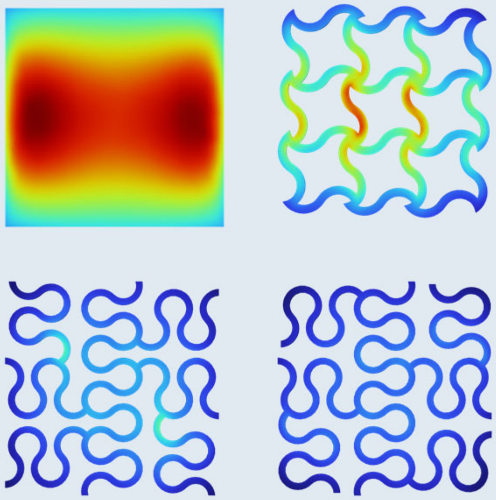

Design Optimization for MRI-Compatible, Transparent PEDOT:PSS Neural Implants using Mesh Strategy

This work introduces a fully MRI-compatible PEDOT: PSS neural interface, optimized with open and closed mesh designs, where the open mesh arrangement significantly reduces temperature rise and imaging artifacts compared to closed configurations.

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Introduction

Understanding brain function is essential for advancing our comprehension of human cognition, behavior, and neurological disorders. Magnetic resonance imaging (MRI) stands out as a powerful tool for exploring brain function, providing detailed insights into its structure and physiology. Combining MRI technology with electrophysiological recording systems can enhance the understanding of brain functionality through synergistic effects. However, the integration of neural implants with MRI technology presents significant challenges due to the strong electromagnetic (EM) fields generated during MRI scans.

In this study, we introduce a fully MRI-compatible monolayer open-mesh pristine PEDOT: PSS neural interface. This approach addresses challenges associated with traditional metal-based electrodes in MRI environments, such as induced heat and imaging artifacts. PEDOT: PSS, with its diamagnetic properties, low electrical conductivity, and negative magnetic susceptibility similar to human tissues, combined with an optimized open-mesh structure, significantly diminishes induced currents, leading to enhanced MRI compatibility.

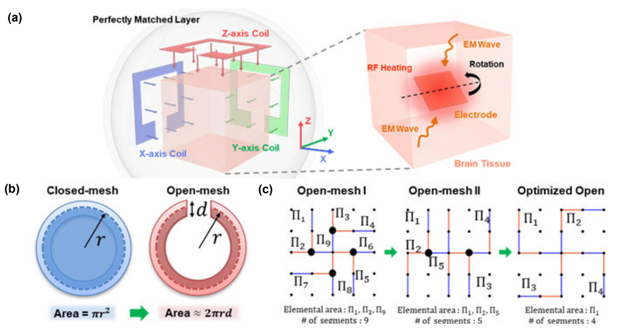

FIGURE 1: (a) Simulation setup. (b) Mesh structure optimization theory. The open-mesh structure effectively reduces the closed contour loop area (CCLA). A decrease in CCLA yields lower induced voltage in an MRI environment. (c) Open-mesh optimization theory. Even though each open-mesh pattern has identical CCLA, optimized open-mesh evokes the lowest induced voltage in the MRI environment.

Methodology

The COMSOL Multiphysics simulation modeled the electromagnetic heating of a neural implant within brain tissue under MRI conditions. The setup involved a brain tissue phantom and electromagnetic coils to simulate MRI environments, using the Electromagnetic Waves and Bioheat Transfer modules. Simulations compared open-mesh and closed-mesh PEDOT: PSS electrodes against a platinum (Pt) electrode, focusing on specific absorption rate (SAR), temperature rise, and induced currents. The study aimed to optimize electrode design for improved MRI compatibility, reducing tissue heating and image artifacts. The total induced voltage is given by

Induced Voltage

$$\oint_{\partial\Pi} \vec{E}\cdot\vec{dl} = \sum_{i=1}^{N} \iint_{\Pi_i} \frac{\partial\vec{B}}{\partial t}\cdot\vec{dA}$$

Total Area of Elemental CCLA

Results

The COMSOL Multiphysics simulation results validated the theoretical analysis, demonstrating that the optimized open-mesh PEDOT:PSS structure significantly enhances MRI compatibility compared to unoptimized designs. The optimized open-mesh design showed a 46% lower electric field magnitude than closed-mesh, resulting in a reduced peak temperature rise of 0.3 K, only slightly higher than the control tissue at 0.2 K. Additionally, the optimized design exhibited significantly lower magnetic field gradients, reducing image artifacts by 88% compared to unoptimized meshes. This design effectively minimizes induced currents and temperature rise, which is crucial for safe and artifact-free MRI imaging, verified experimentally.

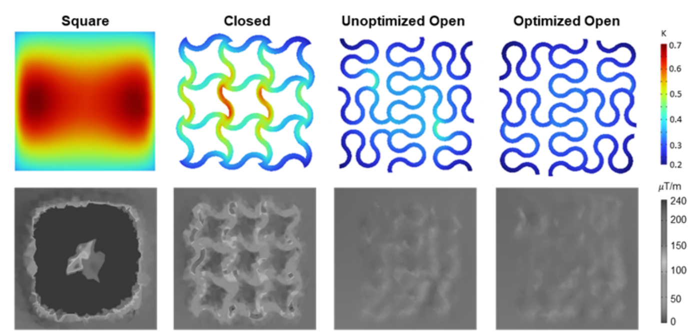

FIGURE 2: (Top)Temperature rise simulations. (Bottom) Magnetic field gradient simulations corresponding to MRI image artifacts.

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