Is it possible to imagine a material that for years has been used to produce durable heart implants, and today has the potential to become the foundation for modern technologies to treat brain and nervous system diseases? Such a material is pyrolytic carbon (PyC). Although it does not sound as spectacular as "graphene" or "carbon nanotube," PyC holds tremendous scientific potential, and its textural variants share many features with carbon nanomaterials due to their similar structural architecture. This unique structure and the "imperfect" arrangement of tiny graphene domains create a network with numerous defects which, previously associated with material flaws, here become an extraordinary asset. Thanks to this architecture, modifying the surface of PyC becomes relatively less problematic and less expensive, which in turn allows for the exposure of even more defects and active sites, enabling precise tailoring of its properties to the needs of medicine and electrochemistry.

Why is PyC so promising? In recent years, scientists have focused intensely on nanomaterials which, although they have excellent properties, are difficult to work with, costly to produce, and often hazardous to health. Pyrolytic carbon, despite certain differences, combines the advantages of these nanomaterials (a large number of active surface sites, high conductivity) with the durability and safety of classic solid materials. Moreover, PyC has long been used in implantology because it is durable and highly biocompatible. Unfortunately, its potential in modern technologies remains largely untapped.

The aim of this project is to study the influence of various functionalization and doping techniques for PyC structure (chemical, electrochemical, plasma/ozonation) on the possibility of achieving such physicochemical, electrochemical, and biological properties that would allow for the prospective creation of a new generation of electrodes and their use in neurostimulation. Stimulation of neurons is a method of intentional, controlled modulation of the nervous system using electrical impulses, aimed at modulating neuronal activity in the treatment of various neurological disorders. Both deep brain stimulation (DBS) and percutaneous electrical nerve stimulation (PENS) are extremely important therapies because—despite differences in location and mechanism of action—they enable effective treatment of diseases sometimes resistant to pharmacotherapy, such as Parkinson's disease, chronic pain, or mood disorders, significantly improving patients' quality of life. An innovative aspect of this project, in the perspective of creating a next-generation electrode material, is also the ability to detect important neurotransmitters such as dopamine (a particularly important factor, for example, in Parkinson's disease). It is precisely the ability to stimulate and monitor the brain's chemical state that opens the way to so-called closed-loop therapy—intelligent treatment systems that in the future could automatically adapt to the patient's needs in real time.

The project will employ an innovative method of pyrolytic carbon synthesis based on chemical vapor deposition with direct electric heating of a fiber bundle (DHF-CVD), which allows for rapid and precise production of carbon fiber-based composites (CF/PyC) with controlled microstructure. These materials will be subjected to three different functionalization methods to improve their electrochemical and possibly biological properties. The introduced, primarily oxygen and/or oxygen/nitrogen functional groups will be decisive in charge storage processes, reactions with neurotransmitters, and safety for neural cells.

The research will include: advanced analyses of structure, texture, and chemical composition; measurements of electrochemical properties; simulated pulsed stimulation tests; dopamine detection; and biocompatibility assessment using human neural cells. The electrode material will also be tested under conditions similar to those prevailing in the human body, including mechanical aspects, which is important in the context of PENS therapy.

Why is this important? This project responds to the growing needs of modern medicine, especially in the face of an aging society and an increasing number of neurological diseases. Currently used metal electrodes are expensive, have limited lifespan, and can cause oxidative stress, glial scarring, and ultimately tissue inflammation. The new, functionalized CF/PyC-Ox composites have the potential to be not only cheaper and more durable, but also more biocompatible and better suited for individualized neuromodulation, additionally enabling neurotransmitter detection—which opens entirely new perspectives for neurological therapies, from Parkinson's disease treatment to modern pain management methods.

The project is based on a modern, interdisciplinary approach and utilizes the potential of the thus-far underappreciated textural pyrolytic carbon. Understanding the relationships between structure, functionalization, and the electrochemical and biological properties of these materials may contribute not only to the development of new therapies, but also to the advancement of carbon science and defect engineering in these materials.