Delay and distortion of light pulses by excitons studied by time-of-flight spectroscopy

T.V. Shubina
Ioffe Physical-Technical Institute, St Petersburg 194021, Russia

Optical dispersion at exciton resonances results in a delay of light transfer due to variation of group velocity [1]. This phenomenon has been observed by time-of-flight spectroscopy in different semiconductors [2-4]. This light retardation is currently of particular interest because it is one of the ways to obtain the so-called "slow light", which is needed for optical communication and data processing [5]. Besides, this effect is important for a set of optoelectronic devices – high-frequency ones or those, where the light should propagate a long distance.

The advanced seminar is aimed to present the time-of-flight spectroscopy studies of wide-gap semiconductors – GaN and ZnO. The experiments were performed using the pulses of tunable ps and fs lasers, propagating through high-quality crystals and registered by a Hamamatsu streak camera. They have revealed that significant light delay about ~1% of the light velocity in vacuum exists near an exciton resonance. This delay is accompanied by distortion of a pulse shape in the time-energy plane. The light transmitted through the GaN crystals contains both ballistic and diffusive components [3]. However, weaker replicas, observed in the time-resolved images due to the reflection of light pulses from the sample boundaries, propagate purely as exciton-polaritons. Their modeling gives excitonic parameters inherent for bulk GaN [6].

ZnO differs from GaN by the presence of numerous lines of donor bound excitons. In this semiconductor, the maximal delay of the higher-energy pulse edge approaches 1.6 ns at 3.374 eV for L=0.3 mm [7]. The general curvature and delay are controlled by the exciton-polariton resonances, while the bound exciton lines provide dips cutting the pulses into several parts and induce extra light retardation nearby. The simulation of the pulse shapes in the time-energy plane has been done assuming the linear regime and using the Gabor transformation. It has been found that: i) the homogeneous width of the exciton-polariton resonances is as small as 3 μeV at low temperature (2 K); ii) the inhomogeneous width cannot exceed 0.5 meV for the A excitonic series. The time-of-flight studies of ZnO done over a wide temperature range demonstrate the strong influence of resonant scattering by phonons on the light delay in polar semiconductors. The homogeneous width of the exciton-polaritons in ZnO derived from the temperature dependencies of the pulse propagation approaches ~1-2 meV at 300 K. This value is well consistent with the theoretical estimation done taking into account the renormalization of the exciton-polariton homogeneous linewidth due to the interaction with optical and acoustical phonons. It is revealed that the output signal at the room temperature is an exclusively scattered light for a 0.3-mm length. The delay of this signal significantly decreases due to the high group velocity at the energy of the scattered photons.

[1] L. Brillouin, *Wave Propagation and Group Velocity* (Academic, New York, 1960)
[2] G. Xiong *et al*., J. Phys.: Condens. Matter **17**, 7287 (2005)
[3] T. V. Shubina *et al*., Phys. Rev. Lett. **100**, 087402 (2008)
[4] T. Godde *et al.* Phys. Rev. B **82**, 115332 (2010)
[5] D. S. Wiersma, Nature (London) **452**, 942 (2008)
[6] T.V. Shubina *et al*, Appl. Phys. Lett. **99**, 101108 (2011)
[7] T.V. Shubina *et al*, Phys. Rev. B **84**, 075202 (2011)