Polarized recombination of acoustically transported charge carriers in GaAs nanowires

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Semiconductor nanowires (NWs) offer new perspectives for low-dimensional semiconductor devices since the small radius favors mesoscopic size effects and lifts the epitaxial constraints associated with the growth of dissimilar materials. In addition, the geometry of NWs enables them to function as active device elements and interconnects, which can lead to highly integrated opto-electronic device structures. In this respect, the crystal structure of the NWs is of high importance since it controls the optoelectronic properties. For the full utilization of these favorable properties one needs to overcome the obstacles of electrical control fields, which normally requires doping and contacting of non-planar nm-sized structures, and the large surface-to-volume ratio, which often affects adversely the electronic properties. Here, we applied surface acoustic waves (SAW) to control remotely carriers in high quantum efficient GaAs/AlGaAs core-shell NWs.

We have recently demonstrated that the oscillating piezoelectric field of a SAW can transport photoexcited charge carriers in GaAs NWs as well as control the spatial location of exciton recombination along the NW axis [1]. One important question is whether electron spins can be maintained during acoustic transport in NWs, as recently reported for spin diffusion in NWs [2]. In this contribution, we address this question by using polarization-resolved photoluminescence (PL) to detect the spin polarization of acoustically transported carriers in NWs.

SAWs are propagating elastic vibrations confined to the surface of a material. On a piezoelectric semiconductor, these vibrations are accompanied by a piezoelectric potential Φ_{SAW}, which traps electrons and holes in spatially separated positions, thus preventing their recombination. The acoustic fields allow to remotely control the PL intensity and to transport charge carriers and spins along the NW axis when it is parallel to the SAW propagation path. In this way, carriers generated on one edge of the NW can be transported by the SAW oscillating field to a remote position, where they recombine [1].

The studies were carried out on NWs with a diameter of 70 nm surrounded by a 15 nm-thick $Al_{0.1}Ga_{0.9}As$ shell [3]. The NWs, which have predominantly a wurtzite structure, were dispersed on a $LiNbO_3$ substrate containing a SAW delay line for an acoustic wavelength λ_{SAW} = 17.5 µm (frequency f_{SAW} = 226 MHz). The acoustic charge transport experiments were performed at low temperature (20 K) by photo-generating carriers using a linearly polarized pulsed laser beam (pulse width of 150 ps << $1/f_{SAW}$) tightly focused (1.5 µm spot diameter) onto one end of the NW and measuring the spatial distribution of the PL along the NW axis with polarization sensitivity.

In the absence of acoustic excitation, the emission of the NWs takes place close to the illumination spot G and is mainly polarized perpendicular to the NW axis (see Fig. 1a). When a SAW is applied, the PL intensity at G reduces and a second PL spot, R, appears a few µm away from G along the SAW propagation direction (Fig. 1b). The latter is attributed to the acoustic transport of electrons and holes towards trap sites at R, where they recombine. This recombination is highly polarized parallel to the wire axis as can be seen in Fig. 1c.

Although the emission characteristics at the G spot is consistent with the selection rules expected for wurtzite NWs, the emission at R shows a different polarization preference. Since the recombination of the transported carriers takes place at a trap, the selection rules can be different. The emission energy of approximately 818 nm suggests that the recombination center consists of a zincblende section at the nanowire extreme.

The previous results show that the polarization of the PL does not depend on the incident laser polarization, thus implying that electron spins are not conserved during transport. To further support this conclusion, we carried out transport experiments where spin-down (σ^-) electrons were generated on one extreme of the NW using left-handed circularly polarized light. The circular polarization of the PL was detected with spatial resolution using a $\lambda/4$ plate and a birefringence prism. Spatially resolved PL of incident left-handed circularly polarized light in absence and presence of a SAW are shown in Figs. 2a and 2b, respectively. In Fig. 2c and 2d the PL intensity along the NW axis integrated around 811 nm (Fig. 2c) and 818 nm (Fig. 2d) in the absence (solid lines) and presence (dashed lines) of a SAW for both spin states (σ^+,σ^-) are presented. Without acoustic power the PL is localized around 811 nm at the generation spot (Fig. 2a). When a SAW is applied, a second spot at the other extreme of the NW around 818 nm appears (Fig. 2b). Note that the emission intensity is equal for both circular polarizations (Fig. 2c,d), thus implying that the spin memory is lost during transport.

