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Surface Acoustic Wave-Driven Carrier Dynamics As A Contact-less Probe For Mobilities Of Photogenerated Carriers In Undoped Nanowires

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Radio frequency (RF) surface acoustic waves (SAW) are versatile tool to control and manipulate charge and spin excitations in semiconductor structures. We recently applied this unique, fast control mechanism to dynamically modulate the optical emission of single semiconductor nanowires (NWs) at radio frequencies exceeding 650 MHz. However, in these experiments surface recombination inhibited the SAW-transport of electrons and holes along the axis of uncapped GaAs NWs [1]. The underlying processes are strongly dependent on the acoustic amplitude and directly reflect the charge carrier mobilities in the investigated structure [2,3].

Here we present that our SAW technique provides a contact-less and massively parallel probe for the intrinsic mobilities of electrons and holes in otherwise undoped surface-passivated GaAs/AlGaAs core-shell NWs. To resolve the SAW-driven carrier dynamics, we perform stroboscopic time-correlated single photon counting (s-TCSPC) of the photoluminescence (PL) emission of individual NWs. A typical unperturbed PL transient is plotted in red in Fig. 1(a) showing a mono-exponential decay with a time constant of τ_{PL}= 1.3 ns. When subject to a SAW (f_{SAW} = 194 MHz, PSAW = +5 dBm), we observe a characteristic beating in the PL transient (blue), matching T_{SAW} = 5.1 ns. As expected, this beating shifts in time by $T_{SAW}/2$ as the local acoustic phase is tuned by 180° (green). This observation is a direct fingerprint of the charge carrier dynamics and acoustic charge conveyance within the SAW-induced type-II band edge modulation [2,3]. As sketched in Fig. 1(b), electrons transfer from the position of the excitation laser (x_0) into the energetically favourable stable points at the minimum of the conduction band. In contrast to electrons, holes remain stationary at the point of photogeneration due to their reduced mobility. $T_{SAW}/2$ later these electrons are conveyed to the position of the holes giving rise to the observed beating.

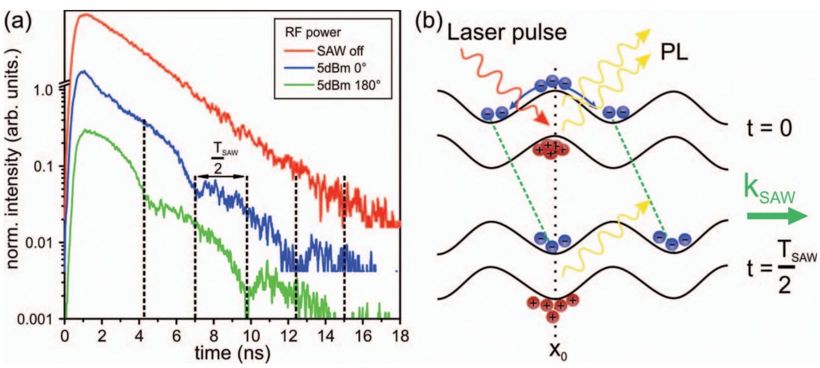

Fig. 1 (a) PL transient of a single GaAs/AlGaAs core-shell NW without SAW (red) and with SAW applied with defined phase shifts (blue, green). (b) Dissociation and acoustic transport of electrons in the SAW-induced type-II bandedge modulation. Spatial overlap of transported electrons and stationary holes gives rise to the observed time-delayed PL emission.

As we further increase the acoustic power, transport of holes sets in. This in turn gives rise to an abrupt and instantaneous quenching of the NW emission. The recorded time transients as a function of acoustic power can be reproduced nicely by numerically solving the semi-classical drift and diffusion equation for electrons and holes in the SAW-induced potentials. From a direct comparison of the experimental data and the numerical simulation results we determine mobilities of μ_e = 500 cm^2/Vs and μ_h = 50 cm^2/Vs for electrons and holes in the core of the investigated NWs, respectively.

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