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Generation of terahertz pulses from the island films of topological insulator $Bi_{2-x}Sb_xTe_{3-y}Se_y$

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A great interest to topological matter is stimulated by the study of the THz response to laser radiation. Angle-resolved photoemission spectroscopy (ARPES) indicates the presence of Dirac electrons in many topological insulators (TI) [1] Besides of fundamental aspects, TI's are very perspective objects for practical purposes both THz detectors as THz emission sources.

In this work, we perform a study of the THz emission properties of $Bi_{2-x}Sb_xTe_{3-y}Se_y$ thick films with thickness of hundreds nm and one island film with total thickness about 40 nm grown by MOCVD method on sapphire substrate. Rhombohedral $Bi_{2-x}Sb_xTe_{3-y}Se_y$ films were grown on (0001) Al2O3 substrates with thin (10 nm) ZnTe buffer layer with orientation (111) at atmospheric pressure of hydrogen in horizontal quartz reactor. An example of AFM scan of thin island film surface is shown in Fig. 1.

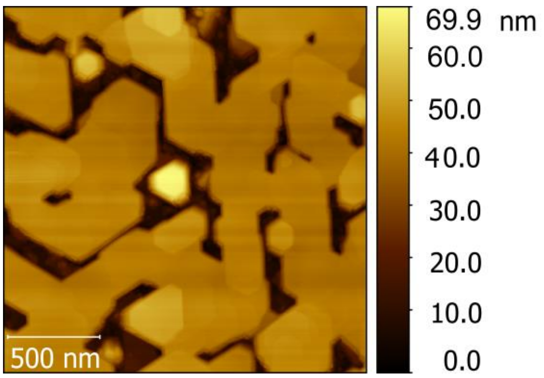

Fig. 1. AFM scan of the TI island film's surface

We use experimental setup for the terahertz emission time-domain spectroscopy (TDS) in the backward geometry. The pump is realized by the Erbium fiber laser in the Q-switched mode locking near a threshold regime at 1.56 μmm wavelength. Er^+-laser laser operated in the picosecond mode, generating optical pulses of 2.5 ps duration with the repetition rate of 70 MHz. The pump bam was divided into two unequal parts with a mean power of 100 and 20 mW, respectively. The low-power beam was focused on a photoconductive dipole antenna. The high-power beam, after propagation through the delay line and an optical chopper, was focused by the through a hole in the parabolic mirror onto the TI sample. The angle of incidence was 15°. The sample was in contact with copper electrodes (the distance between them was 0.5 mm) so that external voltage could be applied. The THz radiation generated in the sample in the backward direction was collected by four parabolic mirrors and focused on the commercial THz antenna. The antenna was oriented to register vertical components of the THz field collinear with the polarization of the pump. Thus, the electric field of THz waves generated in the direction opposite to pumping was measured at different times after the arrival of the pump pulse.

We have shown that the intensity of the THz signal from the island film is 25 times greater than that in "thick" TI samples. In order to demonstrate the amplification effect for THz radiation using an external electric field, we applied a voltage between the electrodes in contact with a surface of the island film. Fig.2 shows the waveforms of THz radiation from an island film with a bias voltage. When the polarity of the bias voltage changed, the THz signal also changed its phase by 180 degrees. Thus, for the first time, the mode of the radiating antenna in a topological insulator was demonstrated.

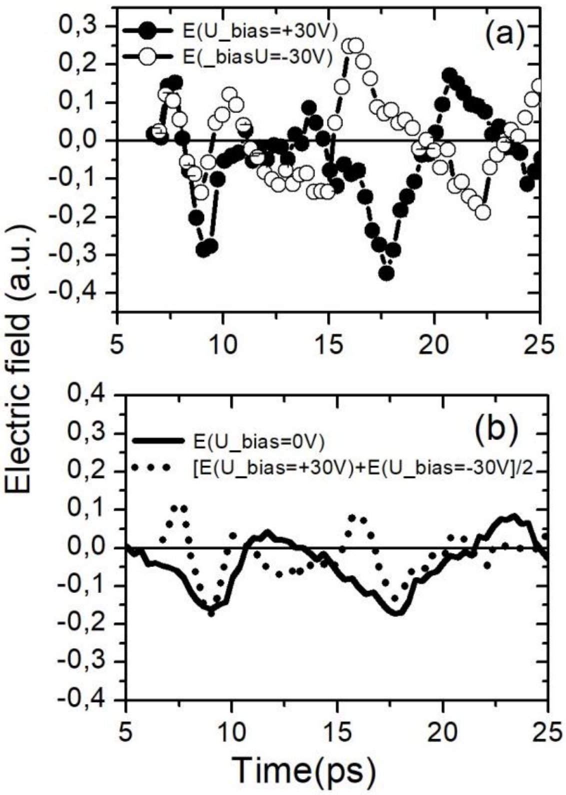

Fig. 2. Waveforms of the THz pulses

The observed waveforms contain some additional signal, which does not change its polarity with the voltage. To reveal this part we have summarized the signals, observed with +30 V and -30V voltages. Half of this sum is shown in Fig.2b (see the dotted line). The opposite-sign parts of the signals from Fig.2a almost canceled each other, so that one could expect to observe the residual constant part of the same shape as the zero-voltage signal. However, this is not true. For comparison, we repeat the zero-voltage signal together with this residual signal. One can see that the antenna pulses contain additional parts corresponding to higher modulation frequencies. This fact is illustrated in Fig.3 where the spectra of the both waveforms are shown.

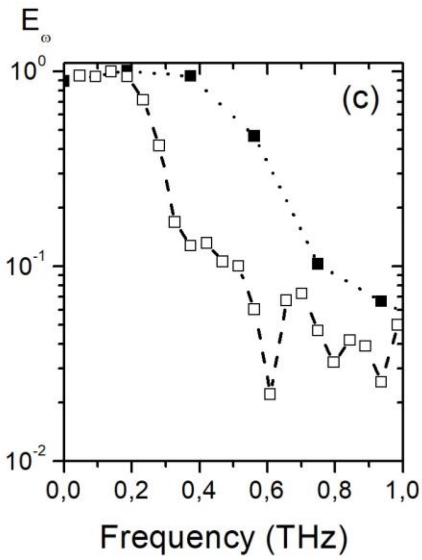

Fig. 3 Spectrum of zero-voltage signal (hollow squares) and spectrum of half-sum of signals at external bias (filled squares).

The spectrum of the residual part of the antenna signal is about two-times broader than the spectra of all the other signals, i.e. the zero-voltage signal, and the polarity-sensitive parts of +30 V and -30V voltages signals. The peak frequency corresponds to times that are of order or even less than the pump pulse duration. It means that some carrier relaxation effects proceed at considerably shorter relaxation times, than it is usually assumed to describe the THz emission of free TI samples. We believe that this effect arises from the relaxation of fast non-equilibrium charge carriers accelerated by an external field. Probably electrons are captured by the traps that are p-type impurities with energy above the bulk valence band maximum in the energy of 3-6 meV or other defects.

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References

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