Bose-Einstein condensation of excitons in oxide heterostructures

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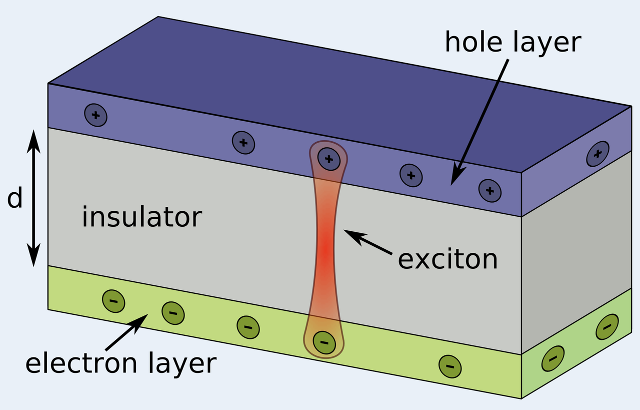
The goal of our research is to investigate theoretically and realize experimentally new states of matter by coupling *p*-type and *n*-type Mott insulators. The physics of Mott insulators is governed by strongly correlated electrons, leading to very rich phase diagrams. Even more interesting phases will arise due to the interplay of electrons and holes at the interface between the *p*- and *n*-type materials. For small layer separation we hope to observe exciton formation with the possibility of exciton Bose-Einstein condensation for low temperatures and low carrier concentrations.

Bilayer exciton condensation

It has been suggested that in electron-hole bilayers the Coulomb attraction between the positive holes and negative electrons can lead to bound electron-hole states known as "excitons".



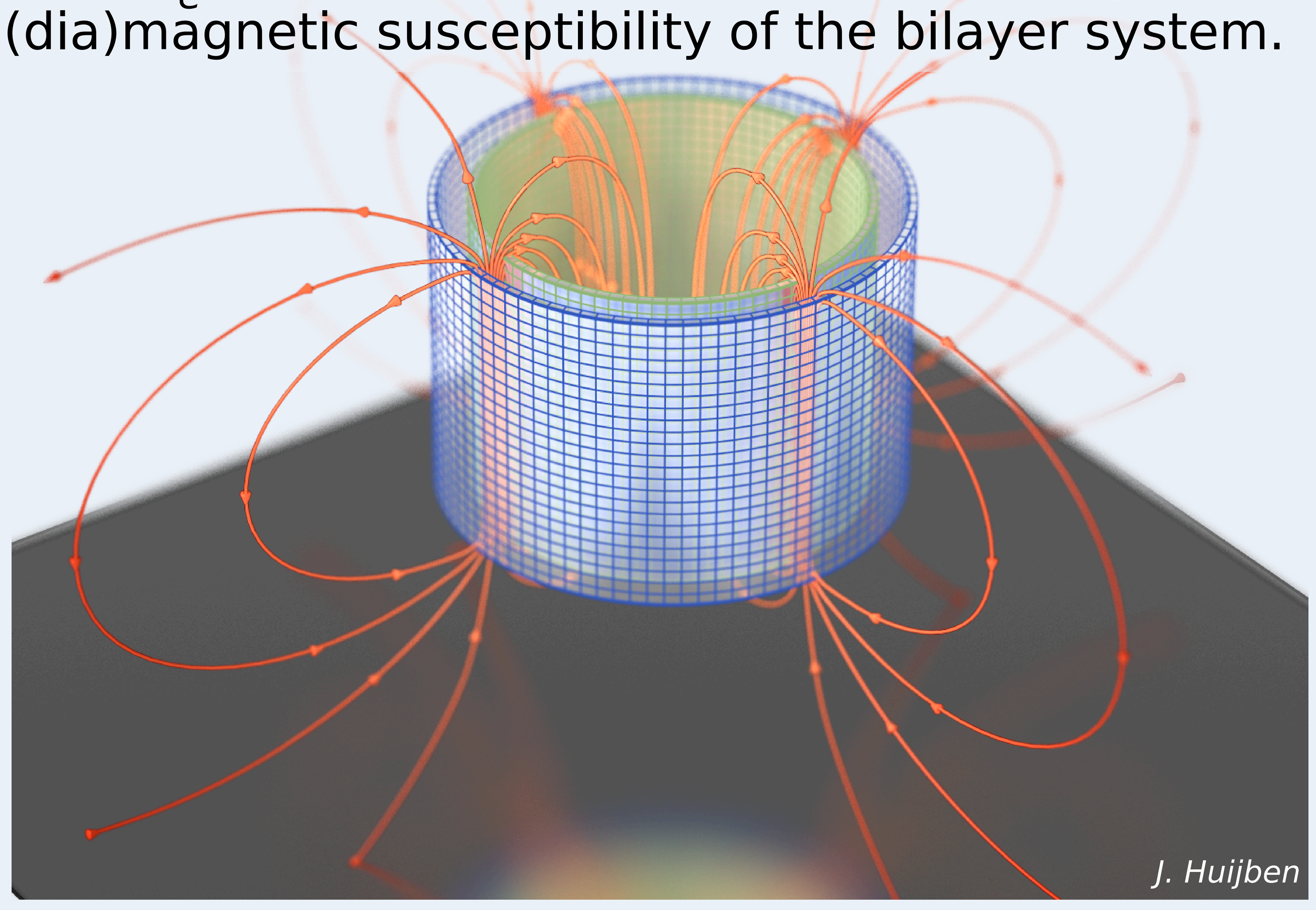
At low temperatures excitons can condense into a superfluid, though the macroscopic coherence inherent to the superfluid phase has not been detected yet.

