Synergy of Graphene and ZnO properties for optoelectronics

R. Yakimova[1] V. Khranovskyy[1]

[1]Linköping University, Department of Physics, Chemistry, and Biology (IFM), 583 81 Linköping, Swewden

Graphene (Gr) is widely reported due to its unique properties and possible respective applications. Furthermore, combination of Gr with other inorganic materials enables modification and improvement or enhancement of its key properties. Potentially, a novel type of hybrid structures may be created and a new beyond graphene area may appear. Zinc oxide is a wide band gap semiconductor material with a large potential for applications in optoelectronics for UV and blue light emitting devices. Intense light emission therefore is critical and may be facilitated by efficient light extraction from the material. Alternatively, the efficiency of light emission may be improved due to enhanced internal efficiency by intensification of the radiative recombination processes. Surface plasmons (SPs) have been earlier reported to enhance the luminescence efficiency of semiconductor materials and devices [1]. Traditionally, the plasmons related phenomena are studied on metals, as a source of abandoned charge carriers. However, Graphene, being a two-dimensional system, enables excitation of surface plasmons (SP) similar to the surface plasmons on metal/dielectric interfaces [2]. We have studied peculiarities of photoluminescence of the ZnO/Gr heterostructures in comparison to conventional ZnO samples by temperature and power dependent micro-photoluminescence (μ-PL). Monolayer (ML) graphene was prepared on SiC substrates by thermal decomposition at 2000°C in an argon atmosphere [3] and used as a substrate template for subsequent ZnO growth by MOCVD at 500 °C [4]. Growth of ZnO on Gr at common conditions results in a conventional thin polycrystalline ZnO film formation, while via respective growth regime modifications different morphologies nanorods (NRs) or nanowires (NWs) - can be obtained. We demonstrate, that: i) despite the significant in-plane lattice mismatch ($\delta\alpha$ ZnO/Gr = + 32%) growth on Gr promotes high quality of the ZnO material in comparison to other substrates, e. g. such of less lattice mismatch, like SiC ($\delta\alpha$ ZnO/SiC = +5%); ii) independently of the thickness of the ZnO films they reveal higher PL intensity in comparison to the similar films, grown on other substrates; iii) the light emission ability of ZnO depends non-linearly on the film thickness. Via HR TEM and XRD analysis we observed experimentally that Gr tends to decompose under longer deposition time of the ZnO. This, however, is assisted by relaxation of ZnO due to accommodation its crystal lattice with SiC substrate. The observed light emission enhancement phenomena can be explained as that the process of excitonic emission from ZnO is enhanced the by exciton-plasmon coupling. Responsible for the observed phenomena can be the surface plasmons, which appears on the interface ZnO/Gr. Finally, we demonstrate a particularly designed ZnO/Gr heterostructure, that reveals superior light emission properties. At room temperature the PL signal from ZnO/Gr was found to be 4 times larger in comparison to conventional ZnO samples. Furthermore, the PL enhancement was found to increase at low temperatures - up to 18 (at 4 K), which is due to increased density of states (DOS) at lower temperatures. The local enhancement of the electromagnetic field occurs due to the surface plasmons resonance on the ZnO/Gr interface. Thus, light emission enhancement occurs due to increased ratio of the radiative recombination processes. However, the issue of need of SPs media surface corrugation for efficient light extraction still has to be clarified for this system. For the optoelectronics such light emission enhancement is of vital importance. Thus, Gr is a proper template for growth of ZnO/Gr hybrid structures with tailored light emission properties and ZnO-Graphene system is prospective for investigation of SPs related phenomena since a substantial practical profit may be expected.

[1] Koichi Okamoto, Isamu Niki, Alexander Shvartser, Yukio Narukawa, Takashi Mukai & Axel Scherer, *Nature Materials* **3**, 601 (2004).
[2] A. N. Grigorenko1, M. Polini and K. S. Novoselov, *Nature Photonics* **6**, 749 (2012).
[3] C. Virojanadara, M. Syväjarvi, R. Yakimova, and L. I. Johansson A. A. Zakharov and T. Balasubramanian, *Physical Review B* **78**, 245403 (2008).
[4] V. Khranovskyy and R. Yakimova, *Physica. B, Condensed matter* **407**, 1533 (2012).