

Materials have always been the driving force behind developments of societal importance. It is no wonder that we have called the epochs of humankind history according to the materials that were responsible for the change, e.g., the Stone or the Bronze age. In recent years, two-dimensional (2D) materials offered a plethora of exciting properties of transformative character. While initially carbon based 2D materials in the form of graphene were important, a large variety of different materials were synthesized soon after. Our ability to tune their compositions and arrangements provides unprecedented opportunities from an electrical, thermal, mechanical or, for us most important, optical perspective.

2D materials, in the pertinent context, are appealing as they provide a versatile playground for nanoscale optoelectronics: different materials with a thickness of a single atom layer offer a great variety of optical properties. From material to material, these properties differ across a broad range of electromagnetic frequencies. Effects of interest are the broadband optical absorption with applications to photovoltaics, the transduction or the light emission from microwave to ultraviolet frequencies. In particular, the incorporation of defect sites enables emission of photons with statistical properties tailored for quantum applications. In 2D materials, charge mobility can be controlled by ultrafast gating, which enables optoelectronic applications of paramount importance such as fast, broadband, and atomically-thin electro-optical modulators or tunnel transistors.

Yet, 2D materials allow much more: whole new potentials unfold when monolayered materials are stacked, forming artificial, man-engineered heterostructures of properties controllable by design, but also electrically, or optically tunable. For example, combining a graphene with a hexagonal boron nitride monolayers allows to modulate graphene's optical and electronic properties, turn it from a metal to a semiconductor, and ultimately to integrate it into optoelectronic devices such as field-effect transistors, Ohmic contacts, and Schottky barriers. A heterostructure combining different 2D materials playing roles of electrical contacts, tunnel barriers and active regions where electron-hole recombination occurs, can make a microscaled light emitting device. Bilayer transition metal dichalcogenides sustain a unique optical response at so-called magic angles which enables guided propagation of extremely confined electromagnetic fields; giving rise to the field twistorics which might potentially replace traditional electronics in some applications.

While some of these properties have been explored for infinitely extended layers, our project is tailored to provide insights into the physics of heterostructures made from flakes or ribbons of different 2D materials. We will explore the potential of 2D materials to achieve optoelectronic devices miniaturized down to the nano- or microscale. We combine beneficial aspects of various materials and to unlock properties encountered only upon combining different materials. We will study pristine materials but also those with defects, often considered as a nuisance. We expect to exploit them to tune the properties, such as the spatial location of a light emission site, to the point in an optimal sense. Combining or rotating several material flakes we will engineer the spectral properties of such sources and their directionality. We will explore how the energy characteristics of such nanoflakes or ribbons rely on external electric gating, and exploit that information to develop our contribution further towards miniaturized electro-optic modulators. We will study the electron tunnelling through insulating barriers in nanostructures for nanoscaled tunable tunnel transistors. FLAT will provide and exploit tools to study the electron dynamics in such devices with a spatial resolution at the level of single atoms.