Nitrogen-ion-implanted GaAs Fabry-Pérot cavity Photoconductor for THz photonics

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***Abstract*— Ultrafast photoconductors using GaAs implanted by low energy N^+ ions (< 55 keV) are fabricated and characterized up to 320 GHz by means of a photomixing experiment. Around 90 µW of output power was obtained at 290 GHz with a 2-µm-diameter photoconductor based on GaAs implanted with a main dose of 1.1×10^{12} cm^{-2} and a subsequent annealing at 600°C.**

I. INTRODUCTION

GaAs grown at low-temperature (~200 °C) by molecular beam epitaxy (LT-GaAs) exhibits highly suitable properties for ultrafast/THz optoelectronics such as high dark resistivity, ultra short carrier lifetime and relatively high carrier mobility. These properties come from the As excess incorporated during the growth resulting in a high density of deep-level defects, which are efficient electron traps. However, these properties vary rapidly with the growth temperature and a fine control is needed, which is a difficult task at temperature around 200 °C in a standard reactor.

On the other hand, implantation of ions such as As^+, H^+, N^+ or O^+ in GaAs is known as a efficient way to obtain similar properties [1],[2] with the advantage of the reliability and the repeatability of the implantation. However the absorption length of an incident 0.8-µm-wavelength light in GaAs is about 1 µm, and high ions energies are needed (~1 MeV), to reach such implantation depths even for light ions such as N^+ [2]. This energy range is not easily achieved by standard implanters which limits its dissemination. Last years, we developed a LT-GaAs FP cavity photodetector using a metallic back mirror, which exhibits high photocurrent responsivity, even with a GaAs layer thickness around 0.16 µm [3]. Such implantation depths are reached with low ions energies (<100 keV) provided easily by a standard commercial implanter.

Here, we present the fabrication and the characterization by means of a photomixing experiment up to 320 GHz of a FP cavity photodetector using 0.16-µm-thick GaAs implanted by low energy N^+ ions with targeted densities lying between ~10^{17} cm^{-3} and ~10^{19} cm^{-3}.

II. RESULTS

Sample name	Simulated ion density	Dose at *E*=55 keV	Dose at *E*=25 keV
D1	10^{17} cm^{-3}	1.2×10^{12} cm^{-2}	8×10^{11} cm^{-2}
D2	10^{18} cm^{-3}	1.2×10^{13} cm^{-2}	8×10^{12} cm^{-2}
D3	10^{19} cm^{-3}	1.2×10^{14} cm^{-2}	8×10^{13} cm^{-2}

Tab. 1. Implantation parameters

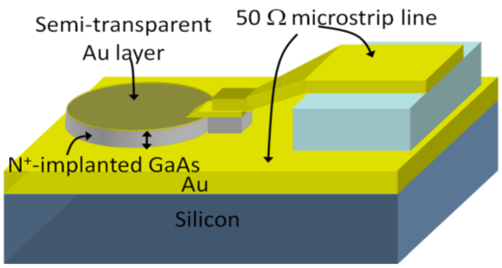

Fig. 1. Schematic of the Fabry-Pérot cavity photodetector

Samples were fabricated using the following procedure: starting from a 450-µm-thick semi-insulating GaAs substrate, a 0.1-µm-thick GaInP barrier was grown by gas-source molecular beam epitaxy (GS-MBE) followed by a 0.16-µm-thick, 10^{17} cm^{-3} n-doped GaAs layer. The implantation doses and energies were chosen thanks to Monte Carlo simulations of ions interaction in the matter (software SRIM [4]), in order to obtain N^+ ions densities lying between 10^{17} cm^{-3} and 10^{19} cm^{-3} in the GaAs layer. Two successive implantations with 55 keV and 25 keV ions energies have been performed in order to increase the concentration homogeneity in the layer. Implantation parameters are summarized in Table 1. A 600°C/40s post implantation annealing was made on the three samples.

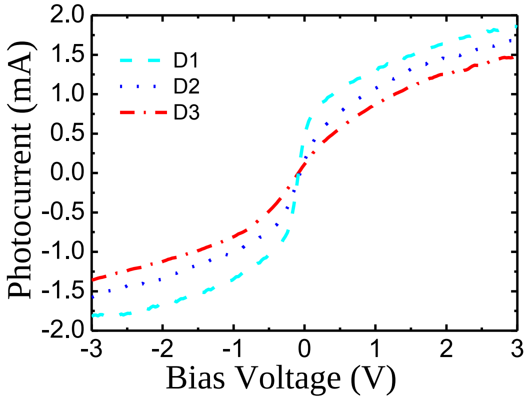

Fig. 2. Measured dc photocurrent as function of the bias voltage with an optical power P_{opt}=7.6 mW.

