New Generation of Photoconductive Terahertz Emitters

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A photoconductive Terahertz (THz) emitter based on low-temperature-grown GaAs and integrated with Bragg mirror is presented. The emitter exhibits improved terahertz emission efficiency due to the increased pumping light absorption in the Bragg mirror assisted resonant cavity, due to spatial confinement of the photocurrent, and due to optimized photoconductive response.

Introduction

The generation of few-cycle Terahertz radiation into the free space from a biased photoconductive gap illuminated by an ultrashort laser pulse is known more than a decade [1]. Since then, many attempts were presented to increase the generated THz power without compromising the radiation bandwidth [2], [3].

In this contribution, we report on a low-temperature-grown GaAs (LT GaAs) based photoconductive THz emitter integrated with a Bragg mirror. This design improves the generator's THz output power by about one order of magnitude. The optical resonance and the confinement of the photogenerated carriers in the high electric field region of the LT GaAs layer are responsible for the observed enhancement of the THz emission.

In addition, we have focused on optimization of the growth temperature of the LT GaAs layer with respect to a maximum photoresponse of the material and a maximum breakdown field. It is known that annealed LT GaAs changes its properties (resistivity, carrier lifetime) with the growth temperature. Our experiences from THz emission experiments suggest a decrease of the output THz power when the growth temperature is lowered. Therefore, we designed and tested a multilayer LT GaAs structure to increase the performance of the THz emitters.

Photoconductive THz Emitters

A low-temperature MBE GaAs layer grown at temperatures 220 – 350 °C and annealed in-situ at 600 °C (10 minutes) was used as photoconductive material. The modified THz emitter is made of a 326 nm thick LT GaAs grown directly on a Bragg mirror (Fig. 1). The Bragg mirror itself consisted of 30 pairs of $Al_{0.2}Ga_{0.8}As/AlAs$ layers designed for a center wavelength of 800 nm. As reference emitter, a 2 µm thick LT GaAs layer was used grown directly on a high resistive GaAs (100) substrate. Electrical contacts to the LT GaAs layers were made of Ti/Au metal and had the shape of coplanar striplines (20 µm wide and separated by a gap of 300 µm (Fig. 1)). The same contact shape was used also for the reference THz emitter structure made of the semi-insulating GaAs. The emitter chips were mounted onto a highly resistive silicon aplanar extended hemisphere lens to efficiently couple the generated THz radiation into free space.

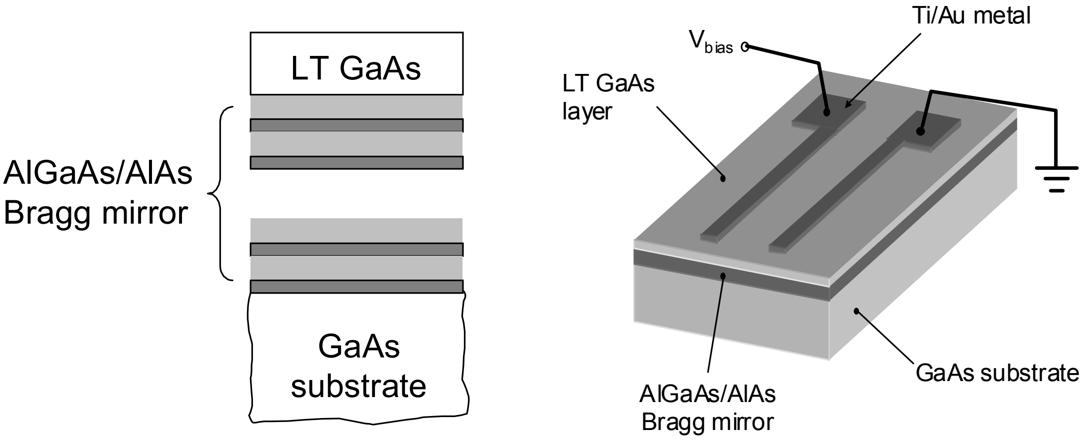

Fig. 1: Schematic of the photoconductive THz emitter.

To access the photoresponse of the LT GaAs layers grown at various temperatures, we used the attenuated unfocused laser beam from a Ti:sapphire laser to homogeneously illuminate the area between the electrodes of the emitter structures. In this configuration, the measured DC photocurrent depends on the lifetime and mobility of the photogenerated charge carriers. As expected, the lagest photocurrent was observed for the emitter structure made of semi-insulating GaAs, a material with the highest carrier lifetime-mobility product (Fig. 2). All structures involving LT GaAs exhibited much lower photocurrent with clear monotonic decrease with decreasing growth temperature.

To compare the emitters with respect to their THz emission efficiency, we have excited the emitter structures with pulses from a *fs* Ti:sapphire oscillator. The repetition rate was 76 MHz and the average excitation power reached about 250 mW. The emitted THz beam was collimated and then focused by a set off-axis parabolic mirrors onto an electro-optic sensor.

