SUSTAINABLE MATERIALS, PROCESSES AND SYSTEMS FOR ENERGY TRANSITION

DM 629 Transizioni/UNIAQ - Electronic properties of topological materials and their surface excitations for the energy and environmental transition

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Context of the research activity	The sustainable production of hydrogen is essential for a clean and environmentally friendly energy future. Currently, most hydrogen is produced via steam reforming, a process that utilizes fossil fuels and generates CO2 emissions. However, water splitting offers a sustainable alternative by using renewable energy to produce hydrogen from water. Water splitting, the process of splitting water into hydrogen and oxygen, is fundamental to the sustainable and eco-friendly production of hydrogen. The Hydrogen Evolution Reaction (HER) and the Oxygen Evolution Reaction (OER) are the two electrochemical reactions that occur during water splitting, taking place at the cathode and anode surfaces, respectively. HER generates hydrogen from water, while OER produces oxygen. The success of these reactions hinges on the efficiency and stability of the materials used as catalysts. Progetto finanziato dal PNRR a valere sul DM 629/2024 "Transizioni digitali e ambientali" - CUP: E14D24002250006

	Similarly, membrane distillation is an emerging technology in the field of environmental transition that benefits from electronic excitations in innovative materials. Quantum materials, such as Weyl and Dirac semimetals, exhibit unique electronic properties that can enhance the efficiency of both catalysis and thermoplasmonic membrane distillation. This research proposal aims to design, synthesize, and characterize these quantum materials, analyzing their electrical conduction properties and evaluating their catalytic performance in HER and membrane distillation, also leveraging new technologies based on quantum material plasmons. The doctoral candidate will use surface-science experimental tools to

Objectives	investigate the excitation spectrum in topological materials in order to carry out research able to support the new technologies enabled by the unusual properties of plasmonic modes in topological materials for the energy and environmental transition. The electronic and optical properties of topological materials play a pivotal role in next-generation technologies for the energy and environmental transition. Specifically, collective electronic excitations in nanostructures of topological materials represent nano-sources of heat, beneficial for thermoplasmonic effects. The primary focus will be on experimental approaches, involving the synthesis and characterization of new quantum materials. Single crystals will be synthesized and characterized using advanced techniques such as chemical vapor deposition (CVD) and molecular beam epitaxy (MBE). The catalytic efficiency and stability of these materials will be studied in detail using advanced characterization techniques. In addition, functional inks will be developed through liquid-phase exfoliation of these quantum materials. These inks will be utilized for various applications, including electrocatalysis, sensing, and thermoplasmonic technologies. The versatility of these functional inks will bridge the gap between basic research and industrial applications, providing significant potential impact in the field of energy and environmental transition. The ultimate goal is to develop quantum materials for HER with high catalytic performance, stability, and durability, contributing to the sustainable production of hydrogen and the transition to a low-carbon economy. The same technologies will be used for thermoplasmonic membrane distillation. The success of this research could have a significant impact on hydrogen production, water desalination, precious mineral recovery, and the adoption of clean energy technologies, reducing dependence on fossil fuels and contributing to the fight against climate change. The combined approach of synthesis and experimental characterization will allow for the design, creation, and performance evaluation of these materials. The final result could have a significant impact on the entire energy sector, supporting the transition to a low-carbon future thanks to the potential offered by quantum materials.

Skills and competencies for the development of the activity	The doctoral candidate should have a solid background in surface science and extensive experience with advanced experimental techniques such as angle-resolved photoemission spectroscopy (ARPES), electron energy loss spectroscopy (EELS), and atomic force microscopy (AFM). Furthermore, the candidate should have prior experience in studying plasmonic excitations and their applications in energy and environmental technologies.