NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2024-2025

Quasi-ballistic charge transport in ultra-pure diamond

General Scope :

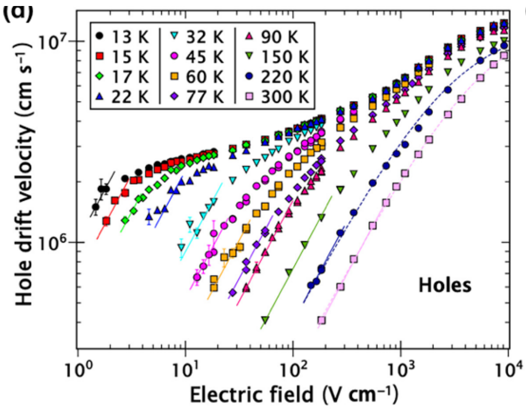

Figure : The velocity of the holes is measured as a function of the electric field and at different temperatures in order to determine the mobility of the carriers in ultra-pure diamond (slope at very low electric field).

Diamond is a very promising material for various applications in the fields of power electronics, detectors and quantum information. Understanding its fundamental properties is essential for the development of future devices. In this context, Institut Néel has developed, as part of a thesis in collaboration with the LPSC (M.L. Gallin Martel's team), an original Time of Flight Electron Beam Induced Current (ToF-EBIC) technique. This technique enabled a world first to be achieved, namely, to measure the mobility of free carriers by ToF-EBIC in ultra-pure diamond at low temperature. The principle of the experiment is that a 1 ns pulsed electron beam (from a scanning electron microscope) impacts the diamond semiconductor, inducing the creation, and then the displacement, of charge carriers through a solid diamond more than 500 µm thick to which a bias electric field is applied. The resulting signal is analysed using the current transient technique. Electron and hole velocities were evaluated as a function of temperature from 13 to 300 K and as a function of electric field with values ranging from 1.5 to 9200 V.cm^{-1}. We measured a low-field mobility value of more than 10^6 cm^2.V^{-1}.s^{-1} for holes at 13 K, demonstrating that diamond is a suitable material for transporting charge carriers in a ballistic regime on a scale of 10 µm [1]. This mobility is the highest value ever achieved for holes in a bulk semiconductor. At the same time, we succeeded in reproducing for the first time the measurements of generation, transport and detection of valley-polarized electrons in diamond first reported by the group at Uppsala University in Sweden [2]. These two major results demonstrated the power of the technique for measuring charge transport properties in ultra-pure diamond.

[1] Portier, A., Donatini, F., Dauvergne, D., Gallin-Martel, M.-L., Pernot, J., 2023. Carrier Mobility up to 10^6 cm^2 V^{-1}.s^{-1} Measured in Single-Crystal Diamond by the Time-of-Flight Electron-Beam-Induced-Current Technique. Phys. Rev. Appl. 20, 024037. https://doi.org/10.1103/PhysRevApplied.20.024037

[2] Isberg, J., Gabrysch, M., Hammersberg, J., Majdi, S., Kovi, K.K., Twitchen, D.J., 2013. Generation, transport and detection of valley-polarized electrons in diamond. Nature Materials 12, 760–764. https://doi.org/10.1038/nmat3694

Research topic and facilities available :

As part of our proposed internship, we want to take our techniques and methods even further to measure electronic properties that have never been explored before in this field. By developing cryogenic RF amplification as close as possible to the sample holder, we hope to achieve lower temperatures (of the order of 5 K). By optimising the injection of electrons, we expect to be able to minimise the internal shielding of the charge carrier drift at very low applied electric fields. This should make it possible to approach a hole mobility measurement of 10^7 cm^2.V^{-1}.s^{-1} to 10^8 cm^2.V^{-1}.s^{-1}. The aim of this work is to apply this technique to other samples, to achieve ballistic or quasi-ballistic transport between two electrodes.

In the longer term, as part of a thesis, we could design and even demonstrate the possibility of : 1) ballistic, and therefore coherent, transport of holes between two NV centres (nitrogen-carbon monochromatic centre in diamond) separated by hundreds of micrometres, 2) manufacture of electronic components using the 'valleytronics' principle thanks to the valley polarisation of electrons in diamond. The two objectives of this thesis would be world firsts, paving the way for new applications in the field of electronics.

Although experimental development is envisaged during this thesis, the measurement bench already exists, and developments will be limited to RF and cryogenics aspects.

Possible collaboration and networking :
Collaboration with the LPSC will continue. The samples envisaged come from a number of sources: commercial substrates from Element 6 identical to Ref [1], ultra-pure and thick self-supported epitaxial layers in collaboration with Dr Teraji (NIMS, Tsukuba, Japan) as part of the international J-FAST laboratory (Grenoble-Tsukuba) or diamond substrate from Prof Achard of the LSPM (Univ Paris), or the Diamfab company.

Possible extension as a PhD : Yes see above

Required skills : Semiconductor physics, solid state physics and condensed matter physics.

Starting date : February 2025

Contact : Julien Pernot– co-encadrants: Fabrice Donatini (Institut Néel) et Christophe Hoarau (LPSC)
Institut Néel - CNRS : 04.56.38.70.83,
e-mail : julien.pernot@neel.cnrs.fr
More information : http://neel.cnrs.fr