Effect of Doped Buffer in Low-Temperature-Grown GaAs Terahertz Photoconductive Antenna Emitters and Detectors

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***Abstract*—Terahertz (THz) photoconductive antenna (PCA) fabricated on low-temperature-grown GaAs (LT-GaAs) with layer structure consisting of a doped buffer exhibited enhanced THz emission for LT-GaAs grown at lower temperature. As THz emitter, the LT-GaAs grown at 270°C with doped buffer generated THz radiation with amplitude twice as that of its undoped counterpart. Similar effect is not observed when the LT-GaAs is grown at 320°C with doped buffer, which is expected to have higher THz emission. As THz detector, both LT-GaAs with doped buffer exhibited identical and improved detection sensitivity regardless of the LT-GaAs growth temperature.**

I. INTRODUCTION

Low-temperature-grown GaAs (LT-GaAs) has been a material substrate for terahertz (THz) photoconductive antenna (PCA) [1-4]. An LT-GaAs PCA can serve both as THz emitter and detector. However, it has been shown that the optimum efficacy of LT-GaAs as THz emitter and detector depends on high crystallinity and short carrier lifetime, respectively [4]. These characteristics are nonconcurrent for a single LT-GaAs. The crystal quality and carrier lifetime of LT-GaAs both decreases with decreasing growth temperature as more arsenic-related defects are incorporated [4-6]. Essentially, LT-GaAs grown at lower temperature is less effective as THz emitter but is more relevant as THz detector. Nevertheless, modifications in LT-GaAs structure can be implemented to increase its build-in field such that there is an enhanced acceleration of photoexcited carriers thus generating higher THz emission [7-10]. This has been achieved by simply incorporating a thin doped buffer in LT-GaAs [10]. The enhancement in THz emission of LT-GaAs with doped buffer has been demonstrated for a bare LT-GaAs. In this study, the same modification is implemented but the LT-GaAs structure has been tailored further to be suitable for THz PCA fabrication. The effect of the doped buffer in the LT-GaAs PCA is presented in the results.

II. EXPERIMENTAL DETAILS

Two LT-GaAs samples with structure consisting of an n-doped GaAs buffer layer, an LT-GaAs active layer, and an n-doped GaAs cap layer were grown by molecular beam epitaxy (MBE) on a semi-insulating GaAs (SI-GaAs) substrate. Shown in Fig. 1 is the schematic of the grown samples. The thickness of each layer was 0.2μm, 2.0μm, and 0.02μm, respectively. The two samples varied in the growth temperature, T_g, of the LT-GaAs active layer. LT270 [LT320] had LT-GaAs grown at T_g=270°C [320°C]. The buffer and cap layers were grown at T_g=630°C and 600°C, respectively, and were doped with silicon (1.0x10^{18}cm^{-3}). Correspondingly, the LT-GaAs active layer was annealed at 600°C for 10 minutes. A reference LT-GaAs [LT270(ref)] with undoped buffer was also grown. Standard photolithography processes were employed for the fabrication of a 5μm-gap Hertzian dipole-type PCA. The PCA is illustrated on the top surface of the grown sample in Fig. 1. The metal contacts, which consisted of Au-Ge(55nm)/Ni(15nm)/Au(85nm) alloys, were annealed at 400°C for 60 seconds in a furnace that was purged with nitrogen gas. A standard THz time-domain spectroscopy system was used to investigate the THz emission efficiency and detection sensitivity of the fabricated PCA devices. A 780nm Menlo C-fiber femtosecond fiber laser was the excitation source with 100fs pulse duration and 100MHz repetition rate. When the fabricated PCA device was utilized as the emitter (detector), a 3.4μm-gap commercial Herztian dipole PCA was used as the standard detector (emitter). A 20KHz square wave provided by a function generator was the bias source of the emitter.

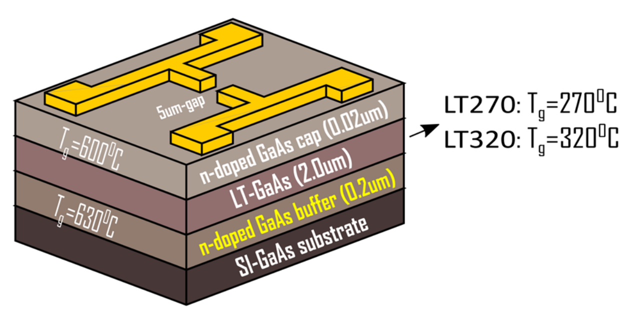

Fig. 1. Schematic diagram of the MBE-grown samples with the fabricated 5μm-gap Herztian dipole PCA illustrated on the top surface.

