1.55-μm GaNAsSb-Based Photoconductive Switch for Microwave Switching

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Abstract—We report a GaNAsSb-based photoconductive switch for microwave switching application. The GaNAsSb layer was grown by molecular beam epitaxy in conjunction with a radio-frequency plasma-assisted nitrogen source and a valved antimony crater cell. The switch shows a maximum ON–OFF ratio of 9 dB at 1.5 GHz under 1.55-μm laser excitation at 80 mW. The switch also shows a positive ON–OFF ratio up to 10 GHz. This is the first successful demonstration of a photoconductive switch for microwave switching application under 1.55-μm wavelength excitation. Further analysis suggests that the high contact resistance may degrade the performance of the photoconductive switch.

Index Terms—InGaAs, LT-InGaAs, photoconductive switching, picosecond response.

I. INTRODUCTION

PHOTOCONDUCTIVE switches are potential devices for terahertz (THz) optoelectronic applications due to its picosecond response to optical excitation. The photoconductive switch was first reported by Auston et al. [1] in 1975. Following that, Smith et al. [2] demonstrated picosecond response in photoconductive switches based on low-temperature grown gallium arsenide (LT-GaAs) as the active material in 1988. However, the GaAs-based photoconductive switches have one major drawback, which is the optical bandgap of 1.43 eV of GaAs. This prohibits the GaAs-based photoconductive switch to operate at common optical communication wavelengths of 1.3 and 1.55 μm.

Efforts such as utilization of the trap assisted two-step absorption in the LT-GaAs photoconductive switch have been demonstrated [3]. The photoresponse of the LT-GaAs photoconductive switch at 1.55 μm is rather weak due to the non-band-to-band absorption process. The utilization of small bandgap material such as LT-InGaAs [4]–[6] and ion-irradiated InGaAs [7] have also been reported. However, the carrier lifetime in the LT-InGaAs material [8] is relatively long (100 ps). Ion-irradiated InGaAs [7] has shown reduced carrier lifetime down to the subpicosecond regime (0.9 ps). However, its low dark electrical resistivity value of <1 Ω·cm is detrimental to the performance of the photoconductive switch. ErAs : InGaAs superlattices structure [9], [10] and LT-InGaAs–InAlAs multilayer structure [11] have been reported to increase the dark resistivity of InGaAs-based photoconductive switch. Their structures are more complicated compared to the conventional photoconductive switch, which only consists of single bulk photoabsorption layer. Presently, there is no viable bulk material system for photoconductive switching at a wavelength of 1.55 μm, which has the characteristics of high photoresponsivity at 1.55 μm, short carrier lifetime, and high dark electrical resistivity.

In our previous report [12], we have demonstrated the application of GaNAsSb-based photoconductive switches for microwave switching under laser excitation at 790 nm. The photoconductive switches have shown a high dark electrical resistivity value (1500 Ω·cm) and short carrier lifetime (60 ps). Pulsed response to incident light at the wavelength of up to 1.6 μm was demonstrated. However, due to the GaNAsSb material having bandgap of 0.9 eV, the photoresponse of the device at 1.55 μm is weak compared to that at short wavelength (i.e., 790 nm). As a result, the GaNAsSb-based photoconductive switch was only capable of showing a positive ON–OFF ratio at a wavelength up to 790 nm for microwave switching application.

In this letter, we present the characteristics of a GaNAsSb-based photoconductive switch with high photoresponse under 1.55-μm wavelength excitation for microwave switching, by building upon the high dark resistivity and short carrier lifetime material we have previously reported [12]. We have reduced the optical bandgap of the GaNAsSb material in the photoconductive switch to 0.8 eV by increasing the concentration of nitrogen and antimony. Measurements were carried out on devices fabricated with different gap dimensions. Analysis of ON–OFF ratio of the GaNAsSb-based photoconductive switch is presented.

II. EXPERIMENT, RESULTS, AND DISCUSSION

The photoconductive switch was fabricated from a sample with layer structure as shown in Fig. 1. The sample was grown using molecular beam epitaxy in conjunction with a radio-frequency (RF) plasma-assisted nitrogen source and a valved antimony crater cell. The 0.4-μm-thick GaNAsSb layer was grown at 400 °C. X-ray diffraction measurement shows the GaNAsSb layer is fully strained and contains 3.5% of nitrogen and 15% of...
antimony. From the band anti-crossing (BAC) model [13], the bandgap of the GaNAsSb layer is estimated to be 0.8 eV.

