Fabrication and Subpicosecond Photoresponse of a Novel LT-GaAs Photoconductive Switch
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Photoconductive devices based on various semiconductor materials such as ion-implanted InP,1, 2, ion-implanted silicon-on-sapphire,3 amorphous silicon and low-temperature-grown GaAs (LT-GaAs),4-7 as well as metal-semiconductor-metal diodes8 have been under investigation to generate picosecond and subpicosecond electrical pulses for the last two decades. Those photoconductive switches, however, suffer from a difficulty to integrate them with optoelectronic circuits due to their nonstandard active materials. The hybrid integration unavoidably reduces their intrinsic multigigahertz bandwidth. We present here a new method of making a freestanding LT-GaAs photoconductive switch, which can be placed at virtually any place of the circuit containing a coplanar strip (CPS) transmission line. We also demonstrate that the freestanding LT-GaAs photoswitch exhibits a subpicosecond photoresponse time.

One-µm-thick LT-GaAs films were grown in the Varian Mod GEN II molecular beam epitaxy (MBE) system on indium-free-mounted semi-insulating GaAs substrate at a temperature range of 200°C to 250°C. An As4/Ga beam-equivalent pressure of 19 and a growth rate of 1 µm/h were used for the process.9, 10 Since our LT-GaAs film and the GaAs substrate have the same chemical composition, it is difficult to perform LT-GaAs etching process with such accuracy that it can be terminated just at the substrate-thin film interface. To overcome this difficulty, a 0.5-µm-thick AlAs etch-stop interlayer was grown between the substrate and the LT-GaAs. After the growth, wafers with LT-GaAs layers were annealed in situ at 600°C for 10 minutes under local As overpressure. The multiple-step process was used to lift and transfer the LT-GaAs layer from the GaAs substrate.9, 10, 11 First, LT-GaAs was covered with a photoresist and then the photoconductive switch structure, approximately 5-µm wide and 15-µm long, were defined by photolithography. Next, the wafer was placed into the diluted HF solution (HF:H2O 1:9) for selective AlAs etching, which led to separation of the LT-GaAs film from the substrate. Finally, the separated LT-GaAs switch was gently placed on a predetermined spot on the Si substrate. Special care was taken to ensure that the contacting surfaces were exceptionally clean so that the LT-GaAs would adhere to the Si through molecular bonding without the use of adhesive. After the switch was placed, a 10-nm/300-nm-thick Ti/Au CPS lines was fabricated on top the switch, resulting in the structure shown in Fig. 1.

The subpicosecond response of our LT-GaAs photoconductive switches was measured with an electro-optic (EO) sampling system,12 using a LiTiO3 total internal reflection (TIR) probe.4, 13, 14 A commercial Ti:Sapphire laser emitting pulses with 110-fs-duration, 810-nm-wavelength at a repetition rate of 82 MHz was used as a light source for the EO sampling system. The pulse train was split by a beam splitter into two beams: a switching beam and a
sampling beam, as illustrated in Fig. 2. The switching beam was modulated by an acousto-optic modulator and was directed to excite the LT-GaAs switch by a single 10×, long-working-distance microscope objective. The sampling beam traveled through a computer-controlled delay line, polarizer and the same as the switching beam objective, reflected by the TIR probe in a total-internal-reflection mode, and guided to the analyzer and detectors. The sampling beam is 45° linearly polarized according to the optical axis of LiTaO₃. The TIR configuration enabled us to position both the excitation and probing spots (typically, ~5 µm in diameter) very close to each other, eliminating the signal distortion caused by propagation effects, and resulting in the measurement of close-to-intrinsic electrical transient.

Figure 3 shows a 470-fs full-width-at-half-maximum (FWHM) electrical pulse generated by our freestanding LT-GaAs photoconductive switch, which was DC biased at 30 V and illuminated by the average optical excitation power \( P_{ex} \) of 2.7 mW. The electrical pulse has the risetime (10% to 90%) of 340 fs and the falltime (90% to 10%) of 460 fs. The electrical transient results from a temporary increase of conductivity due to photogenerated free carriers in the pulse-illuminated region of the LT-GaAs switch. The measured rise time is limited by the excitation laser beam pulse-width and the time resolution of our EO sampling system, which includes factors such factors as the finite spot size of the sampling beam, the thickness of the LiTaO₃ crystal and the equivalent lumped-element circuit parameters. The fall time, on the other hand, is limited by the lifetime of photogenerated free carrier.

When the excitation power was changed, the electrical transient signals were obtained with different amplitudes but the same pulse shape and width. Figure 4 shows that the photoresponse amplitude was a linear function of \( P_{ex} \), below a well-defined saturation threshold, when the bias voltage \( V_b \) was set at 30 V. The slope of this linear function was ~23 V/W, which can be interpreted as the voltage responsivity of our photoconductive device. We observed the signal amplitude saturation when \( P_{ex} > 4.5 \) mW.

![Fig. 3. 470-fs FWHM electrical photoresponse of our free-standing LT-GaAs photoconductive switch biased at 30 V and excited by 2.7 mW average optical power at 810-nm wavelength. The optical power was measured at the sample plane. Small ripples on top of the ~5-ps-long shoulder after the main peak are due to the electrical signal reflection of the interfaces of our >50-µm-thick LiTaO₃ crystal of the TIR probe.](image1.png)

![Fig. 4. The amplitude of the photoresponse signal as a function of \( P_{ex} \) for the fixed, 30-V switch bias. The slope of the linear photoresponse was ~23 V/W, which can be interpreted as the voltage responsivity of our device.](image2.png)

The photoconductive switch behavior shown in Fig. 4 is expected. With dark resistance of above 40 MΩ, we can safely assume that the measured signal is entirely due to photogenerated carriers inside our 1-µm-thick LT-GaAs sample, which has penetration of ~0.86 µm at wavelength 810 nm. With gradual increase of \( P_{ex} \), more and more electron-hole pairs are generated, increasing conductivity and leading to proportional increase of the electrical pulse. Above a certain level, however, all available carriers for given photon energy are excited, so the further increase in \( P_{ex} \) does not produce more carriers and the signal reaches saturation. For \( P_{ex} = 4.6 \) mW, the number of photogenerated carriers corresponds to a total carrier density of ~10¹⁸ cm⁻³, which is reasonable value for LT-GaAs near the saturation.
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References