TECHNOLOGY BRIEF

NEXT STEP FUSION

THOR: Steady-State Hall Effect Magnetic Field Sensor

A graphene-on-silicon-carbide, radiation-hard, high-temperature-capable diagnostic for next-generation magnetic confinement fusion (MCF) devices and future fusion pilot/power plants (FPPs).

THE CHALLENGE

In MCF devices, the magnetic field confines the plasma, and any deviation in field topology destabilizes it and ends the discharge — so continuous, accurate, real-time field measurement is essential for plasma control and device safety. Conventional inductive diagnostics measure only field variations, and existing steady-state sensor materials degrade in the neutron and thermal environment of a power plant.

THE TECHNOLOGY

THOR is built on an **Al_2O_3/QFS-graphene/6H-SiC(0001)** structure — a single atomic layer of quasi-free-standing epitaxial graphene grown directly on a radiation-hard silicon carbide substrate and protected by an alumina passivation layer [1]. This combination brings four qualities no existing sensor material offers simultaneously:

- **High magnetic sensitivity** — ~75 V/AT, vs <1 V/AT for metals and semimetals currently used in fusion [2].
- **Stable operation from room temperature to 770 K** [2], [3].
- **Self-healing of neutron radiation damage** through a simple thermal anneal at 623 K — the sensor recovers its original performance after exposure rather than degrading permanently [1].
- **Miniaturized footprint of just 1.4 mm × 1.4 mm** — enabling dense placement in geometrically constrained in-vessel locations inaccessible to conventional coil-based diagnostics [2].

THOR VS. CONVENTIONAL MAGNETIC DIAGNOSTICS

Flux loops / Rogowski coils — measure dB/dt and require time integration, making them blind to steady-state fields and prone to drift over long pulses; THOR measures absolute field instantaneously with no integration required.

Bismuth / antimony / metal Hall sensors — the leading ITER/DEMO steady-state candidates, but limited to <1 V/AT sensitivity, ~0.1 %/K thermal drift, and no self-healing; THOR delivers 75–80× higher sensitivity, lower drift, and full recovery after moderate neutron doses [1], [2], [4].

Mirnov coils — share the same dB/dt limitation and are vulnerable to mechanical vibration and electromagnetic interference; THOR is a solid-state chip, vibration-insensitive, and directly implantable.

AlGaN/GaN HEMT Hall sensors — reach comparable sensitivity but only below ~673 K, with no demonstrated neutron hardness and higher radioactivation under neutron flux than SiC; THOR operates to 770 K with proven radiation resistance and a low-activation substrate [2], [3], [4].

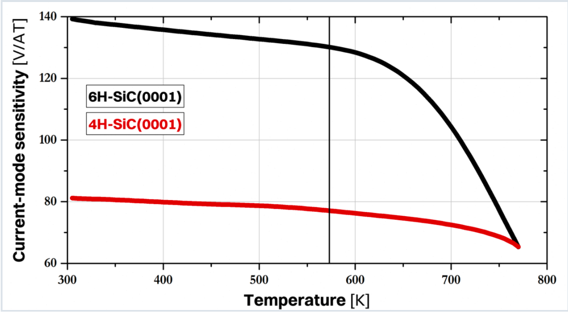

Fig. 1. Current-mode sensitivity of graphene Hall sensors on 6H- and 4H-SiC(0001) — stable operation up to 770 K.

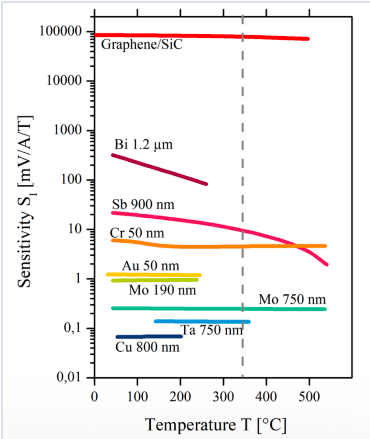

Fig. 2. Sensitivity of graphene/SiC vs. metal thin-film Hall sensors — a 2–5 orders-of-magnitude advantage across the full temperature range.

PARTNERSHIP & MATURITY

THOR is being developed by **Next Step Fusion** (Luxembourg) and the **Łukasiewicz Institute of Microelectronics and Photonics** (Poland).

The next goal of this long-term partnership is to mature THOR from **TRL 4 to TRL 6** — from validation in a relevant laboratory environment to demonstration in a relevant operational environment — paving the way toward deployment in future FPPs.

REFERENCES

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