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Terahertz generation by periodic arrays of GaAs/AlGaAs core/shell nanowires

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Abstract. This paper presents the experimental studies of the generation of terahertz radiation in periodic arrays of GaAs/AlGaAs core/shell nanowires via excitation by ultrashort optical pulses. It is demonstrated that terahertz emission occurs via excitation of photocurrent in the nanowires. The dynamics of photoinduced charge carriers is studied via the influence of an electron-hole plasma on terahertz radiation.

1. Introduction

Semiconductor nanostructures in the form of freestanding semiconductor nanowires are among the most promising 1D nano-objects for application in nanoelectronics, nanophotonics, and nanobioelectronics. In addition, the use of quasi-1D nanostructures, such as nanowires (NWs), as terahertz emitters is a promising way to improve existing emitters of terahertz radiation because of their unique electrical and optical properties [1-6]. First experimental studies of THz emission from InAs [4] and GaAs [5] NW arrays, excited by femtosecond laser pulses, demonstrated that the efficiency of terahertz (THz) generation can be increased by a factor of 15 when compared to bulk materials after accounting for the NW filling factor. Furthermore, since the efficiency of the THz emission is defined by the concentration and the mobility of charge carriers, studies of THz emission can be used to determine the transport, relaxation and recombination properties of electrons and holes in nanowires. In this work, we present the results of experimental studies of the generation of terahertz radiation in ordered arrays of GaAs/AlGaAs core/shell nanowires under excitation with ultrashort optical pulses.

2. Samples and experimental

The GaAs nanowires were grown on n-type GaAs (111) B substrates by metal-organic vapor-phase epitaxy (MOVPE) with the passivation of the surface of the nanocrystal with an AlGaAs layer. Fig. 1 shows 20° tilted scanning electron microscope (SEM) images of the fabricated GaAs NW arrays.



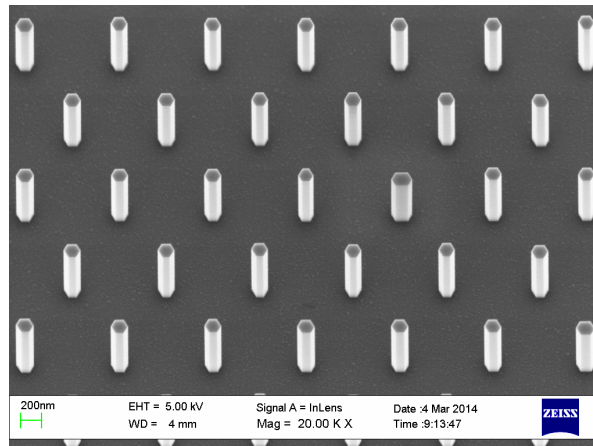


Fig.1. A typical SEM image of arrays with different distance (density\impact factor) between nanowires.

The main experiments were performed by using time-resolved spectroscopy: the amplitude of the electric field of a THz wave and the phase information of the THz pulse were recorded. A femtosecond Ti:Sa laser generating 15-fs pulses (central wavelength of the light pulse was 795 nm) served as the light source. The THz radiation was detected by electro-optical sampling.

3. Results

Investigations of THz generation processes in nanostructures based on GaAs/AlGaAs core/shell NWs were carried out. Waveforms of the THz pulse, obtained by exciting NWs with a diameter of ~ 150 nm and with different nanowire density, are shown in Fig.2. As already noted in [7], the field of terahertz radiation in periodic arrays of NWs with a distance between nanocrystals greater than the length of the exciting light (in this case ~ 800 nm) represents the sum of the fields of electromagnetic waves emitted by each nanocrystal. Correspondingly, the negative sign of the THz field for NWs' arrays with pitch of 1200 nm to 2100 nm indicates that the electron drift should be directed from the substrate towards the upper face of the nanocrystal. Since the contact field formed between the substrate and the nanocrystal is directed from the substrate to the upper face of the nanocrystal, the drift of the photoexcited electrons will be directed toward the substrate. Consequently, its contribution to THz generation should be negligible due to the experimental results (the amplitude of the terahertz pulse is negative). Thus, the obtained results confirm the band diagram shown in Fig. 2 on the right for the n-GaAs / n-AlGaAs heterojunction.

In this transition from the side of the GaAs nanocrystal there is an electric field directed toward the substrate. In this case, the photoexcited electrons will move in this field to the upper face of the NWs. The change in the sign of the THz pulse for NWs' arrays that have a period comparable to or shorter than the wavelength of the excited light indicates that for these samples the contribution of ambipolar diffusion that is associated with inhomogeneous excitation of the nanocrystal along its length (electrons move to the substrate) becomes substantial.

