E1-ARRESTER FOR PROTECTION AGAINST NANOSECOND VOLTAGE TRANSIENTS

ARPA-E AWARDEE

PROJECT IMPACT SHEET

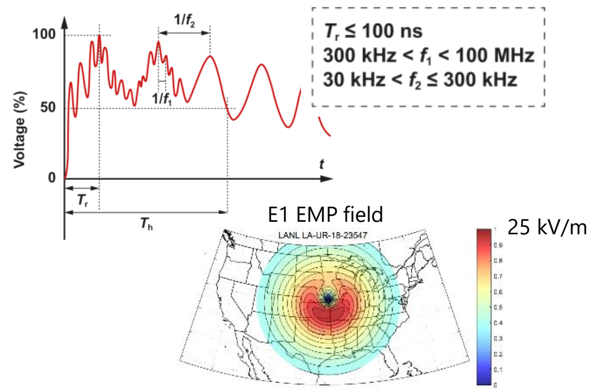
Program: ULTRAFAST

Award: $2.56M

Project Team: Sandia National Laboratories (Lead), University of New Mexico, Virginia Tech, Switched Source LLC, Carbice Corporation

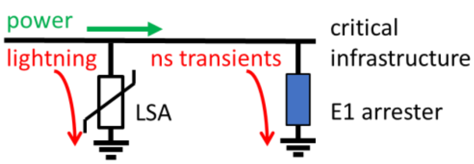
Project Term: 36 months

Principal Investigator: Dr. Laura Biedermann



Motivation

Very fast-front overvoltages (VFFOs) threaten inverter-based resources and power electronics directly connected to the grid[1]. VFFO sources include gas-insulated substation switching events, switchgear restrikes, and insulation faults. Arresters that respond in nanoseconds can improve power quality and shunt switching transients, increasing the lifetime and reliability of grid-connected electronics.

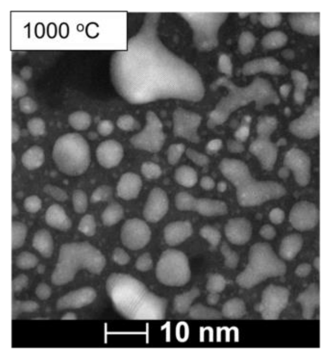


Notional integration of E1-arrester to augment LSA protection.

Additionally, electromagnetic pulses (EMPs) generate dangerous electric fields that couple to transmission lines to produce high-voltage, high-current transients, which compound over long distances.[2] Early-time (E1) EMPs are severe threats to the electric grid that cannot yet be mitigated.[3,4] While lightning surge arresters (LSAs) protect against lightning strikes, self-inductances limit existing LSA response times to ~100 nanoseconds. New nanosecond-responsive E1 arresters can augment LSA protections.

Technical Opportunity

This project is developing new self-breaking, nanosecond-responsive arresters to protect the electrical grid from high-voltage, high-current transients. Grid application nanosecond-responsive arresters require materials with high breakdown strength to enable low-inductance shunt devices. Such arresters need high input impedance at grid voltages and frequencies, and high conductance when triggered by an incident high-voltage transient.



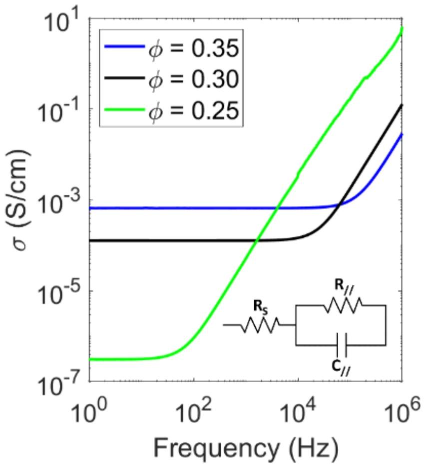
Scanning TEM image of a granular metal. Mo-SiN Mo nanoparticles (bright) are embedded in SiN_x (dark).

As part of this project, Sandia National Laboratories developed granular metals for high-voltage, high-current switching applications. Granular metals combine metal nanoparticles within an insulating matrix. Molybdenum-silicon nitride (Mo-SiN_x) granular metals will be the active material in these E1-arresters. Silicon nitride provides a high breakdown strength while refractory Mo is thermally stable to handle kA current surges.