The photoconductive switches with linear tapered electrodes were fabricated with electrode gaps measuring 1, 2, and 5 μm. The length of the device is 100 μm. These electrodes, made of Pt(100 Å)/Ti(300 Å)/Pt(100 Å)/Au(3000 Å) metallization, were deposited on the GaNAsSb active layer followed by 30 s of rapid thermal annealing at 450 °C.

The microwave switching performance of the GaNAsSb-based photoconductive switch is characterized by measuring its ON–OFF ratio, where the S-parameters (S21) were extracted using a vector network analyzer with and without laser excitation at the electrode gap. The laser emits at wavelength of 1550 nm at an average power of 80 mW. The ON–OFF ratio is derived from the difference in the S21 value with and without the laser excitation.

Fig. 2 shows the ON–OFF ratio of the photoconductive switches with linear tapered electrodes and electrode gaps of 1, 2, and 5 μm. At frequency < 2 gigahertz (GHz), the switches show an ON–OFF value of 9 dB, indicating that the devices are highly sensitive to 1.55-μm laser excitation. This is the first demonstration of a photoconductive switch, which utilizes bulk photoabsorption layer, showing a positive ON–OFF ratio value under 1.55-μm laser excitation. At frequencies between 2 and 10 GHz, the ON–OFF ratio drops rapidly to a level of 1 dB. The magnitude and trend of the change in the ON–OFF ratio are independent of the electrode gap dimension. This suggests that the electrostatic gap resistance is not the main factor which degrades the ON–OFF ratio at high frequency.

Fig. 3 shows the insertion loss of the GaNAsSb-based photoconductive switch with linear tapered electrode and electrode gaps of 1, 2, and 5 μm. The photoconductive switch basically behaves as a light-sensitive variable resistor in parallel with a gap capacitor. The insertion loss exhibits a flat response following increase in the frequency if the resistance of the switch is smaller compared to its capacitive reactance. Otherwise, the insertion loss decreases in response to increase in the frequency if the capacitive reactance is smaller compared to the resistance of the switch. Fig. 3 shows that the insertion loss decreases as the frequency increases, even at the low frequency region (<100 MHz), where the capacitive reactance is extremely high (see inset of Fig. 3). This indicates that the switch has high ON state resistance of >10 kΩ. The resistance value is estimated from the insertion loss value of 46 dB. The resistance of the switch consists of the electrode gap resistance and contact resistance. The change in the electrode gap distance affects the gap resistance of the switch. As shown in Fig. 3, the high resistance nature of the switch bears no correlation to the electrode gap distance. Thus, the only likely cause of the high switch resistance is the contact resistance. Our previous resistivity measurement reveals that the contact resistance is ~40 kΩ [12], which is consistent with our observation of the insertion loss.

The high contact resistance leads to large insertion loss at the low frequency regime, and thus limits the ON–OFF ratio of the switch to 9 dB. Moreover, the high contact resistance also leads to the rapid decrease in the ON–OFF ratio at frequencies from 2 to 10 GHz. At such frequencies, the switch impedance is mainly affected by the gap capacitance due to the high switch resistance. Since the gap capacitance hardly changes with and
without the 1.55-μm laser excitation at the electrode gap, the switch has negligible ON–OFF ratio at high frequency. Reduction in contact resistance could improve the magnitude of the ON–OFF ratio and extend the maximum frequency range of the switch to >10 GHz. Thus, further investigation to improve the contact metallization technology of the GaNAsSb material is warranted in order to improve the switch performance.

III. CONCLUSION

We have demonstrated a GaNAsSb-based photoconductive switch with a maximum ON–OFF ratio of 9 dB at 1.5 GHz under 1.55-μm laser excitation for microwave switching application. The contact resistance limits the ON–OFF ratio of the switch, and leads to reduction in the ON–OFF ratio at frequencies between 2 and 10 GHz.

REFERENCES