In Fig. 1 is shown a schematic of the photoconductor, consisting of a 0.16-µm-thick LT-GaAs layer sandwiched between two gold layers, which serve at the same time as bias electrodes and optical mirrors of the FP resonator. The 0.4-µm-thick buried gold layer is obtained thanks to the transfer of the N^+ implanted GaAs epitaxial layer onto a 2-in.-diameter silicon wafer. The transfer technique, based on Au-Au thermocompression, is detailed in Ref. [5]. The upper bias electrode consists of a 20-nm-thick semi transparent gold layer and is linked by an air bridge to a 50-Ω thin film microstrip line patterned on a 2.55-µm-thick-SiO_2 layer.

In Fig. 2 are shown the bias voltage (V_{bias}) dependences of the dc photocurrent (I_{ph}) at a constant optical power. These measurements are obtained by illuminating 40x50 µm²-area-photoconductors by an incident optical power P_{opt}=7.6 mW provided by a fiber coupled distributed feedback laser (DFB) working at λ=780 nm. The incident power is focused on the device by a lensed fiber providing a gaussian spot of width $w \approx$ 4 µm. The decrease of the slope of the I_{ph} (V_{bias}) curves at low V_{bias} when the implantation dose increases is related to the dependence of the electron mobility with the density of defects in the GaAs crystal.

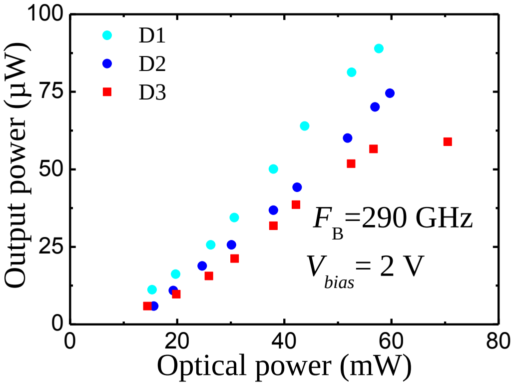

Fig. 3. Output power generated by a 2-µm-diameter and 0.16-µm-thick N^+ implanted GaAs FP cavity photodetector as a function of the optical power. A 600°C/40s post implantation annealing was performed on the three samples.

In Fig.3 are shown the optical power dependencies of the output power when the photodetector is illuminated by an optical beatnote of frequency f_B = 290 GHz, generated by the spatial overlap of the emission of two fiber-coupled DFB laser diodes and amplified by a semiconductor optical amplifier (SOA). The wavelengths of the DFB are near 780 nm. The generated power is collected by a waveguide J-Band coplanar probe and sent to a powermeter (Erickson PM4). The losses induced by the coplanar probes and the waveguides were measured and taken into account. They reach 5 dB at 290 GHz. A maximum power of around 90 µW before destruction was generated on a 2-µm-diameter photoconductor (capacitance=2.2 fF). In the whole range of optical powers, the output power increases when the ion doses decreases. It is consistent with the highest dc-responsivity shown in Fig.2.

III. SUMMARY

It has been shown that nitrogen implanted GaAs could be an alternative to LT-GaAs layers to develop ultrafast photoconductors adapted to THz waves generation by photomixing.

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REFERENCES

[1] K. Chen, Y. Li, M. Yang, W. Y. Cheung, C.-L. Pan, and K. T. Chan, “Comparison of continuous-wave terahertz wave generation and bias-field-dependent saturation in GaAs:O and LT-GaAs antennas,” *Opt. Lett.*, vol. 34, no. 7, p. 935, Mar. 2009.

[2] M. Mikulics, M. Marso, P. Kordoš, S. Stanček, P. Kováč, X. Zheng, S. Wu, and R. Sobolewski, “Ultrafast and highly sensitive photodetectors fabricated on high-energy nitrogen-implanted GaAs,” *Appl. Phys. Lett.*, vol. 83, no. 9, p. 1719, Aug. 2003.

[3] E. Peytavit, P. Latzel, F. Pavanello, G. Ducournau, and J.-F. Lampin, “CW Source Based on Photomixing With Output Power Reaching 1.8 mW at 250 GHz,” *IEEE Electron Device Lett.*, vol. 34, no. 10, pp. 1277–1279, Oct. 2013.

[4] J. F. Ziegler, M. D. Ziegler, and J. P. Biersack, “SRIM – The stopping and range of ions in matter (2010),” *Nucl. Instruments Methods Phys. Res. Sect. B Beam Interact. with Mater. Atoms*, vol. 268, no. 11–12, pp. 1818–1823, Jun. 2010.

[5] E. Peytavit, C. Coinon, and J.-F. Lampin, “A metal-metal Fabry–Pérot cavity photoconductor for efficient GaAs terahertz photomixers,” *J. Appl. Phys.*, vol. 109, no. 1, p. 016101, 2011.