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ABSTRACT

Research problem and objectives

Experimentally realizing quantum phases of matter and manipulating their properties is a central goal of the physical sciences. The key objective of the proposed program is to utilize ultra-fast light pulses to discover new forms of transient quantum matter by driving complex materials out of equilibrium. The PI will focus on optically-induced phenomena in atomically layered van der Waals (vdW) materials including graphene and transition metal dichalcogenides (TMDCs). Prior work on these vdW systems (including research by the PI) has largely focused on observing and elucidating the enigmatic physics of these solids. Empowered by these observations, the PI has developed a higher ambition – to create *on-demand* novel quantum phases by applying nano-optical quantum methods and intense femtosecond light stimulation to state-of-the-art vdW meta-structures. Spatially confined light ("nano-light") provides unrivaled advantages for implementing non-equilibrium states of quantum matter on demand.

Technical approaches

The proposed program is a trailblazing effort that will use ultra-fast control in the regime of strong light-matter interaction, in which coherent light pulses alter the electronic structure of vdW systems through photon dressing effects. The PI will create, visualize and exploit ondemand topologically protected states in vdW meta-structures (Thrust 1). Furthermore, the PI will investigate a means to create macroscopically coherent states in the excitonic systems of vdW structures (Thrust 2). A signature observable of transient topological properties is the formation of symmetry protected surface or edge states that arise at the interface between a topological phase and a conventional phase. Direct inquiry into edge states and condensation phenomena relies on femtosecond nano-scale optical imaging with unique scanning probe tools already demonstrated by the PI. Pump-probe nano-light experiments will be applied to vdW meta-structures in which the twist angle between adjacent atomic layers can be varied by nanomechanical means, offering extraordinary tunability. The PI will carry out nano-optical experiments on vdW heterostructures fabricated by world leaders at government laboratories and universities collaborating on the proposed program.

Anticipated outcomes and impact on DoD capabilities

The proposed leap from observations to creation of desired effects and states of matter in complex tunable materials/meta-structures is essential for realizing the revolutionary promise of quantum technology in information transfer, processing, and sensing. The proposed work will fully uncover the potential of on-demand properties of vdW materials for quantum technology hardware. Long-sought benefits of topological protection, an exceptionally striking phenomenon in modern physics, will be implemented in compact, lightweight, flexible structures at ambient conditions, thus meeting the many stringent requirements for technological relevance. The proposed research will enable practical control of photo-induced phenomena in new photonic, electronic, and energy technologies, a task of far-reaching societal impact.

The proposed program emphasizes the development and refinement of one-of-a-kind tabletop multi-scale/multi-modal instrumentation suitable for the investigation of new materials at femtosecond time scales and nanometer length scales. This aspect of the program includes the proactive use of machine learning in infrared imaging applications, with broad impact in defense-related photonics capabilities.