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GaInAs Planar Photoconductive Detector Selectively Grown by Low-Pressure Organometallic Vapor Phase Epitaxy

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Abstract- A GaInAs planar photoconductive detector has been fabricated by a low-pressure organometallic vapor phase epitaxy. This device was selectively grown on etched grooves of semi-insulating InP substrate. To increase bandwidth and decrease leakage current, a Zn-doped InP layer was embedded under undoped GaInAs light absorption layer. This detector shows high speed response (~100psec FWHM) with responsivity of 2 A/W. This planar device is suitable for optoelectronic integrated circuits.

1. INTRODUCTION

For future optical fiber communication systems, a high speed photodetector is needed. Recently, photoconductive detectors have been investigated for several giga bits/sec (long wavelength) optical communication.[1] The device structure of photoconductive detectors is similar to that of field effect transistors (FET's). Therefore, these devices are suitable for monolithic integration such as optoelectronic integrated circuits (OEIC's).

To fabricate OEIC's, a photodetector and FET's should be fabricated on semi-insulating substrate for device isolation. Mesa etching is a process for device isolation in conventional OEIC's. However, the reliability of the mesa structured devices is poor. Consequently, planar structured photoconductive detectors fabricated on a semi-insulating substrate are preferable.

Planar embedded *pin* photodiodes on a semi-insulating InP substrate have already been fabricated by chloride vapor phase epitaxy (VPE) and reactive ion etching (RIE).[2] The photodiode layer was grown on a stepped substrate by VPE. The stepped surface was etched by RIE and a planar *pin* photodiodes was obtained. Generally, planar devices can not be obtained by only epitaxial growth, and an additional process (for example, etching) is needed.

Recently, buried growth technique for GaAs has been investigated by low-pressure organometallic vapor phase epitaxy (OMVPE).[3] Using this method, no polycrystalline deposition occurs on the masked areas and planar devices can be obtained by only epitaxial growth.

We fabricated planar photoconductive detectors selectively grown by low-pressure OMVPE on Fe-doped InP substrates for the first time. To reduce the leakage current and increase the bandwidth, a Zn-doped InP epitaxial layer (*p*-type) was embedded under the GaInAs light absorption layer.[4]

2. FABRICATION PROCESS

Growth system of low-pressure OMVPE consists of a vertical, water cooled quartz reactor and a RF heated carbon susceptor on which the substrate was placed. A 2-inch diameter Fe-doped InP substrate oriented 2° off (100) toward the nearest [110] was used.

The substrate was coated with a 100nm SiNx film deposited by plasma chemical vapor deposition (CVD) using SiH_4 and NH_3. Stripes of 200μm width SiNx film were selectively removed by conventional photolithography process, and 800μm width stripes of SiNx remain on the InP substrate. (80% of InP surface is covered by SiNx film.) These stripes are arranged along $[\bar{1}10]$ direction. The grooves were etched in a $5H_2SO_4/1H_2O/1H_2O_2$ solution. After the OMVPE growth, the SiNx film was removed completely. No polycrystalline deposition occurs on masked areas and planar surface can be obtained by only epitaxial growth.

Figure 1 shows schematic (cross sectional) views of photoconductive detectors. A 0.2μm thick Zn-doped (p:$3\times10^{18}cm^{-3}$) InP, a 1μm thick undoped (n^-:$\sim10^{15}cm^{-3}$) GaInAs and a 0.1μm thick undoped InP epitaxial layer were grown successively on an Fe-doped InP substrate.

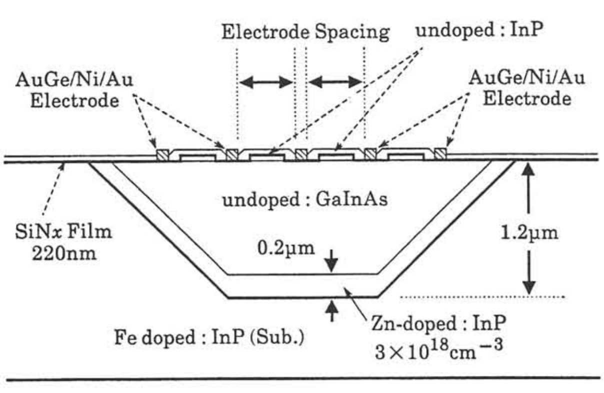

Fig. 1 Schematic (cross sectional) view of the photoconductive detector selectively grown by OMVPE.

