Impact of Intense Neutron Radiation: Two-Channel Damage Model of 2D/3D Heterostructure

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Emerging technologies like magnetic confinement thermonuclear reactors or space exploration require robust magnetic field sensors capable of withstanding extreme conditions. The main challenge is operating under intense neutron radiation. The bulk materials are susceptible to many types of damage caused by neutron radiation including atomic displacement and collision cascades. 2D materials like graphene are attracting growing interest in this context [1], as due to their reduced dimensionality – they exhibit a small cross-section for interactions with neutrons. However, is this advantage retained when a part of a heterostructure? [2] In this contribution we intend to show that graphene does indeed demonstrate beneficial properties and we explore the potential damage modes that the structures experience.

The investigated heterostructures are made out of epitaxially grown graphene on silicon carbide substrate, intercalated with hydrogen layer and passivated with amorphous aluminum oxide (Al_2O_3/G/H/SiC) [3]. The H-intercalation separates the graphene from SiC allowing for quasi-free-standing properties. Due to spontaneous polarization of SiC, it induces p-type doping in graphene [4]. The structures were irradiated inside the MARIA research reactor core in Polish National Center for Nuclear Research [5] and received fast neutron fluence from 1.9×10^{17} to 6.5×10^{18} n/cm^2.

What we have found is that under intense neutron radiation electrical parameters of graphene change, although it's structure is very mildly affected. From that, we introduce two-channel damage model that governs the electrical response of irradiated structures. First is the direct lattice damage of graphene. From micro-Raman analysis we modelled that graphene layer structural disorder reaches only 0.0064% at a neutron fluence of 1.3×10^{19} n/cm^2 and is a soft saturation limit. The other mode of damage is connected to chemical interfacial evolution between graphene and the substrate. The carrier concentration in graphene is highly sensitive to the degree of hydrogen intercalation. With Density Functional Theory calculations we have shown that if depleted – graphene will experience deterioration of electrical properties. We identify this as the most vulnerable and radiation-sensitive component of the system but highlight the robustness of the graphene itself in these extreme conditions.

References

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