TUT 2: 2D Quantum Materials and Heterostructures: From Fabrication to Applications (joint session HL/TUT)

Due to the atomic thickness of 2D materials, stacking of different monolayers has opened the door for artificial van der Waals heterostructures. By exploiting the strongly different nature of the individual layers (semiconducting, metallic, magnetic, superconducting, etc.) and rotating them from layer to layer, heterostructures with unique physical properties and functionalities can be envisioned for novel electronic or optical devices. The tutorial will cover the fabrication of these heterostructures and their potential use in applications ranging from electronic to optical devices, operating at the quantum level.

Time: Sunday 16:00–18:20 Location: H2

Tutorial TUT 2.1 Sun 16:00 H2

Discovering, Creating, and Exploring Novel Atomically-Thin Materials and Heterostructures — •Joshua Robinson — The Pennsylvania State University, University Park, PA, USA

The last decade has seen an exponential growth in the science and technology of two-dimensional materials. Beyond graphene, there is a huge variety of layered materials that range in properties from insulating to superconducting. Furthermore, heterogeneous stacking of 2D materials also allows for additional dimensionality for band structure engineering. In this talk, I will discuss recent breakthroughs in two-dimensional atomic layer synthesis and properties, including novel 2D heterostructures and realization of unique 2D allotropes of 3D materials (e.g. 2D metals and oxides). Our recent works demonstrate that the properties and doping of 2D materials, especially synthetic 2D materials, are extremely sensitive to the substrate choice. I will discuss substrate impact on 2D layer growth and properties, doping of 2D materials, selective area synthesis of 2D materials, and creating 2D allotropes from traditionally 3D materials for photonic and quantum applications. Our work and the work of our collaborators has lead to a better understanding of how substrate not only impacts 2D crystal quality, but also doping efficiency in 2D materials, and stabilization of 3D materials at their quantum limit.

Tutorial TUT 2.2 Sun 16:35 H2

Non-identical moire twins in bilayer graphene — •Rebeca Ribeiro-Palau[1], Everton Arrighi[1], Viet-Hung Nguyen[2], Mario Di Luca[1], Gaia Maffione[1], Kenji Watanabe[3], Takashi Taniguchi[3], Dominique Mailly[1], and Jean-Christophe Charlier[2] — [1]Universite Paris-Saclay, CNRS, Centre de Nanosciences et de Nanotechnologies (C2N), 91120 Palaiseau, France — [2]Institute of Condensed Matter and Nanosciences, Universite catholique de Louvain (UCLouvain), 1348 Louvain-la-Neuve, Belgium — [3]National Institute for Materials Science, 1-1 Namiki, Tsukuba, Japan

I will present recent results which demonstrate that the moire superlattice formed by a bilayer graphene aligned with BN, is present every 60 deg, but the symmetry is broken between the 0 deg and 60 deg alignments, creating non-identical "moire twins" with different electronic properties. In particular, electron transport measurements display a fully developed valley Hall effect at 0 deg while on the contrary, it is completely absent at 60 deg. We explain this effect by performing numerical simulations, which highlight the central role of the atomic-scale structural relaxation of the second graphene layer. This in-plane atomic relaxation, different for the two alignments, impacts on the electronic band structure of our system. Our results demonstrate that in situ control of the rotational order provides a unique insight on the interplay between mechanical and electronic properties, and increases the posibilities for band-structure engineering on van der Waals heterostructures.

Tutorial TUT 2.3 Sun 17:10 H2

Single-photon emitters in 2D materials — •Steffen Michaelis de Vasconcellos — University of Münster, Institute of Physics and Center for Nanotechnology, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany

Single-photon sources are key components for quantum technologies, such as communications, cryptography, computation, and metrology. Recently, the family of solid-state quantum light emitters was joined by single-photon sources in atomically thin materials [1]. Compared to 3D bulk materials, the 2D host crystals with their high structural flexibility allow for a high photon extraction efficiency, new methods for the deterministic creation, and convenient integration with photonic circuits.

In this tutorial, I will introduce the basic properties of single-photon emitters in different 2D van der Waals material systems and discuss present experimental methods for their creation, control, and coupling to photonic nanostructures.

[1] S. Michaelis de Vasconcellos et al., "Single-Photon Emitters in Layered Van der Waals Materials," Phys. Status Solidi B **2022**, 259, 2100566

Tutorial TUT 2.4 Sun 17:45 H2

Introduction to 2D superconducting spintronics — •Elke Scheer — Department of Physics, University of Konstanz, Konstanz

The proximity effect between a conventional (s-wave) 3D superconductor (S) and a ferromagnet (F) can lead to the formation of Cooper pairs with parallel-spin (spin-triplet) alignment instead of the conventional antiparallel-spin (spin-singlet) state. The demonstration of spin-triplet generation in S/F systems [1,2] has inaugurated the field of superconducting spintronics aiming at developing energy-efficient spintronic devices [3]. Both superconductivity and ferromagnetism depend on the dimensionality of the system, but have been shown to exist in 2D or quasi-2D systems [4,5]. The possibility to exfoliate layered van der Waals (vdW) materials down to the few-layer limit [6] in combination with the existence of S and of F vdW materials makes this material basis in particular promising to explore triplet S in 2DS/2DF heterostructures. In this tutorial talk I will briefly recall the physics of SF spintronics in 3D, before I will describe the particular properties and challenges in the investigation of 2D-SF hybrid systems and give an overview over the so far best-studied material combinations and target devices.

[1] R. Keizer et al., Nature 95, 825 (2006)
[2] A. Buzdin, Rev. Mod. Phys. 77, 935 (2005)
[3] J. Linder & J. Robinson, Nature Phys. 11, 307 (2015)
[4] B. Huang et al., Nature 546, 270 (2017)
[5] M. Smidman et al., Rep. Prog. Phys. 80, 036501 (2017)
[6] A. K. Geim & I. V. Grigorieva, Nature 499, 419 (2013).