Toward Radiation-Hard Magnetic Diagnostics: Testing Graphene Sensors for Tokamaks

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As the urgency of addressing climate change grows, nuclear fusion is becoming one of the most promising long-term energy solutions. In magnetic confinement fusion reactors (especially tokamaks) accurate measurement of magnetic fields is essential for monitoring and control. This research explores the potential of advanced graphene-based sensors for this purpose, focusing on their performance in the extreme neutron radiation and high temperatures environment found inside a fusion reactor.

Hall-effect magnetic field sensors were manufactured in form of graphene grown on silicon carbide (SiC) and intercalated with a hydrogen layer. The sensors were coated with aluminium oxide for protection [1, 2]. These devices were then exposed to neutron radiation in the MARIA research reactor at Polish National Centre for Nuclear Research, and separately tested at high temperatures to simulate tokamak conditions.

After irradiation, electrical measurements and material analysis techniques (like Raman characterisation, Transmission Electron Microscopy and Density Functional Theory calculations) were utilised to study how neutron radiation affected the sensors. They revealed that the radiation had a marginal impact on graphene layer. However some performance loss was observed and we attribute it to deterioration of the hydrogen layer, which plays a key role in maintaining graphene's useful properties by separating it from the substrate. Interestingly, heating the sensors to temperatures above 200°C helped partially restore their electrical properties, likely by allowing surface diffusion of hydrogen on the surface of SiC [3].

These results show that while neutron radiation can degrade sensor performance, some of the damage can be reversed with thermal treatment, though only to a certain radiation threshold. Understanding how radiation affects these materials will be crucial for developing reliable magnetic sensors that can operate inside future fusion reactors.

[1] T. Ciuk et al., Carbon Trends 13 (2023) 100303.

[2] T. Ciuk et al., Carbon 139 (2018) 776.

[3] S. El-Ahmar et al., Appl. Surf. Sci. 685 (2025) 161953.