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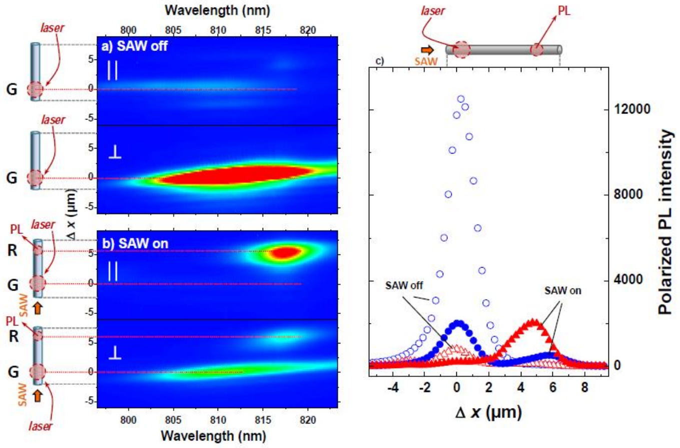

Figure 1: (a,b) Spatially resolved PL excited by a linearly polarized laser beam tightly focused onto the NW edge facing the interdigital transducer used for SAW generation. The PL signal emitted along the NW axis is split by a birefringence prism into two orthogonally polarized rays. The rays with polarization parallel and perpendicular to the NW axis are then detected on the upper and lower regions of the PL images, respectively. (a) In the absence of a SAW the emission is restricted to the region close to the excitation spot and highly polarized perpendicular to the NW axis. (b) Application of acoustic power induces the transport of electrons and holes to a remote recombination spot, where they recombine emitting light polarized parallel to the NW axis. (c) Integrated PL intensity along the NW axis for the emission polarized perpendicular (blue circles) and parallel (red triangles) to the NW axis with (solid symbols) and without (open symbols) a SAW.

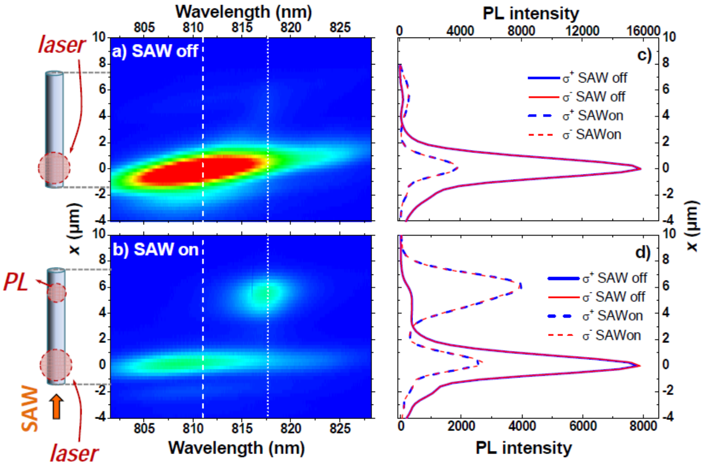

Figure 2: Spatially resolved PL excited by a tightly focused, left-handed circularly polarized laser beam in the (a) absence and (b) presence of a SAW. As in Fig. 1a and 1b, the SAW fields quenches the PL signal at the illumination spot and leads to the appearance of a remote recombination spot 6 μm away for the generation spot. PL intensity along the NW axis with left-handed (σ^-) and right-handed (σ^+) circular polarization integrated around (c) 811 nm (dashed line in 1a and 1b) and (d) 818 nm (dotted line). The solid and dashed curves were recorded in the absence (solid lines) and presence (dashed lines) of a SAW.