Electric Field Induced Superconductivity with Electric Double Layer Transistors

Y. Iwasa
Quantum-Phase Electronics Center, The University of Tokyo,
Hongo 7-3-1, Bunkyo-ku, Tokyo 113-8656, Japan, E-mail: iwasa@ap.t.u-tokyo.ac.jp

We report that interface superconductivity can be induced through electrostatic charge accumulation at the electric double layer (EDL) formed at interfaces between liquid and solid. This interface has been of central importance from the view point of battery applications and catalytic activities. However, their ability to accumulate high charge density at the interface can be used as a transistor with high capacity and high maximum carrier density, which might provide a significant impact on solid state physics.

When voltage is applied between two electrodes in an electrochemical cell, mobile ions in electrolyte move toward corresponding electrodes driven by the electric field. Finally, ions are stabilized right above the electrode surface to form an EDL, a kind of capacitor, where an electric field in the order of 10 MV/cm, which is difficult to achieve in solid capacitors, is produced without any difficulty. This capacitor device, called an electric double layer capacitor (EDLC), is well known for its capability of high density charge accumulation, and is already on market as a high density and high speed capacitor. When one of the electrodes is replaced by a semiconductor with a source and drain electrodes, this device works as a field effect transistor, which can be called an electric double layer transistor (EDLT). This electrochemical device has been investigated for application to ion sensors. Since 2005, we have been investigating EDLT devices aiming at accumulating high density carriers and hopefully inducing electronic phase transitions using organic semiconductors [1]. Recently, we started to apply this technique to oxide semiconductors, and have successfully demonstrated the electric field induced insulator-metal transition in ZnO [2], followed by superconductivity in $SrTiO_3$ [3].

These results may suggest that EDLT could offer a novel direction in materials research at the electrochemical interface between ionic conductors (generally liquid) and electronic conductors (solid). This is not only because both ionic and electronic conductors are of enormously rich variety, but also because this transistor involves rich chemical processes, ranging from electrostatic charge accumulation to chemical reactions at the surface and in the bulk. For example, we found that ionic liquid displayed superior charging capability [4]. This enabled us to observe new electric field induced superconductivity in a layered compound ZrNCl with increased T_c of about 15 K [5]. The present results indicate that EDLT could be a versatile technique for inducing and manipulating superconductivity at interfaces between solid-liquid interfaces.

In this presentation, we particularly focus on the field induced superconductivity in ZrNCl with unique properties of Li doped ZrNCl superconductor [6, 7] and their comparison with the field effect doping. This work has been carried out in tight collaboration among Kawasaki group at WPI-AIMR Tohoku University (A. Tsukazaki, A. Ohtomo, K. Ueno, M. Kawasaki), Low Temperature Center (T. Nojima, S. Nakamura), and our own team at University of Tokyo (H. Shimotani, H. T. Yuan, J. T. Ye, Y. Kasahara).

References

[1] H. Shimotani et al., *Appl. Phys. Lett.* 86, 022104 (2005).
[2] H. Shimotani et al., *Appl. Phys. Lett.* 91, 082106 (2007).
[3] K. Ueno et al., *Nat. Mater.* 7, 855 (2008).
[4] H. T. Yuan et al., *Adv. Funct. Mater.* 19, 1046 (2009).
[5] J. T. Ye et al., *Nat. Mater.* 9, 125 (2010).
[6] Y. Taguchi et al., *Phys. Rev. Lett.* 97, 107001 (2006).
[7] Y. Kasahara et al., *Phys. Rev. Lett.* 103, 077004 (2009).