Project Details	
Project Code	MRCNMH25Br Whitcomb
Title	Optical micro-structures and their application in next-generation brain-computer interface systems
Research Theme	Neuroscience & Mental Health
Summary	Brain-computer interfacing (BCI) could fundamentally transform how humans interact with computers. Current uses include prosthetic limb control, but future use could involve transformative technologies ranging from thought-controlled electronics to joint human-machine decision making. Realising these aims has proved difficult, however, largely due to major technological challenges in: (1) accessing brain signals in sufficient high-fidelity to serve as meaningful input to computer systems, and (2) delivering information from computer systems into the brain in a safe, fast and reliable way. This project will explore solutions to these problems, designing, developing and testing novel BCI technologies.
Description	**Background** Brain-computer interfacing (BCI) holds huge potential to transform how humans interact with computer-controlled systems. Applications range from thought-controlled electronics to human-machine decision making. Such is the potential impact of these technologies that the area is attracting vast investment globally: perhaps the most publicised enterprise, Neuralink, is valued at $5 billion. BCI appears to be poised to make major advances. However, there are major technology road-blocks that still constrain the BCI application space. An effective 'closed-loop' BCI system – where computer systems and neural networks seamlessly communicate - require a means to read brain signals (the 'input' to computer systems), and a way to relay information back into the brain (via neural stimulation) (Wang et al., 2023). Current approaches use metal electrodes (Wu et al., 2021), which stimulate and detect activity of populations of neural cells (Buzsáki et al., 2012). However, electrodes are fundamentally limited. Firstly, only population-level signals are detected, failing to capture the significant signal heterogeneity between neurons (Gjorgjieva et al., 2016). Secondly, stimulation is indiscriminately delivered to large groups of cells, limiting the ability to interact precisely with neural circuits. This means that current BCI approaches are unable to interface with complex neural circuitry, limiting effectiveness. **Objectives** In this studentship, we aim to explore the potential of a novel approach to BCI, where traditional electrical stimulation and signal acquisition is replaced with all-optical components. The Supervisory Team have developed a compelling conceptualisation of what a optical BCI system would look like, and have preliminary pilot data defining basic parameters. The key research question of this project is: How can optical stimuli and signal signatures be used to establish closed-loop neural interface systems? To address this question, the project will take an interdisciplinary approach, from the conceptualisation and manufacture of micro-

	fabricated optical probes, through to biocompatibility testing and ultimately BCI application in vivo. The project objectives are: 1. Using our existing pilot concept as a base; scope, develop and design optical components. 2. Fabricate optical components into integrated optical BCI probes. 3. Determine biocompatibility of probes. 4. Characterise functionality of probes and apply in in vivo rodent models. **Student ownership and steer of project** From the outset, the student has significant scope to take ownership and steer the project. Following a scoping review, using our existing pilot data and conceptualisation as a launching point, the student will develop unique expertise in current approaches to probe design and knowledge of the parameter space within which our optical probe will operate. This will enable the student to drive the direction of the component selection, manufacture, form-factor design and ultimately probe assembly and testing. Importantly, the student will receive training across materials engineering, biocompatibility testing and in vivo implantation and neural measurement applications – reflective of the expertise of the supervisory team. As such, the student will be uniquely equipped with transdisciplinary expertise that will make them the best person qualified to drive the development of the project. The student will first explore existing BCI tools, performing in vivo electrophysiology experiments (Primary Supervisor Dr. Whitcomb). The student will then develop and fabricate optically-active compound semiconductor (CS) materials to produce microstructures representative of those used to create functional BCI devices, in the Institute for Compound Semiconductors (Co-Supervisor Dr. Shutts). The student will then characterise the assemblies through a series of mechanical and conductivity assays, including stress/displacement tests and durability testing (Co-Supervisor Dr. Leese). The student will then explore biocompatibility in brain tissue (Primary Supervisor Dr. Whitcomb), and in human brain organoids (Co-Supervisor Dr. Piers). The student will therefore gain valuable experience in material manufacture, in vitro brain tissue electrophysiology, human cell organoid culturing, and materials stress-testing. Finally, through iteration of the above process, the student will apply, test and characterise their developed technology in real-world applications in vivo.
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