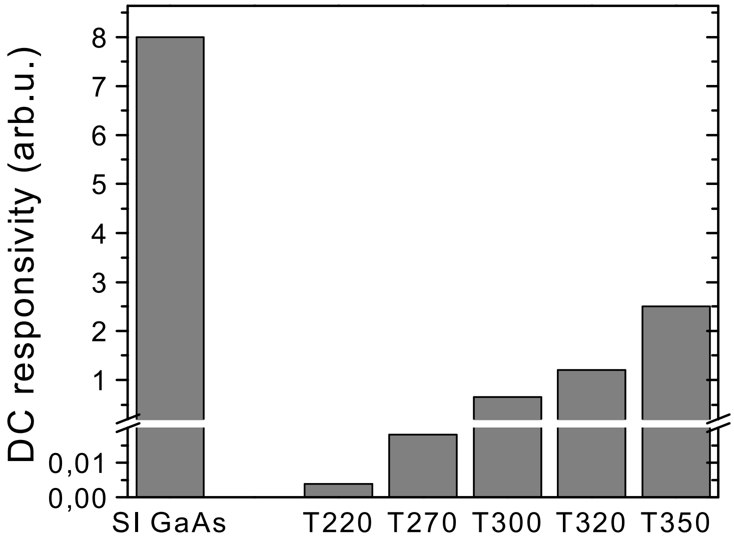

Fig. 2: Photoresponse of the THz emitters.

Figure 3 shows the bias dependence of the amplitude of the THz transients for emitters made of semi-insulating GaAs, a 2 µm thick LT GaAs grown at 220 °C, and a 328 nm thick LT GaAs grown at 220 and 320 °C on the Bragg mirror. The steepest rise of the THz emission with emitter bias was observed for the structure made of semi-insulating GaAs, however, the structure exhibits early breakdown at about 130 V related to heating by the photocurrent. On the other hand, the emitter structure made of 2 µm thick low-temperature GaAs grown at the lowest temperature of 220 °C on semi-insulating GaAs exhibits the weakest increase of the THz radiation with bias. The THz amplitude increases linearly with the applied bias up to 260 V. At biases above 260 V the THz amplitude begins to saturate or even decreases because of Joule heating of the emitter. A heating related device failure is observed for long time operation at these biases. The structure breakdown occurs at biases above 280 V. The lowest THz generation efficiency well correlates with the weakest photoresponse observed for this type of THz emitter (see Fig. 2) and is due to the short lifetime of photogenerated charge carriers and low mobility.

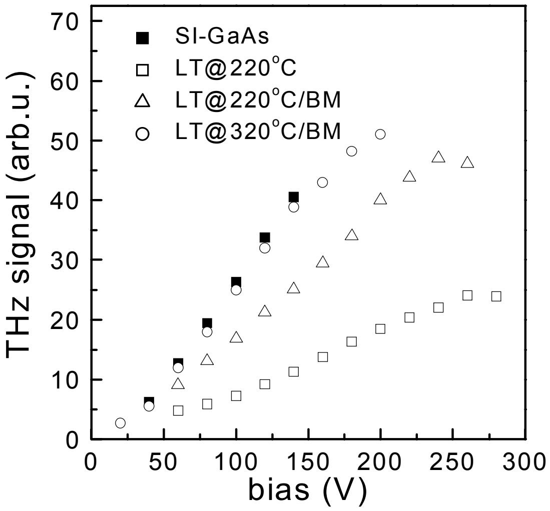

Fig. 3: THz emitter output power as a function of bias.

The emitters based on thin LT GaAs grown on a Bragg mirror exhibit much higher THz generation efficiency in comparison to that based on thick LT GaAs. The presence of the Bragg mirror leads to a doubled THz signal from the same LT GaAs material. The main enhancement is ascribed to the effect of the resonance cavity created by the Bragg mirror, the LT GaAs layer, and the air/GaAs interface. The calculation of the performance of this optical system yields an increased absorption in the LT GaAs [6]. Finally, when we have chosen a LT GaAs material providing a maximum photoresponse (see Fig. 2), the THz generation efficiency has reached a level comparable to that of semi-insulating GaAs. However, the breakdown voltage is higher and so the maximum reachable THz output power. At a bias of 200 V and for an excitation pulse energy of 2.5 nJ the maximum the THz output power was estimated to be 3.8 µW.

Conclusion

The performance of photoconductive antenna THz emitters based on epitaxial GaAs grown at different temperatures on an AlGaAs/AlAs Bragg mirror is presented. The growth occurred at temperatures between 220 and 350 °C. The maximum output THz power was observed for a growth at a temperature of about 320 °C. Moreover, the resonant cavity effect as well as the effective optical and electrical isolation of the photoconductive layer from the substrate by the Bragg mirror leads to an enhancement of the optical-to-THz conversion efficiency. A photoconductive THz emitter with such a design was recently successfully used as an intra-cavity THz generator in a *fs* oscillator [7].

References

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