Flux quantization

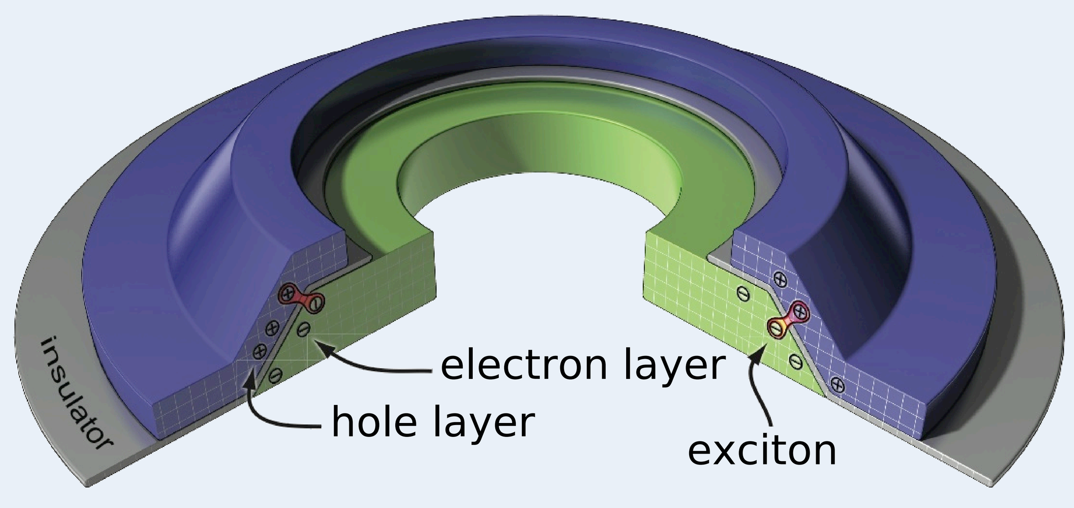
We introduced an experiment that would prove unambiguously the existence of an exciton condensate. We predict that in cylindrical samples the magnetic flux in between the layers (see figure) must be quantized according to

$$\Phi = \frac{h}{e} \chi_m n \qquad (1)$$

where $\frac{h}{e}$ is the fundamental flux quantum, χ_m is the (dia)magnetic susceptibility of the bilayer system.