The surface InP layer was selectively removed and residue InP between two electrodes was used as a window. This window layer reduces the surface recombination of the carriers. The surface was covered by a 200nm thick SiNx film for anti-reflection. After selective etching of the SiNx film, n-electrodes were formed by evaporating AuGe/Ti/Au on the GaInAs layer, which was then sintered at 400°C for 60sec. Ti/Au electrodes for bonding pads were successively evaporated.

3. EXPERIMENTAL

To evaluate the photo-response of photoconductive detectors, a GaInAsP short pulse laser emitting at 1.3μm was used. This laser was driven by a comb generator to generate light pulses at a repetition rate of 100MHz. The full width at half maximum (FWHM) of this optical pulse was measured to be 40psec.

Figure 2 shows the leakage currents of the photoconductive detectors as a function of the bias voltage. The leakage current is 10μA at -2V bias. The leakage currents of conventional photoconductive detector are several milliamperes.[1] The leakage current can be drastically reduced by a p-InP layer. Undoped GaInAs light absorption layer, whose (original) carrier concentration was approximately $10^{15}cm^{-3}$, was completely depleted by the pn-junction. Therefore, the leakage current decreases. Similar results were obtained by a mesa structured photoconductive detector.[4] The leakage current, however, was much greater than that of pin photodiodes. The leakage current can be decreased by an improvement in the fabrication process.

Figure 3 shows the pulse response at 5V bias for photoconductive detector. The FWHM

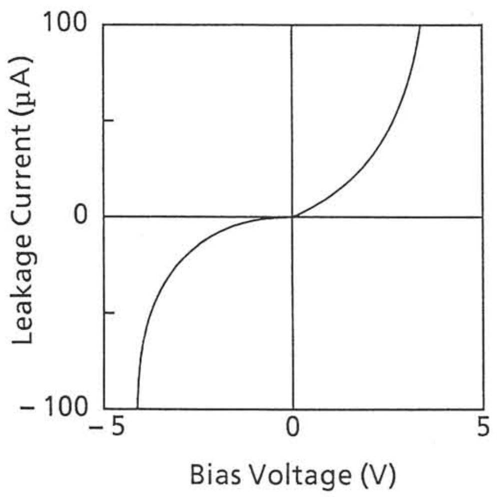

Fig. 2 Leakage current of the photoconductive detectors as a function of bias voltage.

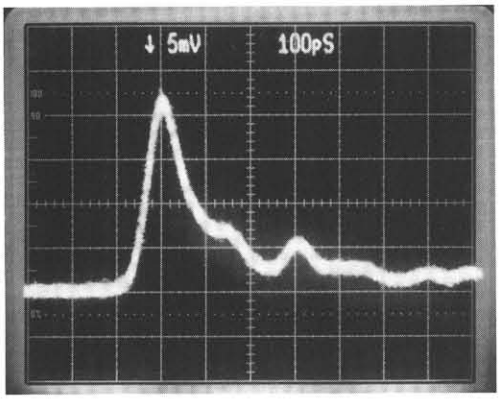

Fig. 3 Pulse response of photoconductive detectors at 5V bias. The full width at half maximum of the incident optical pulse is approximately 40psec.

and fall time of this pulse are 100psec and 200psec, respectively.

Figure 4 shows the equivalent circuit of this photoconductive detector. There is a *pn*-junction of *p*-InP and n^--GaInAs in this device. The *pn*-junctions under E_1 and E_2 electrodes are oppositely biased. The diode D_1 and D_2 represent these two *pn*-junctions. Resistors R_1 and R_2 represent the resistor of the undoped GaInAs layer and the *p*-InP layer, respectively. Two diodes (D_1 and D_2) are serially connected in the opposite direction and two resistors (R_1 and R_2) are parallel connected. The resistor R_1 is much greater than the resistor R_2, because the GaInAs layer is depleted. When a plus voltage is applied to the electrode E_1, almost all the bias voltage is applied to diode D_1, because diode D_2 is normally biased.

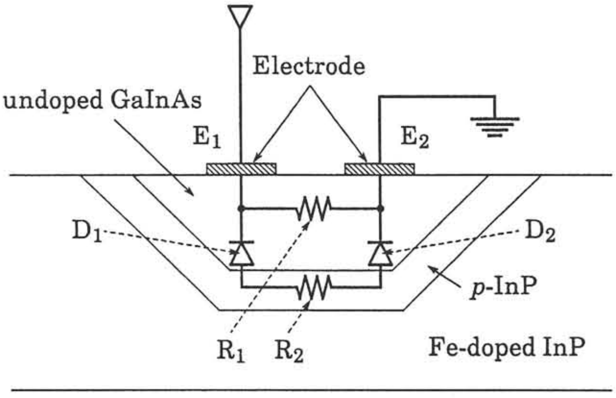

Fig. 4 Equivalent circuit of photoconductive detector.

