Alternative Amplifying with co-tunneling

Metal Nanoparticle Networks are ideal model materials for studying the charge transport properties of Quantum Dots Networks. We designed electrical interconnects addressing sub-micron ‘slices’ of nanoparticles assemblies, typically 80 nm long, and several tens of microns wide. These provide access to electrical properties with a finite number of interparticle tunneling events N, in the range 1-7 by design. The usual device resistance results from a sequential interparticles tunneling process, with a resulting device resistance proportional to \(N \times R_t\), where \(R_t\) is the interparticle resistance value. Metal nanoparticles can also behave as Coulomb Island where strong electron-electron repulsion prohibits sequential charge transfer. At sufficient low temperatures, a coherent process can take place, where adding a charge to one nanoparticle requires a simultaneous charge leaving the island leading to a co-tunneling process. These two experiments demonstrate the opportunity given by co-tunneling processes in nanoparticles networks to realise innovative amplifying devices in electrical transport, open to multiple physical or chemical excitations. These devices could pave the way for creating multifunctional molecular devices with enhancing properties.


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This work was performed within a french-argentinian collaboration, involving a Ph. D student in co-tutelle between the universities of Strasbourg and Buenos Aires, and supported by ECOS-Sud.

Summary

A robust Zirconium-Carbene complex for the polymerisation of lactide.

Engineering Negative Differential Conductance with the Cu(111) surface state

Electron tomography analysis of Pt nanoparticle superlattices.

Spin relaxation near the metal-insulator transition: dominance of the Dresselhaus spin-orbit coupling

Amplifying with co-tunneling

The delay that occurred since the previous issue of IPCMS News has been fully fulfilled by working out new projects in relevant fields as part of the “Investments for the Future” initiative aimed at strengthening the country research landscape and capacities. IPCMS has been very successful in that competition. It was first awarded significant funding as a lab of excellence (LabEx), involving ISIS and ICS teams in Strasbourg, to be competitive with the best international laboratories. The associated project deals with nanostructures in interaction with their environment and will address the two following issues:

- Controlling Light-Matter interactions in Nanostructures,
- Manipulating and controlling spins: from molecules to nanostructures.

Second, IPCMS teams have succeeded in having two equipments of excellence (EquipEx) projects passing the highly competitive selection and insuring funding of new equipments aimed at enhancing the impact of our research. The project UTEM (Ultrafast Transmission Electron Microscopy) proposes the acquisition and the setting up of a transmission electron microscope with ultrahigh temporal resolution. This is a new technique with an enormous potential in the study of nanosystems which behavior at short time scales has hardly been accessible to observation yet. While the project UNION (Ultrafast Optics, Nanophotonics and Plasmonics), in collaboration with ISIS, aims at developing a new experimental platform focusing on the study of the temporal and spatial properties of magnetic and plasmonic nanostructures. The methods of investigation are the ultrafast magnetization dynamics using femtosecond and attosecond optical pulse as well as nanophotonics at the sub-wavelength scale.

It is to be noticed that IPCMS is the only one laboratory for which two EquipEx projects have been selected.

As it has now become a tradition, this issue of our international news reports on some of the most impacting results that have been reported in literature by the researchers at IPCMS.

Marc Drillon, Director
A robust Zirconium-Carbene complex for the polymerisation of lactide.

N-heterocyclic carbenes (NHCs) have been recognized as forming a "privileged" class of ancillary ligands for coordination to late transition metal complexes and subsequent applications as homogeneous catalysts that often feature increased activity and/or selectivity. We have shown that zirconium(IV) complexes may be stabilized by N-heterocyclic carbene ligands. These novel species act as an effective initiator for the ring opening polymerization of rac-lactide under mild conditions giving poly(lactic acid) PLA in a controlled and highly stereoregular (heterotactic) PLA-homopolymer. Furthermore we synthesized novel sterically hindered N-heterocyclic carbene-appended zirconium(IV) precursors (WO 2012076140, CNRS-Clariant Int. Ltd). The use and application of these zirconium catalysts have been patented worldwide (WO 2013015460, CNRS-Clariant Int. Ltd).

In our work, we focus on the metallic side of the Dresselhaus spin-orbit coupling. The experimentally observed spin relaxation times in n-doped semiconductors are maximal close to the doping-driven metal-insulator transition in the impurity band, reaching hundreds of nanoseconds. Such long times are not only interesting from the fundamental point of view, but also for applications in spintronics and quantum information devices. In this study, we report the occurrence of single-molecule NDC with a C2v-terminated tip (see figure). By attaching a molecule to the tip of a low-temperature STM (4.6 K) an increased control is gained over the entire tunnel junction. This method allows exploring the NDC occurrence with well-defined pristine metal surfaces serving as a counter-electrode. We have demonstrated that NDC can be produced by electron tunneling between a molecular orbital of the tip and a two-dimensional electron gas hosted by the copper surface—the Shockley surface states of Cu(111). In this calibrated setup, NDC may be tuned by varying the barrier thickness or by changing the C2v orientation up to complete extinction. Our study demonstrates that molecules act as superlattices and the associated steric effect. A numerical 3D quantitative analysis of the ordering characteristics of the superlattice with a one nanometer resolution has been performed that, for the first time, showed a direct correlation between single entities’ characteristics and their ordering as periodic arrays. Using a precise PDF analysis, it has been shown that the lattice parameter is different in two orthogonal directions of the fcc structure, which indicates the presence of a slightly compressed superlattice. Inside the superstructure, vacancies and axial defects were observed that do blur the occurrence of potential collective effects from the supercrys.

This work focuses on the 3D spontaneous arrangement of individual platinum nanocrystals having a size of about 5 nm as superlattices. 3D information in the real space on these structures has been obtained using electron tomography. Performing tomography in the bright-field TEM mode allowed investigating the short and long-range ordering of the nanoparticles packed as self-organized supercrystals. Systematic fcc plippings were observed with a mean lattice parameter measured to be 0.35 nm, the nature of the arrangement being controlled by the truncated octahedral morphology of the platinum nanocrystals and the associated steric effect. A numerical 3D quantitative analysis of the ordering characteristics of the superlattice with a one nanometer resolution has been performed that, for the first time, showed a direct correlation between single entities’ characteristics and their ordering as periodic arrays. Using a precise PDF analysis, it has been shown that the lattice parameter is different in two orthogonal directions of the fcc structure, which indicates the presence of a slightly compressed superlattice. Inside the superstructure, vacancies and axial defects were observed that do blur the occurrence of potential collective effects from the supercrys.

The experimentally observed spin relaxation times in n-doped semiconductors are maximal close to the doping-driven metal-insulator transition in the impurity band, reaching hundreds of nanoseconds. Such long times are not only interesting from the fundamental point of view, but also for applications in spintronics and quantum information devices. In our work, we focus on the metallic side of the transition, with dopant densities just above the critical value, but low enough to keep the impurity band separated from the conduction band. In this regime, the Dresselhaus-Perel mechanism relating spin and momentum relaxation cannot be used to calculate the spin relaxation, such that the long observed lifetimes have remained unexplained during several decades. We use a model based on electron states localized on the impurities, connected by hopping matrix elements. The presence of spin-orbit coupling leads to hopping matrix elements with and without spin-flip. Based on analytical and numerical approaches, we identify the Dresselhaus spin-orbit coupling as the dominant source of spin relaxation on the metallic side of the metal-insulator transition in the impurity band. The resulting predictions agree with experimentally observed values for different semiconductors with zinc-blende structure (see figure p.4).