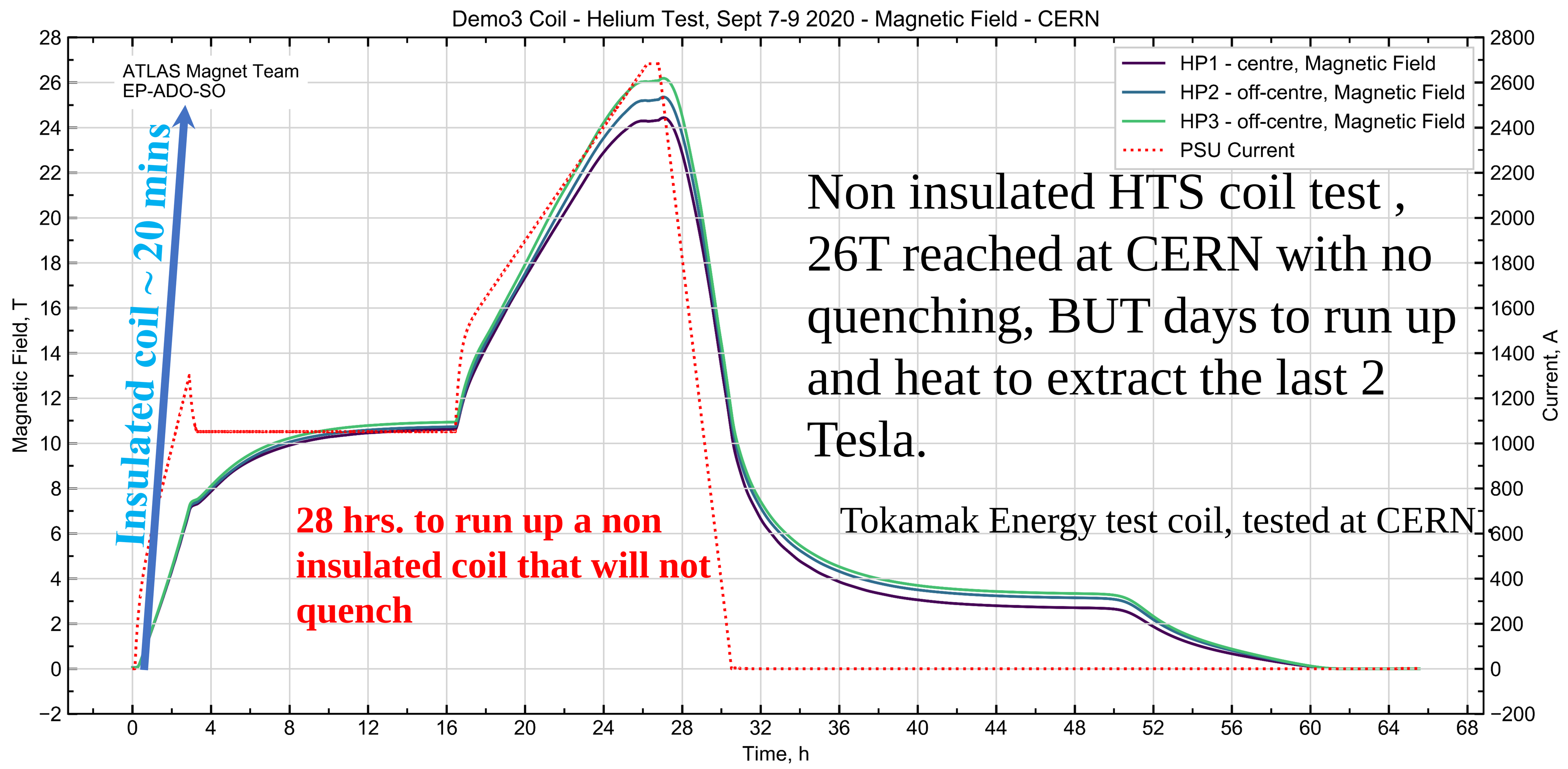
Spacer to control the insulation thickness and prevent electrical shorts, under development. We want the edges to have the paste as that where the current is, but below you see one spacer design. With windows full of paste. Target thickness 0.03 mm – 0.05 ,,