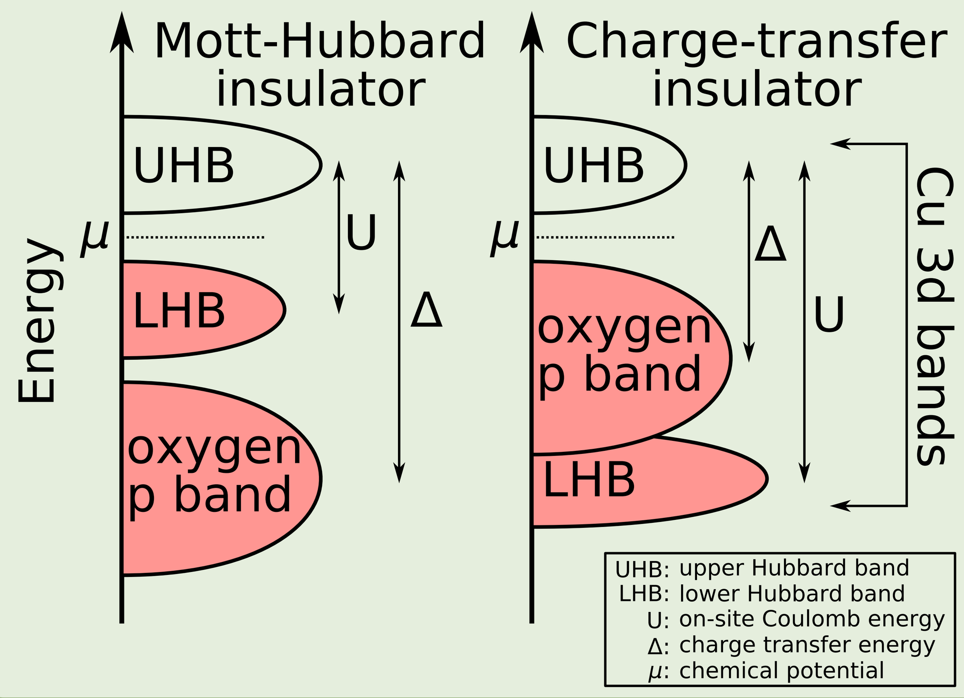
We derived a new model that describes excitons in a *p*,*n*-type Mott bilayer, based on the $t-J$ model. In the future we will derive exciton properties based on this model, such as the single exciton spectral function and the properties of the exciton condensate.

