Development of MRI-compatible Graphene-based Probes for Rodent and Human Electrophysiology

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PROBLEMS

EEG-fMRI (electroencephalography; functional magnetic resonance imaging) is a technique that synchronously records EEG and fMRI data to study electrical brain activity and its hemodynamic changes, in both normal and disorder states [1]. The goal is to optimize and safely collect data from both measures. Current challenges include:

- **Metal-based artifacts**: Metallic EEG electrodes (e.g., gold, platinum, iridium) cause image distortions and signal loss in MRI images, making brain tissue visualization difficult (fig. 1 & fig. 3) [2,6].
- **Safety**: RF fields in MRI can heat EEG components and surrounding brain tissues, and risks from displacement force and torque in the static magnetic field (fig. 1) [3, 4].

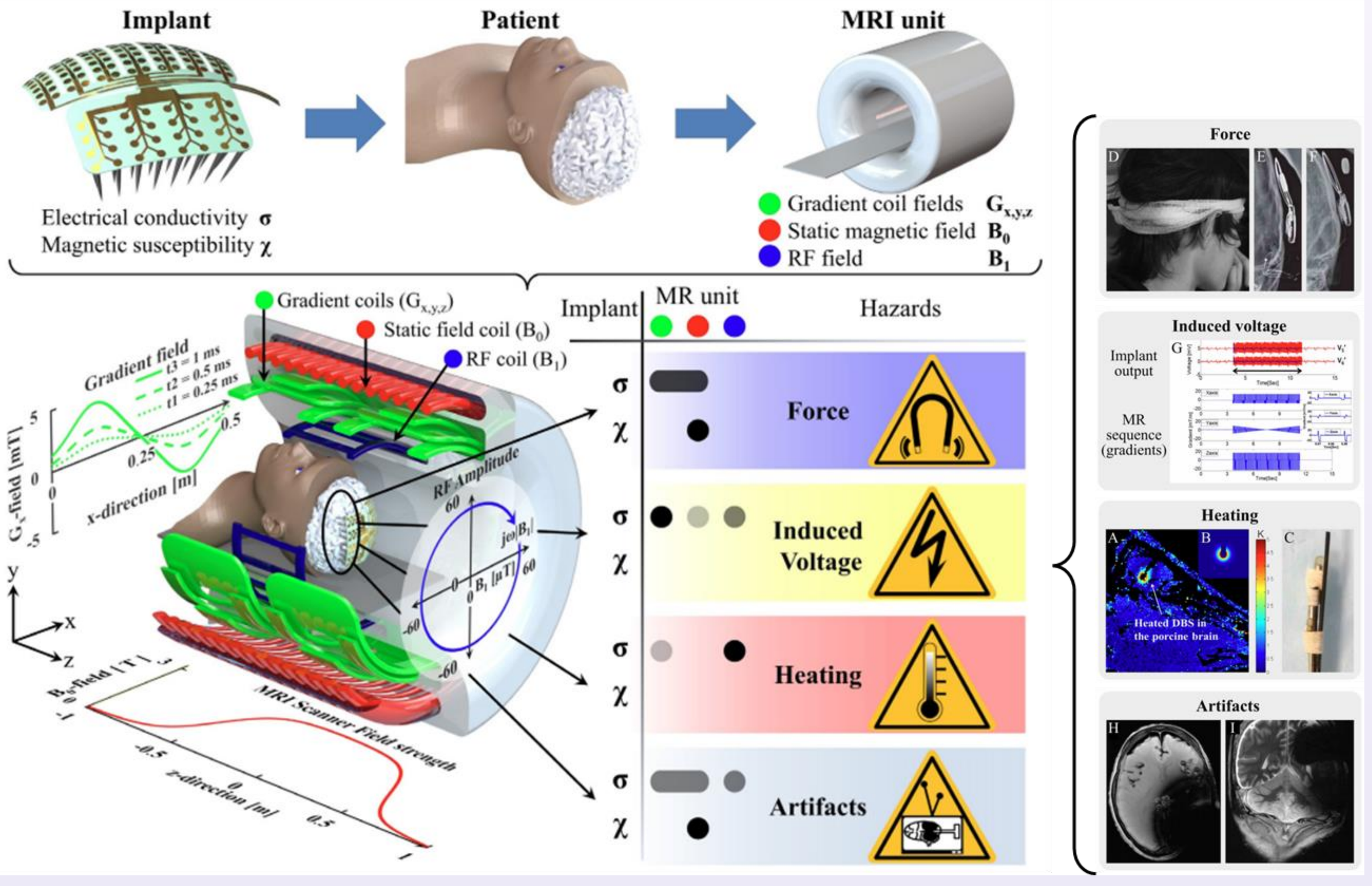

Figure 1. Types of interactions in the MRI environment due to the implant and their related consequences[2,3,4].

