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Frequency Tuning of Photo-Induced Oscillations in Multiple-Quantum-Wells Pin Diodes

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1. Introduction

In the past several years, the negative differential resistance (NDR) of diode structures such as resonant tunneling diode (RTD) and multiple-quantum-wells (MQW) p-i-n diode has been widely studied because of its practical applications and the academic interest in the fundamental principles behind the electrical oscillations of diode circuits. In particular, MQW p-i-n diodes having photo-induced NDR characteristics have been applied to various advanced devices such as microwave oscillator,[1-2] optical bistable device,[3-5] and optical regenerator,[6] etc. Recently, we have observed both the electrical and optical self-oscillations from reverse-biased multiple-shallow-quantum-wells (MSQW) pin diodes under the illumination of a high power laser.[7-8] Those oscillations were present at the negative differential resistance (NDR) region where two current plateaus occurred along with some hysteresis. In this report, we further explore the characteristics and frequency tuning of photo-induced oscillations in MSQW pin diodes.

2. Result and Discussion

The pin-diode structures used in this study were grown by gas-source molecular beam epitaxy. Quarter-wavelength reflector stacks consisting of 14.5 pairs of 72.5 nm-wide AlAs/61.6 nm-wide $Al_{0.1}Ga_{0.9}As$ were grown on a semi-insulating GaAs substrate, and followed by p-i-n-i-p layers. For p- and n-doping, $Al_{0.1}Ga_{0.9}As$ layers were doped with Be ($1x10^{19}$ cm^{-3}) and Si ($5x10^{18}$ cm^{-3}), respectively. In each intrinsic region, 20.5 pairs of 10 nm-wide GaAs/5 nm-wide $Al_{0.05}Ga_{0.95}As$ MSQW were sandwiched between 20 nm-wide undoped $Al_{0.1}Ga_{0.9}As$ spacers. An anti-reflection coating was made on the top of the device. Finally, two pin diodes in the p-i-n-i-p layer were connected in parallel.

For photocurrent-voltage measurements, the 856-nm line of a semiconductor laser with the Gaussian beam of ~10 μm diameter was illuminated on the diode at room temperature. The wavelength of the laser was around the transition energy of the heavy-hole exciton ground state of MSQWs. The transition energy of the exciton ground state of MSQWs was nearly independent of the bias voltage, and this property of MSQWs has been successfully utilized for self-electrooptic effect devices. We used the HP4145B parameter analyzer for *I-V* measurements. The a.c.-components of electrical signals were extracted by a bias-T and monitored by using the rf-spectrum analyzer and the oscilloscope. Optical oscillations of the reflected laser from the diode were measured simultaneously by the same oscilloscope.

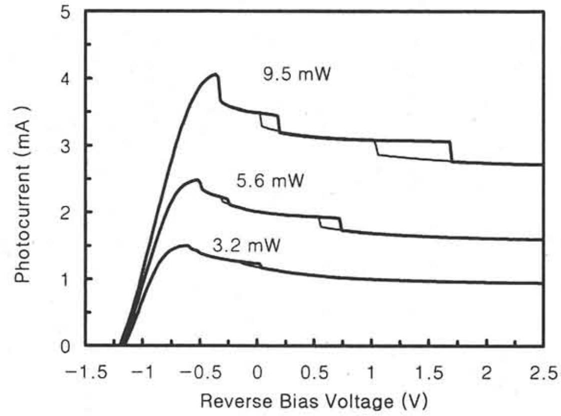

Fig. 1 *I-V* curves of the pin diode at various laser power. The total capacitance of the diode is ~2 pF.

Figure 1 shows the *I-V* curve of a pin diode at various laser power. When the intensity of the input laser was low, the *I-V* curve at the NDR region decreased monotonically with no oscillations. Above a certain laser power, the continuous NDR of each pin diode developed into some current-plateaus, and the bias-circuit and intrinsic oscillations were revealed in the diode-circuit. For increasing the laser power, the position and width of current-plateaus also shifted to the high reverse bias voltage and became wider.

