Quantum engineering of nanofluidic transport

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Abstract:
This thesis focuses on the experimental study of the interplay between nanofluidic transport and electronic excitations at the interface between flowing liquids and semi-conducting systems. The aim is to explore interfacial coupling processes between fluids and solids. This coupling arises from the coherent energy exchange between the collective modes of the fluid (which we coin 'hydrons') and the electronic and lattice excitations – plasmons and phonons – in the confining semiconductors. The coupling between fluids and solids, already validated by experimental and theoretical results in nanofluidics, is opening a new area of investigations at the interface with semiconductor quantum devices that merges today at the same length scale. These nanoscale devices where quantum confinement is an unavoidable ingredient to determine physical properties is the playground where we are going to develop the thesis proposal.

The thesis project will include several objectives and milestones:

- Conception and development of novel nanofluidic systems by exploiting the considerable advances in the semiconductor nanofabrication. This will make use of several semiconductor processing technique, such as epitaxial growth, selective etching and wafer bonding, to define sharp channels for low-dimensional confinement of liquids and ionic fluids. The resulting devices will be supplied with electrical contacts and their electrical properties will be characterized, without and with the presence of fluids at their interface (electronic/ionic impedancemetry).

- Design optical collective excitations in semiconductor materials with controlled sharp resonances in the 5–15 μm wavelength range. The wavelength tuning will be set by the doping level, the quantum confinement and the electronic effective mass. The collective excitations are volume plasmons originating from an electron gas and concentrate the whole interaction with light. They are perfect absorbers and therefore suitable to exchange energy with the collective excitations of the liquid on the surface. We will take benefit of these plasmons to fabricate nanofluidic systems with properly designed "excitation resonances", that determine the coupling between the fluid and the solid at their interface. This requires a detailed understanding of surface excitations in different fluids and solids. Nanofluidic transport in the nanochannels and quantum friction will be investigated versus the designed semiconductor excitations.

- Reversely to a tunable quantum dissipation, fluid motion can induce electron currents. This type of effect, linked to the Coulomb and phonon drag phenomena, has been measured for water transport in carbon nanotubes, and in experiments carried out at ENS. However, the energy transfer across liquid-solid interfaces remains unknown and could be largely dependent on the physical properties of specifically designed materials, that will create new solutions for energy harvesting. This would open the way to 'non-chemical energy transfer between ions and electrons, as an alternative energy harvesting technology.