OBJECTIVES

We recently demonstrated that graphene-based electrophysiology probes (Graphene Solution-Gated Field-Effect Transistors, or gSGFET) probes (fig. 2A) [5], offer several advantages over existing electrodes. These advantages include a significantly reduced amount of metal that can interfere with MRI (fig. 3) [6,7] and high-fidelity DC-coupled brain signal recording (fig. 2B) [8]. The aims of this project are:

1. **Probe localization**: Fiducial technology and validation of rodent probe MR localization and compatibility *ex vivo*.
2. **Evaluation**: Assessing the ability to visualize MRI biomarkers of epilepsy in the immediate vicinity of the probe *in vivo*.
3. **Demonstration**: Showing probe compatibility with MRI for concurrent electrophysiological and fMRI measurements in rodents.
4. **Design and development**: Demonstrating a scaled-up *ex vivo* clinical version of the probes for human use.

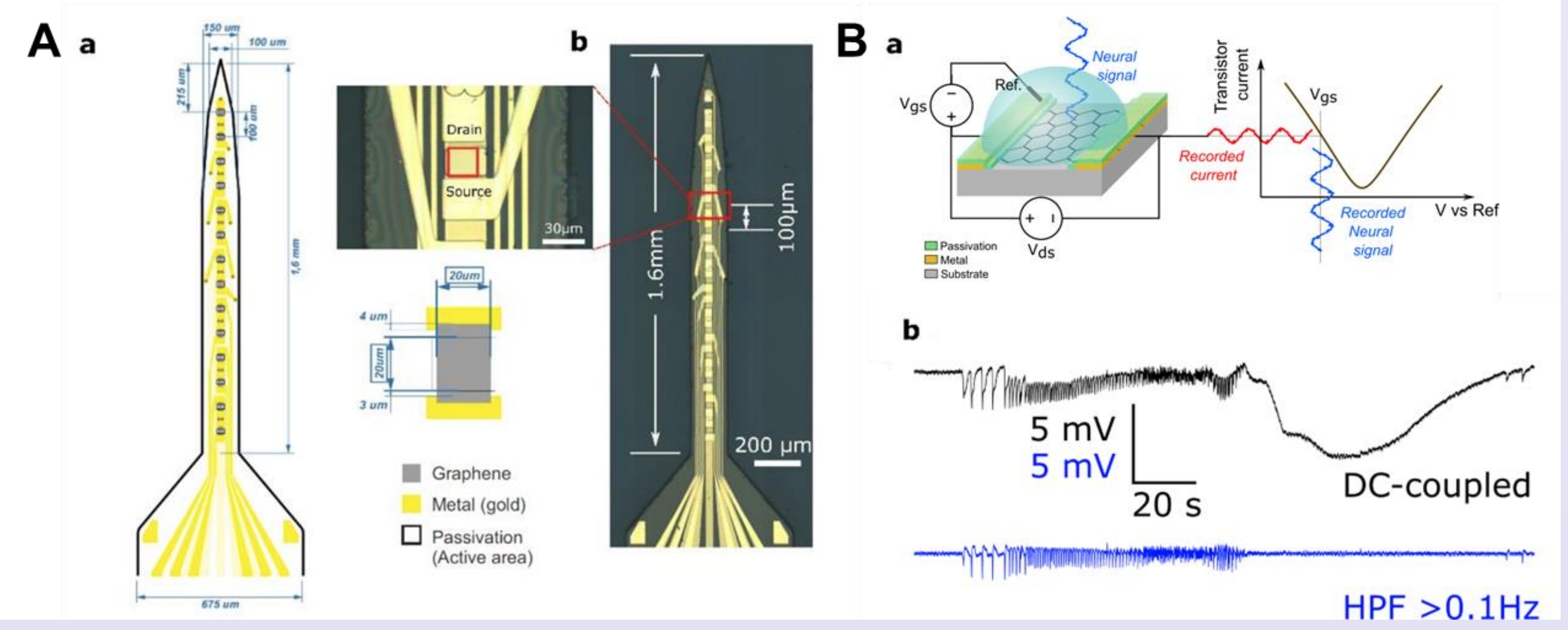

Figure 2. A. Schematic drawing and design of the gSGFET probe array[5], B. Schematic cross-section of a graphene micro-transistor and DC-coupled recording of a seizure and spreading depolarization[8].

EXPERIMENT AND INITIAL FINDINGS

- We conducted *ex vivo* phantom and *in vivo* rodent experiments using the gSGFET probes within the preclinical 7T MRI system at UoM (Fig. 4, 5).
- The initial experiments show promising results, including artifact-free MR images and no breakdown of the graphene probes during functional tests in an *ex vivo* phantom. Ongoing work is to optimize *in vivo* visualization in rodent brain.
- In future work, concurrent EEG-fMRI studies will be conducted *in vivo* in chronically epileptic rodents.