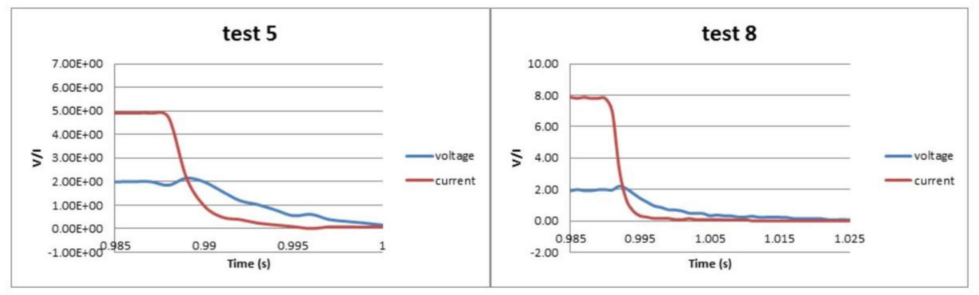




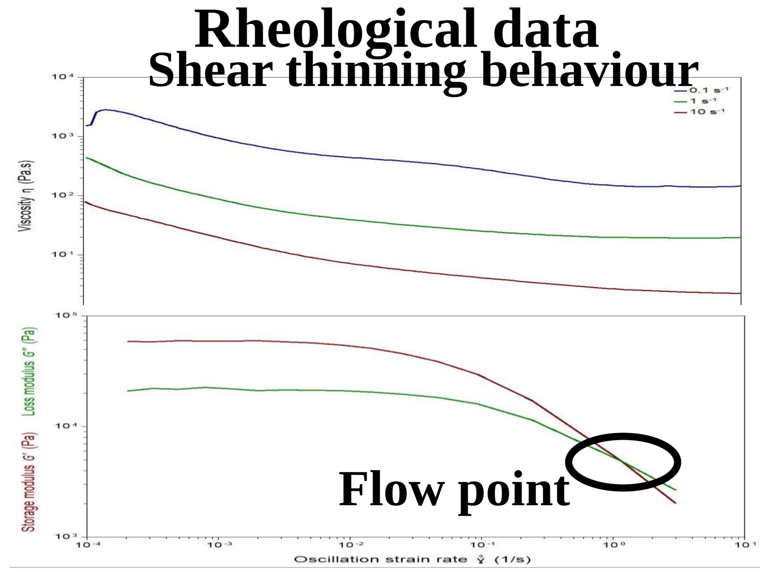


1st test samples, it's like toothpaste and will harden but not crack at low temperatures.

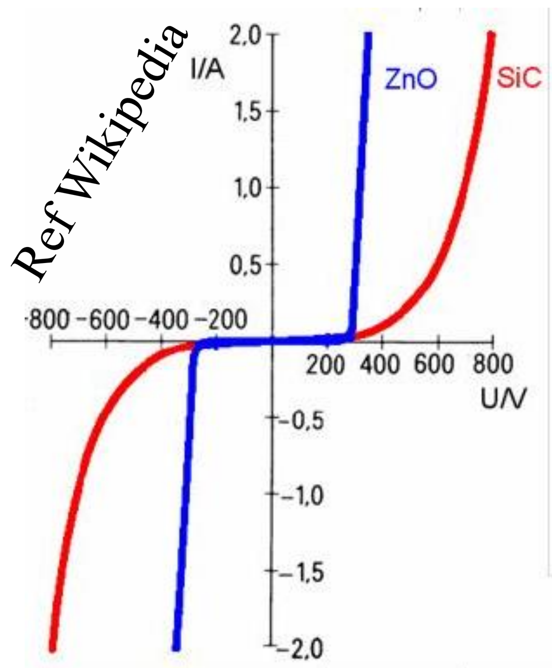




Closing voltages, as the quench voltage reduces the current will stop and become insulating again.



