Ferroelectrics and semiconductor nanocrystals bromance

In semiconductors physics the pn junction occupies a central place being the building block of device such as LEDs or photodiodes. Usually, the junction is obtained by doping semiconductors through implantation of extrinsic impurities. If this procedure is well established for bulk and thin film semiconductors, this is not the case for colloidal nanocrystals. Asa result, alternative strategies had to be developed to manufacture diodes. This may be obtained by coupling the active layers to carrier selective transport layer or using electrostatic gates. Members of the INSP's Physical-chemistry team are proposing an approach that is more energy-efficient and less sensitive to surrounding noise, by coupling the active optical layer with a ferroelectric material.

This project is part of the ANR MixDferro (IPCMS, C2N, INSP collaboration) whose objective is to develop optoelectronic devices coupling semiconductor materials with ferroelectric materials to tune their properties. In particular, the INSP team was interested in HgTe nanocrystals, which are excellent absorbers in the near and mid-infrared. The challenge was to use the polarization of a ferroelectric material to define a pn junction. To do so, the C2N team grew by PLD (pulsed laser deposition) an oxide heterostructure whose upper layer is made of PZT (lead titanium-zirconates). Then, using piezoelectric microscopy (PFM), two opposite polarization domains have been defined on the surface of the PZT (Figure 1b and 2a). This domain will replace the electrostatic gates used previously (Figure 1a). Finally, these domains were functionalized with a light absorbing layer of HgTe nanocrystals, Figure 1b.

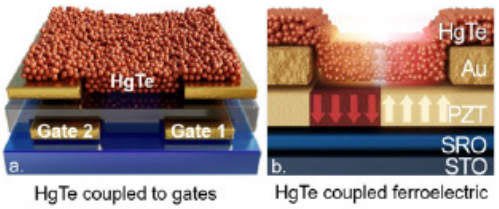

Figure 1
a. Schematic of a dual-gate phototransistor whose channel is made up of HgTe nanoparticles as the active layer in the infrared. b. Schematic of a hybrid ferroelectric/nanoparticle phototransistor in which the area above the up polarization is hole-charged while the area covering the down polarization is electron-rich. SRO stands for $SrRuO_3$ while STO is $SrTiO_3$.

To bring evidence of the coupling between the ferroelectric and the semiconductor, the researchers used photoemission imaging performed on the Antares beamline of the Soleil synchrotron. This beamline nano-beam makes possible the operando energy landscape mapping of a device in operation (figure 2b-c). They noted an energy shift of 115 meV at the interface between the two domains, which corresponds to ¼ of the optical gap. They then demonstrated that this shift was sufficient to induce a pn junction behavior in the HgTe layer with a rectifying current/voltage characteristic matching the expected behavior for a diode.

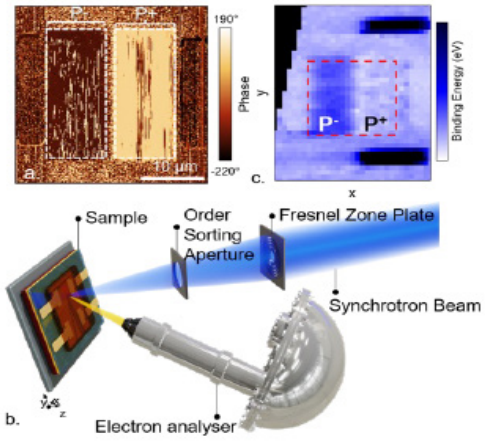

Figure 2
a. PFM (Piezoresponse force microscopy) image of the two ferroelectric domains written on the surface of the PZT. b. Schematic of the photoemission imaging measurement performed on the Antares de Soleil beamline relying on a X-ray nano-beam. C. Binding energy mapp for the 5d state of mercury on the area corresponding to the two ferroelectric domains from part a.

Now, the effort undertaken to probe the electronic structure of optoelectronic component operando will continue with the recent obtaining of the ANR Emap in collaboration with the Synchrotron Soleil.

Reference

"Coupling Ferroelectric to colloidal Nanocrystals as a Generic Strategy to Engineer the Carrier Density Landscape"
Mariarosa Cavallo, Erwan Bossavit, Sylvia Matzen, Thomas Maroutian, **Rodolphe Alchaar, Tung Huu Dang, Adrien Khalili, Corentin Dabard, Huichen Zhang, Yoann Prado, Claire Abadie, James K Utterback**, Jean Francois Dayen, Mathieu G Silly, Pavel Dudin, Jose Avila, **Emmanuel Lhuillier, Debora Pierucci**
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