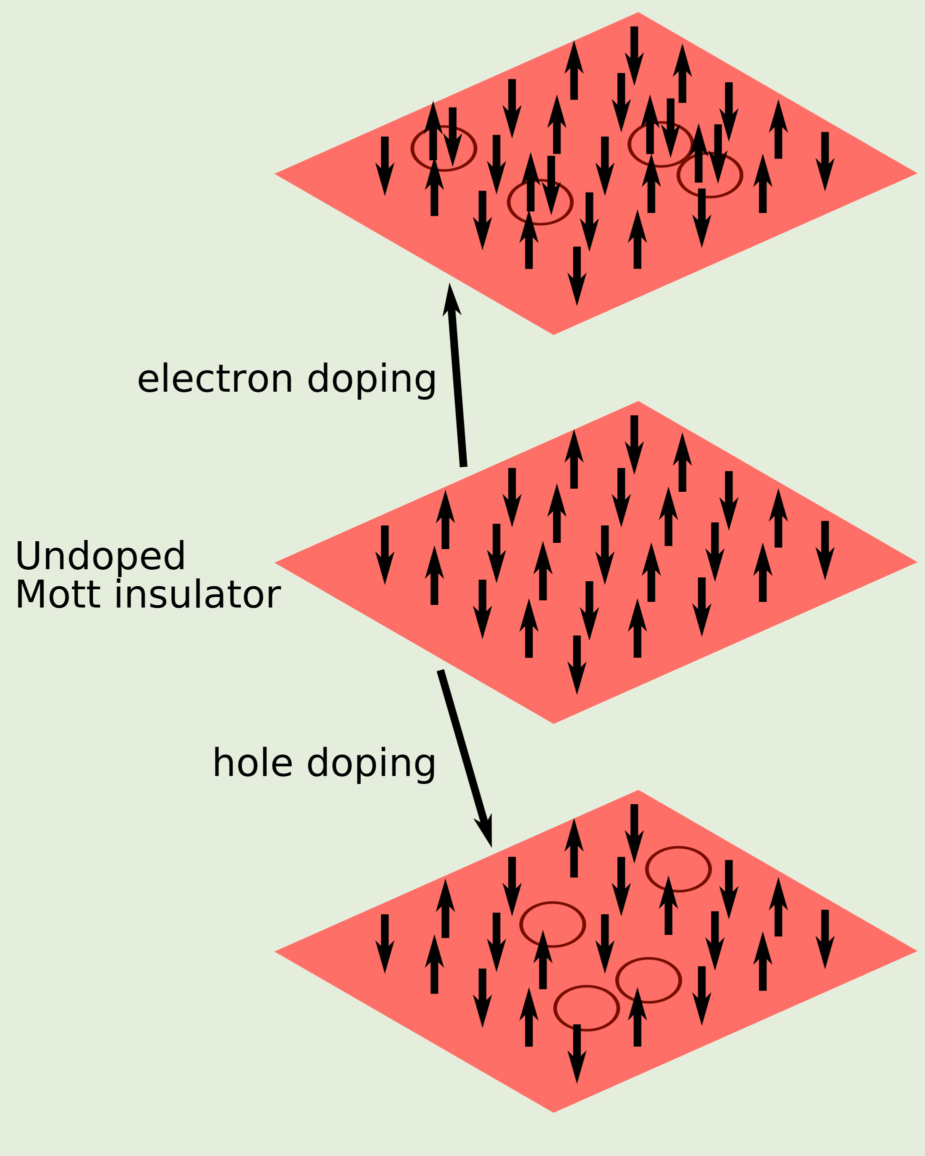


Proposed structure for measuring flux quantization in an exciton bilayer system (image : J. Huijben)

Mott Insulators

Mott materials are characterized by strong correlation among electrons; this leads to a very rich phase diagram, spanning from magnetism to superconductivity; the electronic properties can be tuned by chemical doping, either introducing holes or electron.