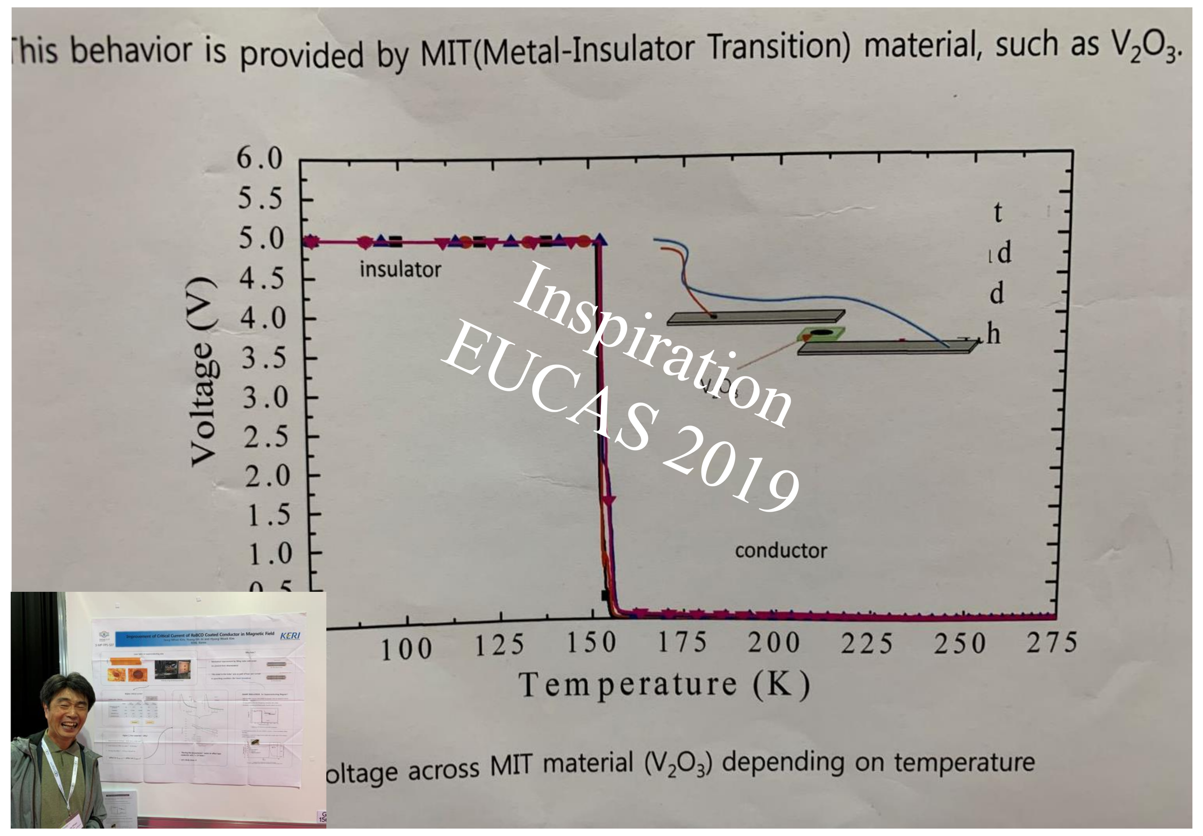
Optimizing the varistor paste viscosity, current density …….