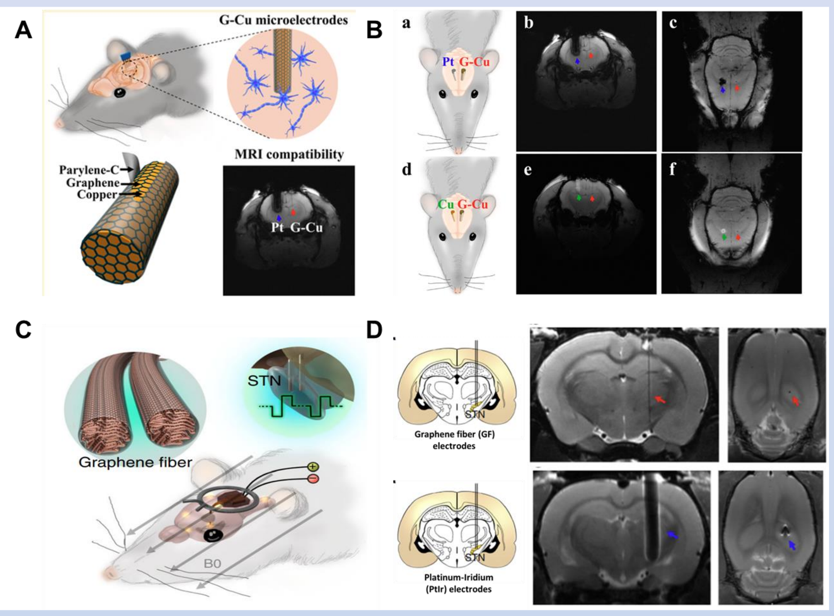

Figure 3. Example of graphene electrodes. A, C. Schematic drawing of the graphene-based implanted neural electrodes; B, D. MRI artifact properties study[6].

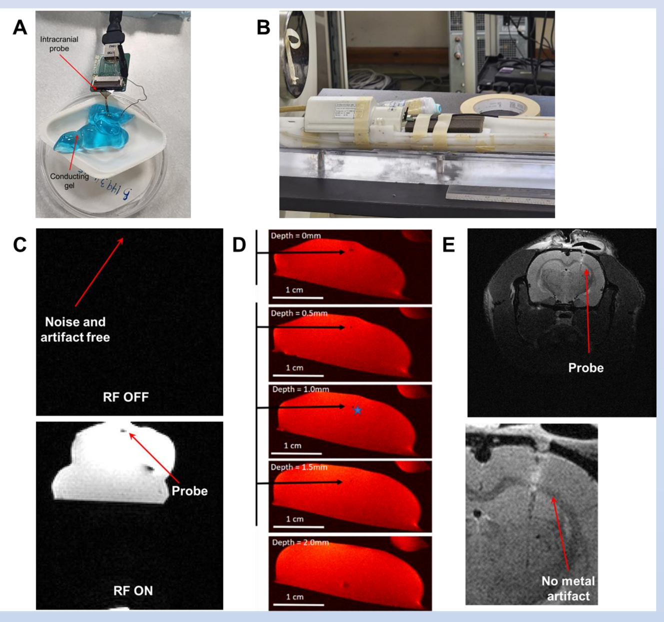

Figure 4. A, B. Experimental setup of the graphene gSGFET in MRI; C, D,E. MRI artifact study in *ex vivo* phantom with epicortical, & intracortical probes, and *in vivo* (rat) with intracortical gSGFET array.

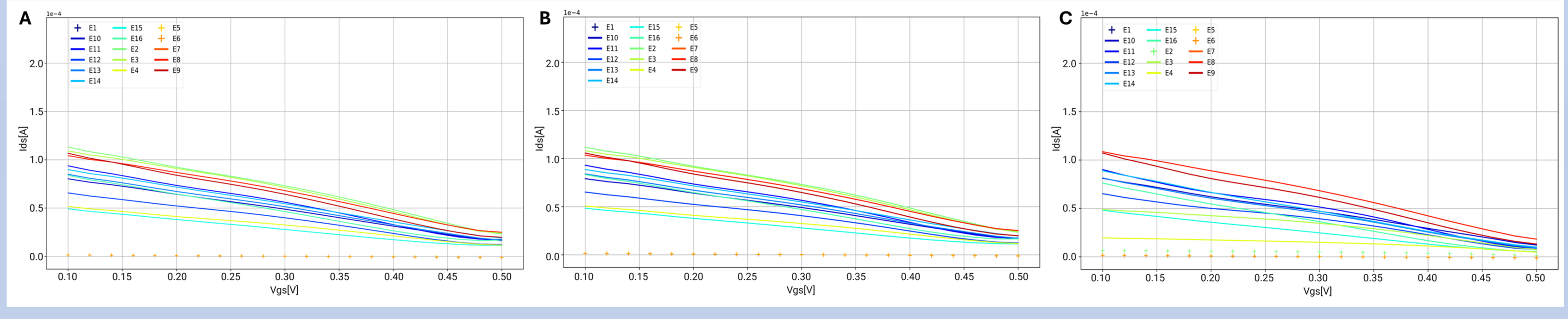

Figure 5. Transfer characteristics of the graphene micro-transistors. A. Transfer curve outside the MRI scanner; B. Transfer curve inside the MRI scanner with both RF and gradient OFF; C. Transfer curve inside the MRI scanner with both RF and gradient ON. The magnetic fields or scanning sequences did not break or damage the micro-transistors.

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