'Physique et Chimie des Matériaux' – ED 397 – année 2022

PhD project for funding, to send by 28/02/2022 to

nadine.witkowski@sorbonne-universite.fr under PDF form « acronyme labo_nom PI.pdf »

Research unit (full name + acronym) : IMPMC: Institut de Mineralogie, de Physique des Matériaux et de

Team if applicable : MIMABADI

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Nber of phD under supervision 2 Participation to supervisor training? select Year

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Research unit : MIMABADI

International co-supervision ? No

Keyword 1 : High Tc superconductors Keyword 2 : 2D Materials

Keyword 3 : moiré Keyword 4 : heterostructures

Select co-funding programme if applicable : select

Project title : Superconductivity with a twist

Project Description :

2D materials, a class of layered compounds with strong intra-layer bonds and weak van-der-Waals-like interlayer bonds, have been intensely studied in the recent past in single layer or few layer forms because of their strictly two dimensional nature. Because of weak interlayer coupling they not only allow for exfoliation but also the artifical reconstruction of new materials by stacking layers of different materials with different properties together. These hybrid heterostructures can then be expected to exhibit new properties. A recent member of this family is the twisted bilayer. In this heterostructure, a bilayer of a given material is formed such that one layer is 'twisted' with respect to the other with a certain angle. This seemingly elementary operation has now been shown to have important consequences on the electronic structure of the twisted bilayer. Electronic correlation, superconductivity, topological phases and novel optical phenomena have been demonstrated in twisted bilayers of graphene and other 2D materials (see for examples some recent reviews [1] and [2]).

In this proposal we wish to study the properties of a twisted bilayer of BSCCO ($Bi_2Sr_2CaCuO_{8-x}$), a high temperature superconductor with a critical temperature of nearly 90K. Indeed there are strong indications that twisted BSCCO may exhibit superconductivity with a gap symmetry different from the bulk form [3], or that it may be a material where topological supercondictivity, sought intensely in the past years, may appear [4,5]. We have been studying ultra-thin layers of BSCCO [6-8] in the past few years and have the expertise and necessary experience to initiate this study immediately. Our group is specliaized in the research field of 2D materials and apart from research involving several different families of materials including high-Tc superconductors, transition metal mono and dichalcogenides, graphene and other materials, we have developped experimental methods, techniques and instrumentation which are necessary for this study.

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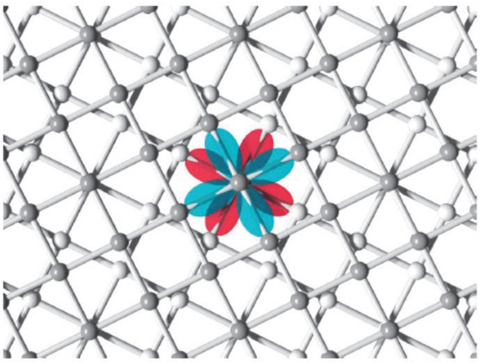
Twisted atomic layers generate composite atomic lattices with what is known as moiré patterns which give rise to a periodicity in real space which is greater than the intrinsic periodicity of the given atomic layer [1]. Moiré lattices are well known in near field microscopy images of 2D materials like graphite where twisting sometimes occurs naturally, appearing typically with a periodicity of several nm, the periodicity being greater the smaller the twist angle. Some general statements about twist angle/periodicity dependent properties induced in moiré lattices can be made [2]. For twist angles of the order of tenths of a degree (periodicity ~100 nm), domain structures and 1D modes have been observed. For twist angles of the order of a few degrees (periodicity ~10 nm), correlated behavior inducing flat bands and superconductivity have been observed in graphene. For twist angles of the order of 10 degrees (periodicity ~1 nm), proximity effects, quasi crystalline (incommensurate) phases and modification of optical properties are expected.

In the case of BSCCO a theoretical study [3] predicts that a 45 degree twist should induce a gapped topological phase with Majorana edge modes and broken time-reversal symmetry. Majorana edge modes are currently thought to be one of the possible ways to construct fault tolerant qubits in the solid state. A recent experiment [4] on such samples observed Josephson tunneling across the thickness of the twisted bilayer. This is unexpected given the d-wave symmetry of the superconducting wave-function in BSCCO, indicating a different symmetry in the twisted bi-layer. Another such experiment [5] claims to see signs of topological behavior in tunneling experiments. The basis of this proposal is our expertise in fabricating and measuring one unit cell BSCCO devices which can be doped electrostatically and where low temperature transport measurements can be performed [6-8]. In recent months we have built a manipulation stage in a glove box which permits the stacking of twisted layers in a controlled manner. Preliminary experiments of vertical tunneling junctions of BSCCO have been performed. Adequate bulk crystalline material of BSCCO for exfoliation is also available.

The candidate will be required to have Masters level knowledge of solid state physics and strong motivation. Experimental experience in the field of 2D materials and devices is welcome though not necessary. The first year of the project will be spent in fabricating and characterising high quality devices with varying twist angles. The next 18 months will involve fine tuning tunneling devices and obtaining low temperature transport and tunnelling characteristics. The last six months will be spent on final measurements and on the thesis manuscript



From [3]. Schematic view of two copper-oxygen square lattices, for example such as those in the BSCCO unit cell, with twist angle close to 45° and the symmetry of the associated superconducting order parameters.

1) He et al. ACS Nano 15, 5944−5958, (2021)
2) Carr et al. Nature Review Materials 5, 748 (2020)
3) Can et al. Nature Physics 17, 519–524 (2021)
4) Yu et al. Phys. Rev. X 11, 031011 (2021)
5) Zhao et al. arXiv:2108.13455v1
6) E. Sterpetti, Johan Biscaras, A. Erb & Abhay Shukla, Nature Communications 8, 2060, (2017)
7) E. Sterpetti, Johan Biscaras, A. Erb and Abhay Shukla, Journal of Physics: Condensed Matter, 32, 045601 (2019)
8) Fang Wang, Johan Biscaras, A. Erb & Abhay Shukla, Nature Communications 12, 2926, 2021