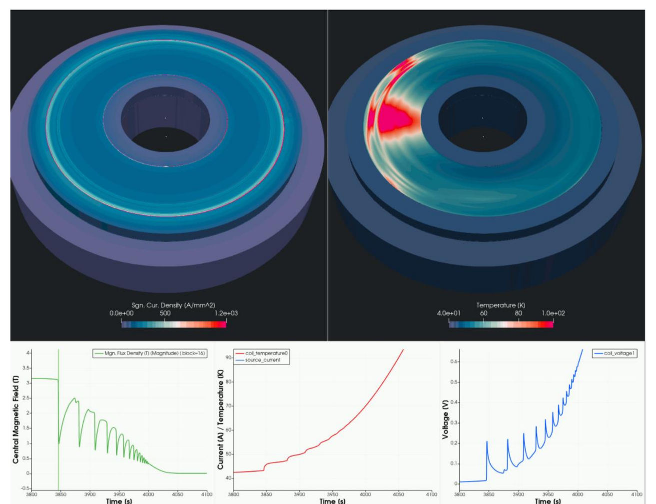
Silicon Carbide semiconductor

Varistors, or voltage-dependent-resistors are bidirectional semiconducting devices that exhibit behaviour between a conventional resistor and a pair of back-to-back diodes. Typically, the voltage across a varistor is modelled using the following power law equation:

$$V = C\,I^{\beta}$$



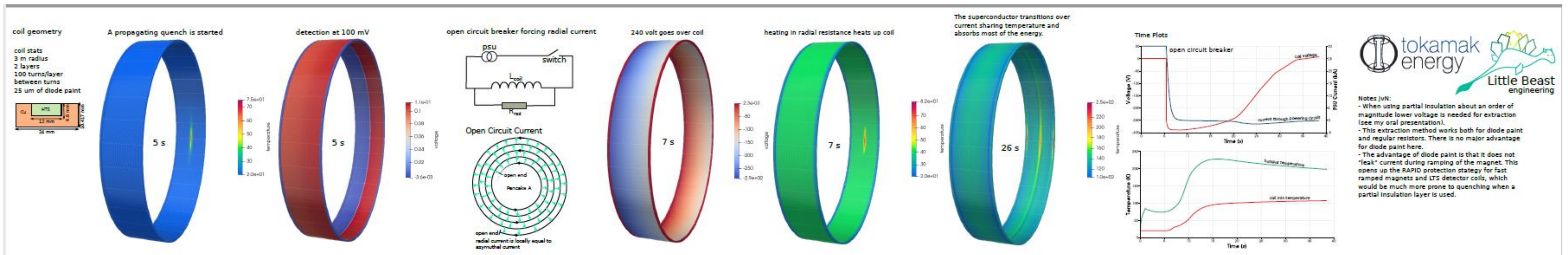
Inspiration for this work was a poster at EUCAS in Glasgow 2019 Seog-whan Kim from MIT, in which the insulation switched from insulating to conducting with a temperature increase of about 150 K. Very interesting! In our paper the semiconductor thin layer switched with voltage increase.



Non-insulated (NI) magnets are self-protected up to a certain size, above that they just burn. In addition, larger NI coils have ramp time constants of many years or decades even.

So, it is proposed to use high but finite resistance between turns (PI coil). Then if circuit breaker is opened, the current is forced through this high resistance path. The heating then takes the turns over critical temperature, making the entire coil normal conducting dumping the energy throughout the coil pack. The concept works, provided that the heat capacity of the coil is sufficient to absorb its stored magnetic energy (same requirement as for quench heaters).

The diode paint allows for partial insulation, without the associated losses during ramping. This may be useful for fast ramped HTS magnets and LTS magnets in general.



Simulations on small and very large coils have shown that it works, modeling is ongoing , we just need to start testing!

Thanks to little Beast Engineering.

CONCLUSIONS

COVID-19 has delayed the development of this project we have initial characterization of the paste but not real cold testing in small and then larger coils. Hence, we will wait to publish this paper when we have the full story.

The opportunity to have a self-protection insulation system for HTS allowing fast ramping and full passive protection is an extremely interesting opportunity ! I thank the teams at METROSIL and Tokamak Energy for their support to develop this idea.