The operation mechanism of this detector consists of two modes, such as the *pin* photodiode mode and the photoconductive mode.[4] The output signal is the sum of two photodetectors, PC and *pin* photodiode. The holes generated by light are absorbed by the *p*-InP layer and extracted from the electrode E_2. But the holes can not completely absorbed, and a comparatively long fall time (200psec) is observed.

Figure 5 shows the frequency characteristics of photoconductive detector. The 6dB bandwidth (3dB down of the current gain) of this photoconductive detector was 1.1GHz and the gain from 1GHz to 3GHz was constant. The decrease of the gain from DC to 500MHz seems to be due to the lifetime of holes. In this device, holes cannot be completely absorbed by the *p*-InP layer. If holes are completely absorbed, the bandwidth is estimated to be more than 3GHz.

The responsivity is depicted in Fig. 6. The responsivity of the photoconductive

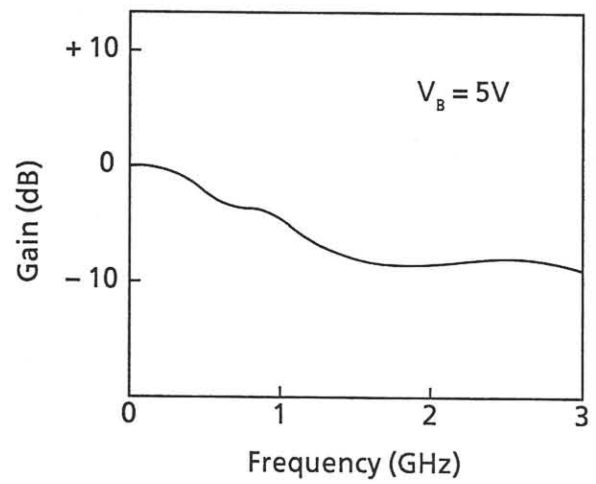

Fig. 5 Frequency characteristics of photoconductive detectors.

detector is saturated, when the bias voltage was more than 1 V. This fact indicates that the drift velocity of the electron is saturated. And the responsivity of this detector was more than 2 A/W, whereas the responsivity of a conventional *pin* photodiode is approximately 1 A/W. This fact indicates that the gain is the sum of two

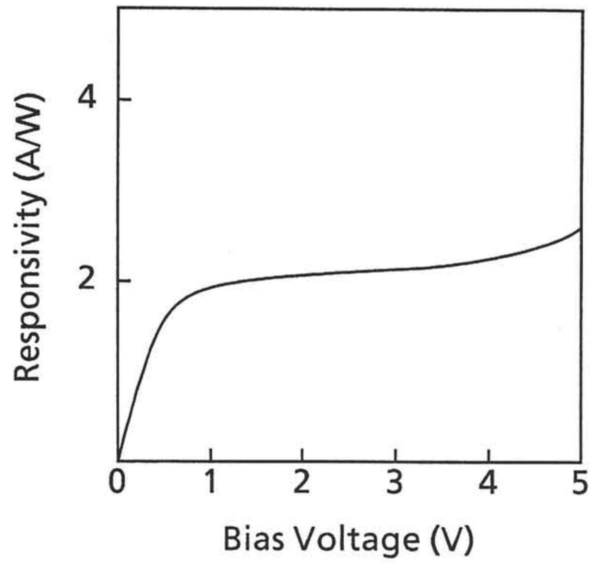

Fig. 6 Responsivity of photoconductive detectors.

photodetectors, the photoconductive detector and the *pin* photodiode. Therefore, the operation model shown in Fig. 4 is reasonable.

4. CONCLUSION

A GaInAs photoconductive detector has been fabricated by a low-pressure organometallic vapor phase epitaxy on a semi-insulating InP substrate. This device was selectively grown on the etched groove of an Fe-doped InP substrate. The FWHM and responsivity of this detector were measured to be 100psec and 2 A/W at 5V bias, respectively. This planar device is suitable for optoelectronic integrated circuits. The leakage current can be decreased by an improvement in the fabrication process.

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