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Gate Length Dependence of Optical Characteristics in Optically Controlled MOSFET

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I. Introduction

It is widely believed that optical interconnection can solve the electromagnetic interference and resistance-capacitance (RC) time constant problems in electrical wiring integration. High performance optoelectronic devices are necessary in order to create this system. Since long-wavelength light is used in optical communication, a device that is composed of a long-wavelength photodetector and a logic circuit in one chip will be useful in regards to optical interconnection in the future. However, the research on devices that have integrated Si logic circuits and long-wavelength light optical receivers has been limited.

We have proposed an optically controlled MOSFET (OCMOSFET) for this type of integrated device [1-3]. In the before reported device, the light absorption region and MOSFET were bonded using a polyimide. But in this device, the voltage drop in the polyimide layer could not be ignored and sufficient current modulation could not be obtained. In order to obtain high current modulation, it is necessary to reduce the applied voltage on the polyimide layer. Hence we used the SiO_2-InP direct wafer bonding technique to decrease the excess voltage drop and to integrate the absorption and the MOSFET regions [4].

In this report we show the gate length dependence of the optical characteristics in optically controlled MOSFET. We have obtained high modulation current and responsivity by decreasing the gate length of the MOSFET region.

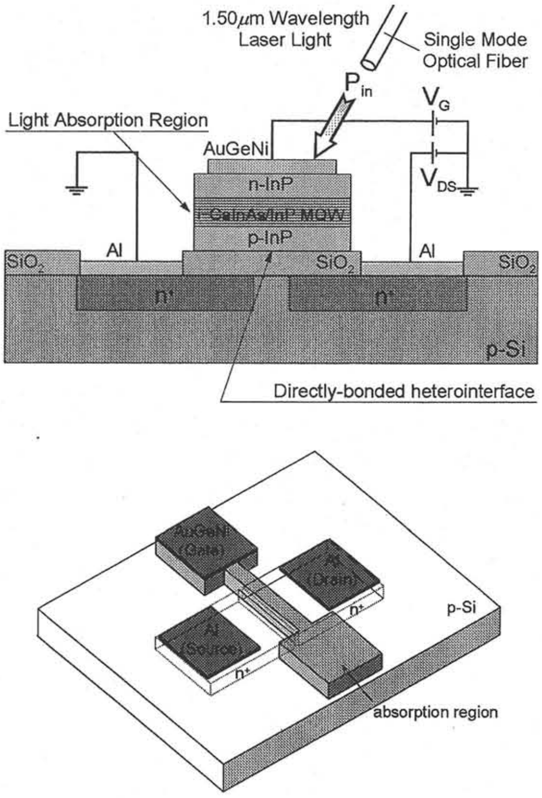

Fig.1: Schematic structure of an integrated optically-controlled MOSFET.

II. Device Structure

In the structure of the OCMOSFET, there is an absorption region that is overlaid on an n-MOSFET region as shown in Fig. 1. The absorption region was formed from a p-i-n photodiode with p-InP, an i-GaInAs/InP MQW on n-InP substrate. The n-MOSFET and the absorption regions were directly bonded and they were electrically insulated in order to block any carrier exchange.

The operation of this device is as follows: when the laser light with a long wavelength is absorbed in the absorption region, the light energy generates pairs of electrons and holes. These electrons and holes drift towards the n-layer and the p-layer of the p-i-n photodiode due to the electric field that is generated by the applied gate voltage. Then the electric field of the gate voltage is reduced by a photogenerated electric field of electrons and holes. Due to the original electric field change, the applied voltage for the MOSFET channel increases, and the drain-to-source current is modulated as a result of gate voltage control by the illumination of light.

III. Experimental Results

The difference between the last reported OCMOSFET [4] was the pattern of the absorption region. By reducing the length of the absorption region that was overlaid on the gate channel of the MOSFET region, the leakage current was remarkably decreased and the current-voltage characteristics of the OCMOSFET had little difference from the metal gate MOSFET as shown in Fig.2. By increasing the drain voltage to the MOSFET region, the drain current was saturated, and the saturation of the current was obtained when the light was illuminated to the absorption region as shown in the dashed line.

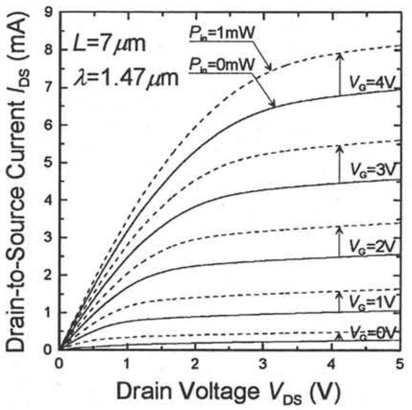

Fig.2: Current-Voltage characteristics with the input light power.

Figure 3 shows the modulation current $\Delta I_{DS} = I_{DS}(P_{in}) - I_{DS}(P_{in} = 0)$ with the gate length of 7μm. By increasing the gate voltage of the absorption region, the modulation current was increased. And as can be seen from this figure, the modulation current was saturated by the increase of the drain voltage. These characteristics were explained from the transconductance of the MOSFET region, and they show that the optically controlled MOSFET was operated by the change of electric field.

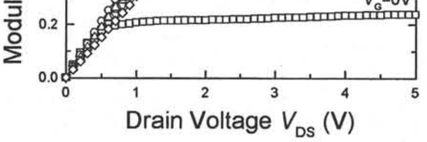

Fig.3: Modulation current ΔI_{DS} versus drain voltage V_{DS} as a function of V_G.

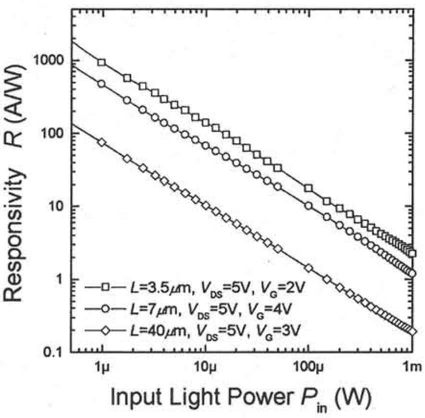

Fig.4: Responsivity versus input light power P_{in} with the gate length of 40μm, 7μm, and 3.5μm.

Figure 4 shows the responsivity $R = \Delta I_{DS} / P_{in}$ where the gate length was 40μm, 7μm, and 3.5μm. When the length of the gate was decreased, the transconductance of the MOSFET region was increased, and the modulation current was increased. Hence shortening the gate length increased the responsivity. We have obtained 1850A/W responsivity when the gate length of MOSFET region was 3.5μm. This responsivity was the highest value on the Si-circuits as we know. In this figure, the responsivity was decreased when the input light power was increased; this is because of the saturation of the modulation current.

IV. Conclusion

We show the optical characteristics in optically controlled MOSFET. This device was the integrated structure of the absorption region and MOSFET region by using the direct wafer bonding technique. The modulation current was increased by shortening the gate length of MOSFET region, and we have obtained 1850A/W responsivity with the gate length of 3.5μm.

References

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