Photovaractor performance for optically controlled microwave circuits

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Abstract — The photovaractor for optically controlled microwave circuits was designed and studied. The photovaractor module was fabricated as a planar p-i-n photodiode chip placed in a fibre optic matching receptacle. Study of C-V characteristics in the light illumination mode has shown that capacitance characteristics are strongly dependent on the light illumination power. These variations of the photovaractor diode capacitance are large enough to be used in optically controlled circuits such as oscillators, mixers and switchers.

Keywords — circuits, photovaractor, optically controlled.

1. Introduction

Various varactor diodes are extensively used in microwave applications, which include phase shifter, frequency multiplier, mixer and nonlinear transmission-line [1 – 4]. In recent years the application of photonic devices for such optically controlled microwave circuits are discussed widely in literature [5 – 9]. The advantages of optical control are high tuning speed and good isolation between controlling and microwave signals.

One of optical control means is the use of junction capacitance variation due to optical illumination. We propose to call such a device as the photovaractor. In this paper we report measurements of photovaractor fabricated as a planar p-i-n InP/InGaAs photodiode placed in a fibre optic matching receptacle. Variation of the photovaractor characteristics due to optical illumination with different light power are studied.

2. Photovaractor diode

The photovaractor described in this paper is a planar p-i-n photodiode with front illuminated p⁺-region and back ohmic contact to n⁺-InP substrate. The p-i-n photodiode has been fabricated in n-InP/n-InGaAs/n⁺-InP heterostructure which was grown on a substrate by low pressure metal-organic vapour-phase epitaxy (LP-MOVPE). The heterostructure has been studied using electrochemical C-V profiling method before making the photodetector chip. Figure 1 shows the cross-section of the planar InP/InGaAs p-i-n photodiode. The epitaxial layer is composed of 0.6 μm, 1.2 × 10¹⁵ cm⁻³ undoped n-InP top layer, 1.5 μm, 1.2 × 10¹⁵ cm⁻³ undoped n-InGaAs absorption layer, 0.5 μm undoped n-InP buffer layer on 400 μm, 3 × 10¹⁸ cm⁻³ Te doped n⁺-InP substrate. The Hall method measurement has given following majority carrier mobility values in InGaAs absorption layer: 7735 cm²/V·s at 300 K, and 64084 cm²/V·s at 78 K.

![Fig. 1. Cross-section of the planar InP/InGaAs p-i-n photovaractor.](image)

The p⁺-region was formed by local diffusion of Zn into the wide band gap n-InP top layer. The Zn diffusion was performed in an open gas flow system into unpassivated InP surface at 470°C [10]. The results of electrochemical C-V measurements indicated that the average doping level in the p⁺-InP layer for this diffusion conditions was 7.5 × 10¹⁸ cm⁻³, and the layer thickness was 0.5 μm. SiO₂ films of 0.25 ± 0.01 μm thickness were used as diffusion mask and passivative layer for the planar diode structure. These films have been made by pyrolysis of tetraethoxysilane at 330 – 350°C in O₂/N₂ flow. Ohmic contacts to p⁺- and n⁺-regions were formed using AuZn and AuGe binary alloys, respectively. Contact annealing was performed at 350°C in H₂ flow. Contact resistance for both p⁺- and n⁺-regions was 1 – 3 × 10⁻⁶ Ω · cm². The diameter of the photosensitive area was 100 μm.

The photovaractor module has been fabricated as a planar p-i-n photodiode chip placed in a fibre optic matching receptacle. To reduce reflection from the fibre-air, air-optics and microwave signals, a refractive index close to that of quartz fibre was used [11].

3. Results and discussion

Measurements of I-V characteristics of the photovaractor have shown that the breakdown voltage was 50 V. The values of dark current were 3.5 – 3.7 × 10⁻⁸ A under 1.0 V reverse bias, and 4.0 – 4.1 × 10⁻⁹ A under 15 V bias. Ca-
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Fig. 5. The capacitance versus optical illumination power variation under different bias voltages.

near bias free region because the photovaractor has wide junction capacitance variation range due to illumination, as well as good sensitivity, frequency bandwidth and low dark current.

4. Conclusions

The receptacled p-i-n photovaractor module incorporating the matching medium are presented. The study of C-V characteristics in the light illumination mode has shown that the capacitance characteristics are strongly dependent on the light illumination power. These junction capacitance variations of the photovaractor diode are large enough to be used in optically controlled microwave circuits such as oscillators, mixers and switchers.

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