In this work, experiments were also conducted on the study of relaxation processes, recombination and transport of charge carriers in NWs by recording the waveform of the terahertz pulse with additional excitation of the NWs by a femtosecond pulse based on the optical-pump terahertz generation-probe time-domain spectroscopy method. To reduce the influence of THz pulse modulation generated by an additional femtosecond pulse (pump pulse), at the modulation frequency of the first femtosecond pulse (probe pulse), the pump pulse was directed toward the sample surface at an angle opposite to the dip angle of the probe pulse.

It was found that the efficiency of terahertz generation in NWs falls with the creation of an additional electron-hole plasma. The drop in the efficiency of generation of THz radiation in semiconductor nanostructures based on GaAs is mainly due to the screening of the internal field in the nanocrystal (the electric field of the n-GaAs / n-AlGaAs heterojunction near the upper face of the nanocrystal and the field of the n + -n junction), due to the separation of nonequilibrium electrons and holes, their drift in the contact fields. With a low level of excitation, the restoration of THz generation efficiency has a monoexponential character, whereas at a high excitation level the restoration of the efficiency of terahertz radiation generation becomes multi-exponential.

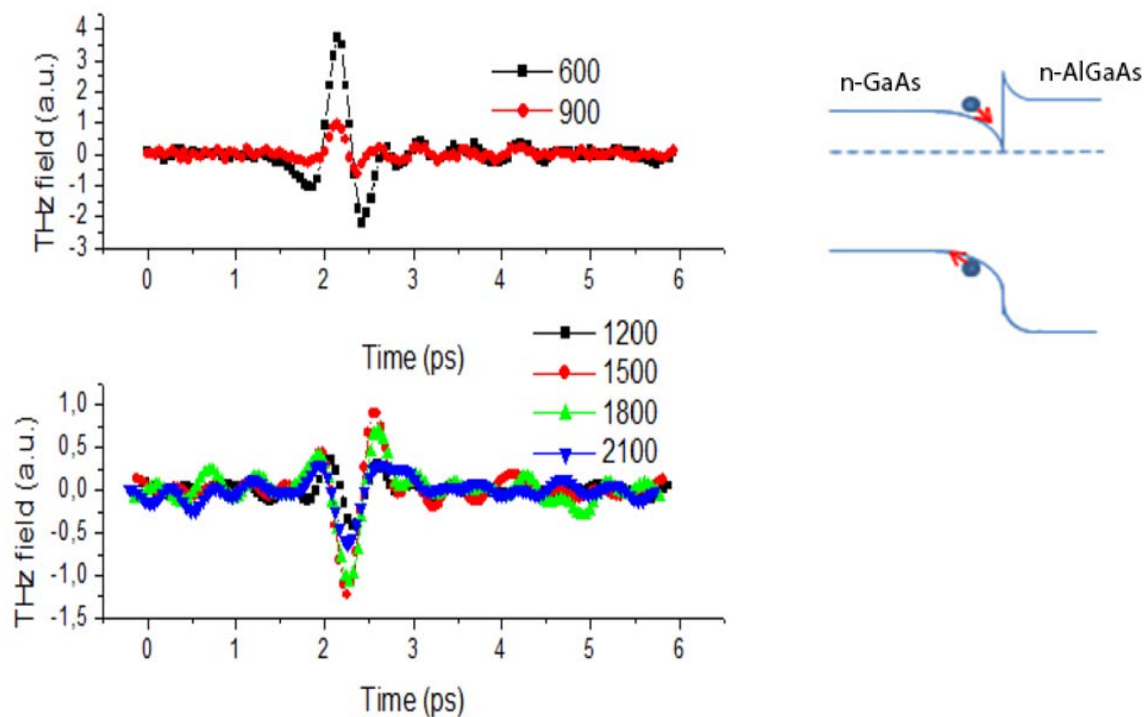


Fig.2. Waveforms of a THz pulse, obtained under excitation of the NW arrays with various densities and a NW diameter of 150 nm. The optical-excitation wavelength was 795 nm. On the right-the band diagram for the n-GaAs / n-AlGaAs heterojunction.

The observed phenomenon is due to the fact that at a high initial concentration of the electron-hole plasma, a gradient of the hole concentration is created due to their drift motion to the upper face of the NW, and then the charge of the depleted layer is recharged due to hole diffusion. The estimate of the hole diffusion time corresponds in order to the time of the fast recovery kinetics observed in the experiment, and subsequently, mainly, hole trapping at the surface levels occupied by electrons.

Thus, it was shown that the time dynamics of photoexcited charge carriers in semiconductor NWs is determined both by the rapid motion of electrons in a local electric field (charge of a depleted layer capacitance) and their rapid capture to surface centers, by diffusion of holes (charge-exchange of capacitance) and their slow capture to surface centers and nonradiative centers in NWs.

Acknowledgments

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