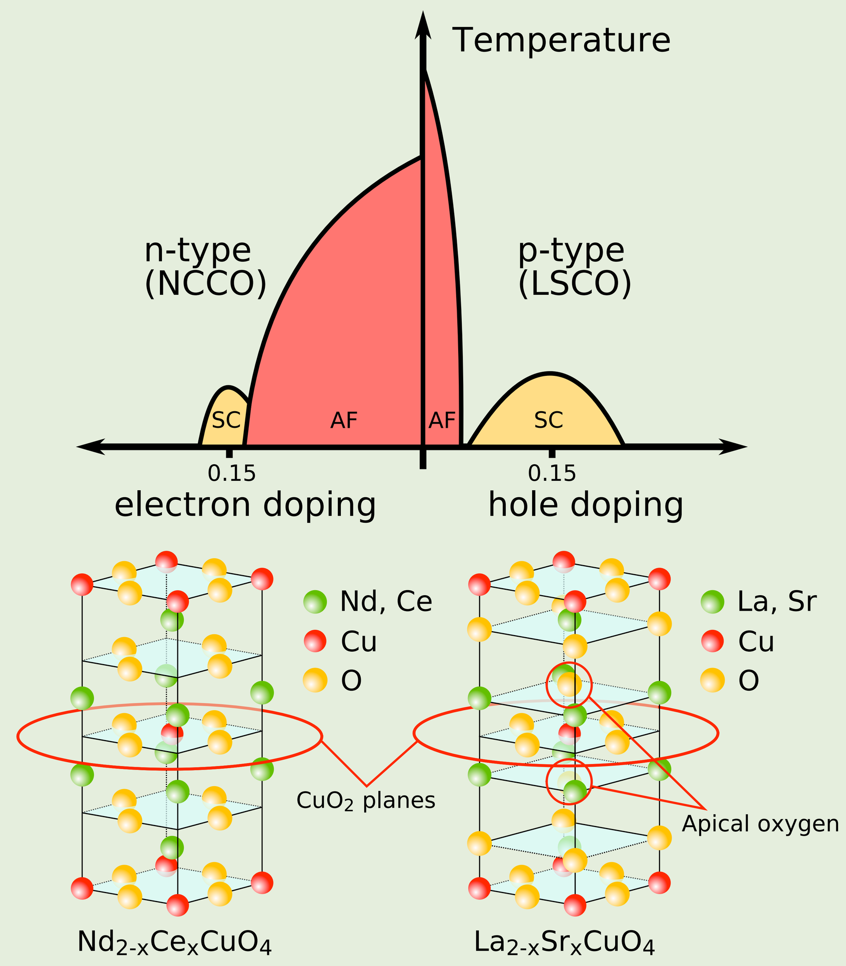


Doping in a Mott insulator

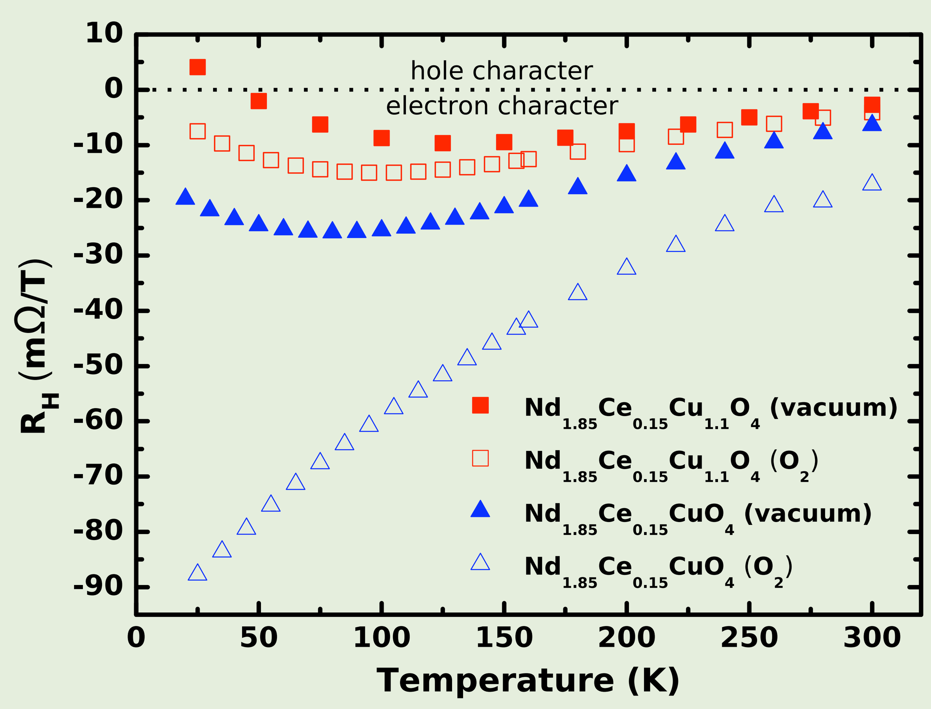
Candidate materials

Among Mott materials, cuprates are considered as candidate materials for the exciton bilayer systems. In particular we choose $Nd_{2-x}Ce_xCuO_4$ (NCCO,*n*-type) and $La_{2-x}Sr_xCuO_4$ (LSCO,*p*-type).

Multilayers can be easily grown by Pulsed Laser Deposition (PLD) in specific annealing conditions; because the electrons and holes are localized in the CuO_2 planes they can provide an equilibrium system suitable for exciton formation/condensation.



Experiments on NCCO



Hall coefficient for NCCO films annealed in vacuum or oxygen

Different growth conditions are required for the *n*- and *p*-type layers; this make the experimental realization of such a system more difficult. We succeeded in growing good quality *n*-type NCCO layers under oxygen pressures suitable for the growth of *p*-type LSCO. Our samples have been characterized by AFM, XRD, and Hall measurements.

Future experiments

By focusing on the target fabrication for the PLD process we will achieve complete control over the doping level and thus we will be able match the doping for the p- and n-type materials. Drag and tunnelling experiments will give informations about the interaction between layers.

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