Terahertz emission from non-vertically aligned semiconductor nanowires

Ieva Beleckaitė*, Gediminas Molis*†, Ramūnas Adomavičius*, Aloyzas Šiušys‡, Anna Reszka‡, Arūnas Krotkus*
and Janusz Sadowski‡§
*Center for Physical Sciences and Technology, A. Goštauto g. 11, Vilnius, Lithuania
Email: ieva.beleckaite@ftmc.lt
†Teravil Ltd., A. Goštauto g. 11, Vilnius, Lithuania
‡Institute of Physics, Polish Academy of Sciences, al. Lotników 32/46, Warsaw, Poland
§MAX-Lab, Lund University, P.O. Box 118, Lund, Sweden

Abstract—**In this work THz emission of the non-vertically aligned GaMnAs and InGaAs nanowires (NWs) were investigated for the first time. THz emission azimuthal dependencies on different nanowire layers were measured. In addition THz pulse amplitude dependencies on an angle between the incident laser beam and a normal to the sample surface were accomplished for the removed NW layer. The investigated layers can be used in rotating polarization THz emitters. This application is very important because the principle of half wave plate cannot be used due to a wide spectrum of the THz pulses.**

I. INTRODUCTION

OVER the last years, terahertz (THz) radiation from semiconductor surfaces illuminated by femtosecond laser pulses is finding multiple application areas. It has recently been reported that nanorods [1] and nanowire [2], [3] arrays in comparison with bulk semiconductors are able to enhance THz emission from optically excited surfaces. Surprisingly, THz radiation was observed also from Si NWs excited by Ti:sapphire laser pulses, whereas bulk silicon do not emit THz pulses due to its indirect energy bandgap [4], [5]. THz emission was also observed from InAs nanowires grown by metal-organic vapor phase epitaxy (MOVPE) and by catalyst-free molecular beam epitaxy (MBE). In both cases the amplitude of the signal was found to be weaker than that from InAs crystals [6], [7], however, taking NW fill factor approximations into account, the authors of [6] estimated that the emitted THz power is increased by 15 times with respect to the n-type InAs substrate. Despite the increase of the efficiency of optical – terahertz radiation conversion, vertically aligned NW arrays have the same limitation (i. e. the main part of the radiation propagates in parallel to the surface resulting the low THz emissivity outside the sample) as bulk semiconductors. In this work THz emission of the non-vertically aligned NW was investigated for the first time.

II. RESULTS

In the present work, THz pulse emission from samples of InGaAs and GaMnAs NW grown by molecular beam epitaxy (MBE) on high temperature (550°C) GaAs (111) and (110) substrates has been studied. NWs growth was induced by gold droplets. The length of the NWs was approximately 3 μm, their diameter - 70 nm. One nanowire layer was removed from the substrate for the transmission measurements. The surface of the sample was flooded with epoxy resin and after the epoxy has hardened, the sample was placed in a cryostat. At low temperature the epoxy layer with nanowires separates from the substrate due to different thermal expansion coefficients of epoxy and semiconductor layers. Experiments have been performed using Ti:sapphire oscillator generating 150 fs, 800 nm pulses at the repetition rate of 76 MHz. THz electric field transients were detected with a low temperature grown GaAs antenna. The emitters under investigation were measured in quasi-reflection and transmission geometry. During measurements the samples were rotated around normal to the sample surface – so called azimuthal dependencies were measured. Also THz pulse amplitude dependencies on an angle between the incident laser beam and a normal to the sample surface have been accomplished for the removed NWs layer.

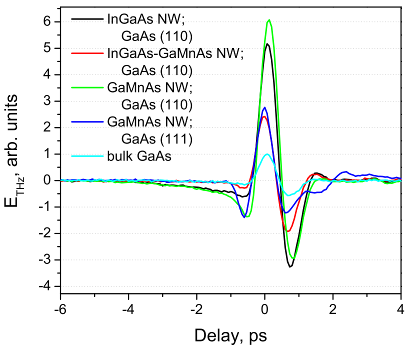

Fig. 1. THz pulses radiated from bulk GaAs and four nanowires samples excited by femtosecond Ti:Sa laser pulses.

The amplitude of the THz signal obtained from NW was 2 to 6 times stronger than that from GaAs substrate (Figure 1). The THz pulse amplitude was not sensitive to the azimuthal angle for the NW grown on (111) orientation substrates. By contrast, the azimuthal dependencies for nanowire layers

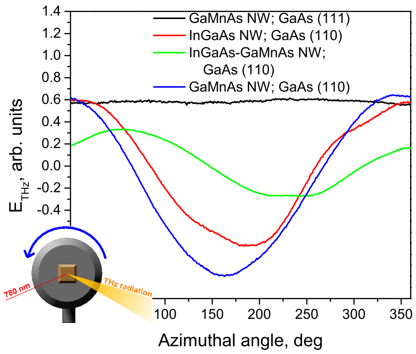

Fig. 2. THz pulse amplitude dependencies on an azimuthal angle for GaMnAs and InGaAs NWs

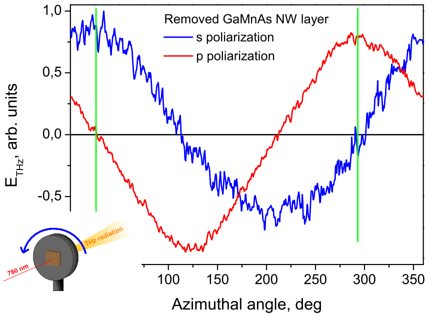

Fig. 3. THz emission azimuthal dependencies for the removed GaMnAs NW layer for s and p THz electric field polarization.

grown on (110) substrates can be approximated by $\sin\alpha$ function (Figures 2 and 3). These dependencies can be by the orientation of NW in regard to the GaAs substrate: it is known that the angle between the NW and the surface is 55° [8]. Photoexcited carriers move along the nanowires in the built-in electric field [3] and create linearly polarized THz radiation. The polarization axis moves around a terahertz beam when an azimuthal angle is changing. The registered signal changes in the sinus law as the detector registers only one polarization.

Figure 4 shows dependencies of THz pulse amplitude on an angle between an incident laser beam and a normal to the sample surface for the epoxy encapsulated GaMnAs NW layer and GaAs substrate. No terahertz radiation is registered when the laser beam falls perpendicularly to the surface of GaAs substrate since the radiation cannot propagate along an axis of photoexcited electron-hole dipole. On contrary, the NW layer emits the THz radiation well enough as the GaMnAs nanowires are not perpendicular to the plane of the layer

III. SUMMARY

THz emission of tilted nanowires was investigated for the first time. Investigated layers can be used in rotating polarization terahertz emitters. This application is very important given that the principle of half-wave plate cannot be used in pulsed THz radiation systems due to the wide THz spectrum.

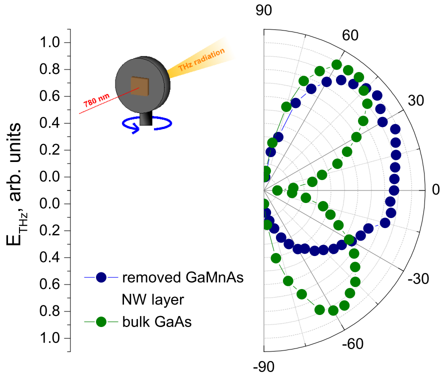

Fig. 4. THz pulse amplitude dependencies on an angle between the incidence laser beam and a normal to the surface for removed GaMnAs NW layer and bulk GaAs.

ACKNOWLEDGMENT

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