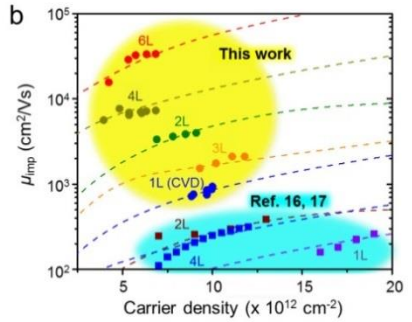
Center for Nanostructured Graphene

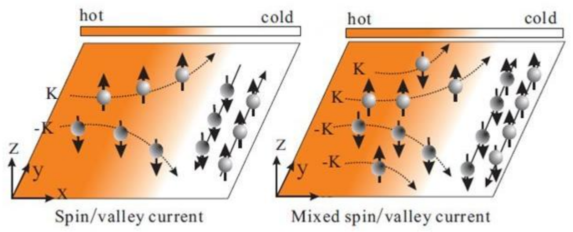
Technical University of Denmark

Center for Nanostructured Graphene - Highlights in 2015

Graphene has extremely high carrier mobility, but lacks the bandgap necessary for use in photovoltaics and field-effect transistors. Transition metal dichalcogenides (TMDC), such as molybdenum disulphide (MoS_2), is a broad family of 2D materials that in addition to bandgaps can be combined layer by layer with graphene and hexagonal boron nitride (insulator) to form complex van der Waals heterostructures with highly customized properties. Two PhD students from CNG, Bjarke Jessen and Filippo Pizzocchero, spent 8 months at James Hone's world leading group at Columbia University, to learn the assembly technique. Here they added crucial improvements to the method, and contributed to an article in Nature Nanotechnology, which for the first time showed that the high performance theoretically predicted for MoS_2 in terms of carrier mobility can indeed be achieved in practice. By fully encapsulating MoS_2 with hexagonal boron nitride as a dielectric and graphene for electrical contacts, and carefully avoiding water and polymer contamination, carrier mobilities up to 34000 cm^2/Vs for multilayer MoS_2 were achieved at low temperatures. With graphene instead of metal as contact material, the contact resistance could be tuned by an electrical field. The article has been cited 60 times in less than a year. The device fabrication method has been further improved by the van der Waals team at CNG, today achieving not just better quality but also much higher yield, which allows batches of devices to be fabricated in short time with predictable outcome. The work is now a cornerstone in the CNG research strategy towards nanostructured ballistic electronic devices with ultrahigh performance.



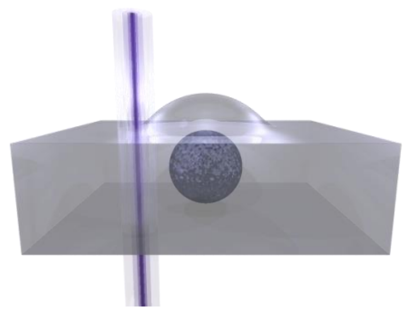
Cui, X., Lee, G.-H., Kim, Y. D., Arefe, G., Huang, P. Y., Lee, C.-H., Chenet, D. A., Zhang, X., Wang, L., Ye, F., Pizzocchero, F. and Jessen, B. S. (2015) *Multi-terminal transport measurements of MoS2 using a van der Waals heterostructure device platform*, Nature Nanotechnology **10** (6), 534-540, doi: 10.1038/nnano.2015.70



Two-dimensional materials with a hexagonal lattice structure possess a valley degree of freedom, in addition to the more familiar charge and spin degrees of freedom. If they are gapped – such as MoS_2 they may have a nonvanishing Berry curvature, which is a special property of their band structure. Berry curvature gives rise to extra driving forces in addition to external electric and magnetic fields, or thermal gradients. Materials belonging into this category host a plethora of exotic transport phenomena, in particular if a finite spin-orbit coupling is present. In a recent work a team consisting of Chinese researchers from Chinese Academy of Sciences, Beijing, and Prof. Jauho of CNG, a new transport phenomenon in this class is predicted: a pure transverse spin current driven by a longitudinal thermal gradient. Likewise, a pure valley current may occur, as illustrated in the figure. Importantly, no net charge current is induced, and the predicted effects are thus nondissipative. Also, a device geometry, where this new effect may be observed, is proposed. Estimates for MoS_2, and for other TMDCs, suggest that the new effects could be useful in a new family of devices – called spin caloritronics.

Yu, X.-Q., Zhu, Z.-G., Su, G. and Jauho, A. P. (2015) *Thermally driven pure spin and valley currents via the anomalous Nernst effect in monolayer group-VI dichalcogenides*, Physical Review Letters **115** (24), 246601, doi: 10.1103/PhysRevLett.115.246601

Localized surface plasmons (SP) are collective oscillations of the electron gas confined in small metallic nanoparticles excited by impinging electromagnetic waves. These excitations can focus intense light on the scale of a few nanometers, and are used in applications like spectroscopy of single molecules. For nanospheres with diameters larger than 50 nm, modes of higher angular momenta can also be excited by light and be used to modify their electromagnetic properties. However, for nanospheres smaller than 50 nm, experiments involving light have proven that it is difficult to excite these higher order (HO) modes and HOs have therefore been neglected in the design of plasmonic nanostructures at these scales. Our team used silver nanoparticles encapsulated in a thin dielectric membrane to demonstrate experimentally for the first time that these HO modes are still present for nanospheres with radii smaller than 50 nm when the spheres are excited with electrons in a Transmission Electron Microscope. Interestingly, HO modes persist for silver particles with diameters as small as 4 nm. Furthermore, below 4 nm, the resonance energies of the HO modes are shifted to higher energies, are strongly damped, and eventually disappear. The size dependent blueshift and damping of the HO modes are due to quantum effects, and modify the electromagnetic response of the metallic nanoparticles. These results are of great interest in nanoplasmonics and must be taken into account in systems where single atoms or molecules are coupled to plasmonic nanospheres, for example in quantum optical or sensing applications.



Raza, S., Kadkhodazadeh, S., Christensen, T., Di Vece, M., Wubs, M., Mortensen, N. A. and Stenger, N. (2015) *Multipole plasmons and their disappearance in few-nanometre silver nanoparticles*, Nature Communications **6**, 8788, doi: 10.1038/ncomms9788