Sandia National Laboratories | The University of New Mexico | Virginia Tech | Switched Source | Carbice

1. IEEE Std 2426-2024, "IEEE Guide for Field Measurement of Fast-Front and Very Fast-Front Overvoltages in Electric Power Systems."
2. Coordinating National Resilience to Electromagnetic Pulses (2019-06325, 2019 https://www.govinfo.gov/app/details/DCPD-201900176).
3. EPRI, "High-Altitude Electromagnetic Pulse and the Bulk Power System: Potential Impacts and Mitigation Strategies," (Electric Power Research Institute, Palo Alto, CA, 2019).
4. Resultant spatial E1 EMP field for a benchmark 1000 kT weapon detonated 200 km above ground. From LA-UR-18-23547.

Granular metals have 'unique and complementary' tunneling and capacitive conduction paths to safely shunt deleterious transients to ground.



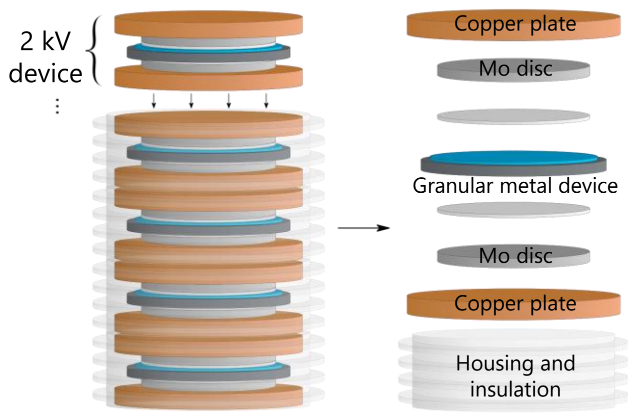
This figure shows the frequency-dependent conductivity response, *σ(ω)*, of Mo-SiN_x granular metals. The low-frequency conductivity decreases monotonically with decreasing Mo volume fraction, *φ*. At nominal grid conditions, the insulating silicon nitride matrix limits leakage currents. However, *σ(ω)* increases orders-of-magnitude at MHz/GHz frequencies, providing the desired high-pass filter response for shunt devices.

This *σ(ω)* response is intrinsic to granular metals' nanostructure.[5,6] Through careful control of Mo-SiN_x synthesis and integration,[7,8] unprecedented and highly-desirable high-pass filter response has been achieved.[9]

Long-term Impacts

Our innovative integration of granular metals will enable the first E1-arresters operating at grid voltages and currents. These arresters are self-breaking, two-terminal devices incorporating best practices from wide bandgap devices and press-pack architectures.

Granular metal films are deposited onto conductive Si wafers sandwiched between copper plates to create series-stacked devices. This compact packaging architecture minimizes self-inductance.



Prototype arrester design showing series-stacked elements.

At the end of the project, a prototype packaged self-breaking arrester will be demonstrated and validated to meet metrics of ≥500 V/ns and ≥200 A/ns slew rates at 10 kV. Device-level pulse tests will evaluate reliability and failure modes following up to 30,000 cycles of operation. We envision two commercialization pathways for these E1-arresters: 1) grid-level shunt devices to protect against E1 EMPs; and 2) as integrated overvoltage protection for solid-state transformers and medium/high voltage power converters.

Intellectual Property

Sandia has filed a patent application, 18/238,556, for "Granular metals comprising transition metal nanoparticles in a silicon nitride matrix" and a provisional patent application, 63/595,400, for "A granular metal arrester for improved EMP protection."

Project & Contact Details

Learn more and connect with this project team.

5. L. Merle *et al., J. Appl. Phys.* **132**, 015105 (2022).
6. H. Bakkali *et al., Sci. Rep.* 6, 29676 (2016).
7. S. Gilbert *et al.,* "*J. Phys.: Condens. Matter* 34, 204007 (2022).
8. S. Gilbert *et al., Nanotechnology* 34, 415706 (2023).
9. M. McGarry *et al., J. Appl. Phys.* **136**, 055101 (2024).

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