III. RESULTS

Shown in Fig. 2(a) is the power spectra of the THz radiation generated from the fabricated PCA devices at bias voltage of V_b=9V, pump power of P_{pump}=0.8mW, and pump probe of P_{probe}=9.5mW. The shorter carrier lifetime in LT-GaAs grown at 270°C is evident in the higher THz frequency components in LT270(ref) and LT270 relative to LT320. The higher negative

THz peak amplitude following the positive main peak of the LT270 samples shown in the inset of Fig. 2(a) also suggests faster photocurrent decay in LT270 than LT320 [1]. Given the shorter carrier lifetime and faster photocurrent decay, it can be inferred that the crystal quality of LT270 is inferior in comparison with LT320 suggesting a lower THz emission. However, the generated THz radiation of LT270 is higher than LT320 as shown in the inset of Fig. 2(a). As an emitter, LT270 demonstrated the highest THz emission and relative to LT270(ref), the doped buffer increased the THz amplitude by a factor of 2. The increase in the THz emission relative to LT270(ref) is attributed to the additional electric field at the LT-GaAs/doped buffer interface [11]. On the contrary, the doped buffer has negligible effect in enhancing the THz emission of LT320. The THz amplitude of LT320 is comparable with that of LT270(ref), which has an undoped buffer. In a previous work, it has been shown that near the interface of an LT-GaAs/doped buffer, the carriers from the n-doped GaAs buffer diffuse to the LT-GaAs [12]. This is more likely to occur for LT-GaAs grown at T_g>300°C, which has better crystal quality. As a consequence, the carrier density gradient decreases at the LT-GaAs/doped buffer region. This in turn, effectively reduces the interface electric field. THz emission enhancement in LT320 is therefore not observed despite the improved crystal quality and the addition of the doped buffer.

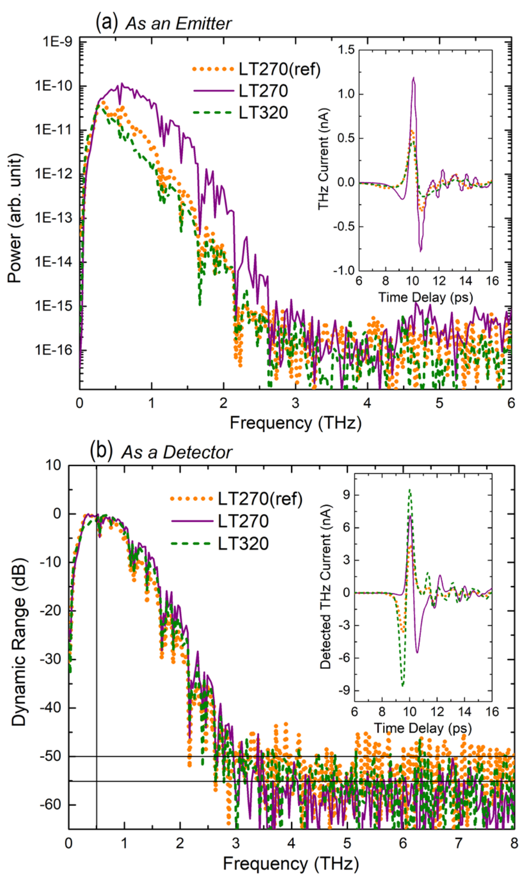

Fig. 2. (a) Power spectra of the THz radiation (inset) generated from the fabricated PCAs at bias voltage V_b=9V, pump power P_{pump}=0.8mW, pump probe P_{probe}=9.5mW. (b) Frequency spectra of the THz radiation (inset) detected using the fabricated PCAs at commercial PCA emitter bias of V_b=9V, P_{pump}= P_{probe} =9.5mW.

As a detector, a dynamic range of 55dB is obtained at 0.5THz for LT270 and LT320 as shown in Fig. 2(b), which is 5dB higher than LT270(ref) suggesting an advantageous effect of the doped buffer in increasing their detection sensitivities.

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