The photo-induced intrinsic oscillations of the diode were measured after a parallel connection of a 10 μF-capacitor to stabilize the bias circuit. The electrical and optical oscillations in the pin diode at the bias voltage of 1.6 V are shown in the top and bottom traces of Fig. 2(a), respectively. The frequency spectrum of the intrinsic electrical oscillations of the diode at the same voltage shows a sharp peak at 57.9 MHz as shown in Fig. 2(b). By adding a capacitor in parallel, the diode reveals unique oscillation frequency at a given bias due to circuit stability, and its *I-V* curve reveals single current plateau as plotted in the solid line in Fig. 3. More interesting observation as plotted with the solid squares in Fig. 3 is that the frequency of the intrinsic oscillations increases continuously from ~54.5 to ~58.5 MHz as a function of the bias voltage. The oscillation frequency can also be tuned by the control of the input laser power. For instance as shown in Fig. 4, the oscillation frequency of the pin diode at no external bias increases from ~51 to ~60 MHz with increasing the laser power from 3 to 13 mW, respectively.

3. Conclusions

We studied the characteristics of photo-induced self electro-optical oscillations in MQWS pin diodes having the negative differential resistance properties under the illumination of a high power laser, and demonstrated that the frequency of intrinsic oscillations in the diode could be tuned by the bias voltage and the laser power. The change in the reflected light and the contrast ratio of the oscillation amplitude were ~20 % and 2, respectively. The oscillation performance can be further improved by optimizing the diode structure and the device size, etc. We believe that the photo-induced self-oscillation of QSQW pin diodes has a great potential for all-optical self modulators and micro-wave components.

Acknowledgment

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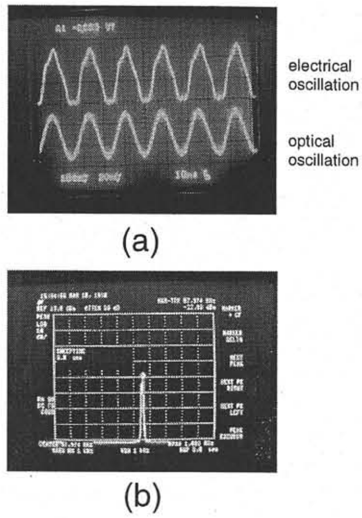

Fig. 2 (a) Electrical and optical oscillations in the pin diode at a bias voltage of 1.6 V, and (b) the spectral characteristics of electrical oscillations at the same bias voltage: peak frequency = 57.9 MHz; span = 1 MHz.

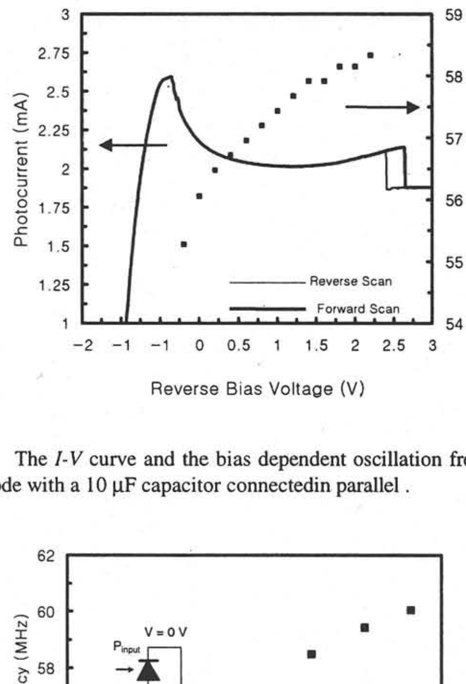

Fig. 3 The *I-V* curve and the bias dependent oscillation frequency of the pin diode with a 10 μF capacitor connectedin parallel .

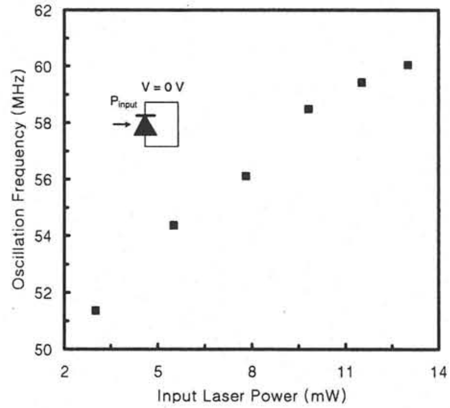

Fig. 4 Frequency tunability of the pin diode at various input laser power without the external bias. The inset shows the measurement circuit.