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Photodetector with the Embedded Schottky Electrode

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Two types of photodetectors with the embedded Schottky electrodes are proposed. One of them is the embedded metal-semiconductor-metal photodetector which has an increased light sensitive area compared with the conventional one. The other is the back gated photoconductive detector which has a reduced fall time. The reduction of the fall time is due to the draining of the hole through the back gate.

I. Introduction

In optoelectronic integrated circuits (OEIC's), it is necessary to tranform electrical signals into optical signals and vice versa. Transforming optical signals into electrical signals needs photodetectors. Optical detectors in OEIC should be compatible in their fabrication processes, with the other devices.

Here we propose two photodetectors as possible candidates for the photodetectors suitable for OEIC. The common feature of them is the use of the embedded Schottky electrode. We used the semiconductor-metal-semiconductor (SMS) structure to embed the Schottky electrodes. The SMS structure will make the vertical integration of electronic devices and optical devices in OEIC possible. The vertical electronic devices such as permeable base transistor have small parasitics so that the operating frequency of them can be very high [1]. The compactness of their structures also enables high power operation. In spite of these advantages, the use of SMS structure is limited to the trasistor application. We used this SMS structure for photodetectors. One of the detectors is the embedded metal-semiconductor-metal photodetector (MSM-PD). The main advantage of this device lies on its full use of the available detection area. The other is the back gated photoconductive detector (PCD). The major advantage of the detector is the reduction of the fall time in the pulse response. The design and operation of them are described.

II. Structure and Fabrication.

II.1 Embedded Metal-Semiconductor-Metal photodector

Metal-semiconductor-metal photodetector (MSM-PD) is consisted of two back to back Schottky diodes. One of the diodes is forward biased and the other reverse biased. The electron hole pairs photogenerated inside the semiconductor are swept across the electrodes by the electric fields and collected by the electrodes. Until now, MSM-PD's exhibit the capacitances smaller than any other junction based detectors so that high speed operation is observed. Furthermore, they show the symmetric and the smallest rise and fall times [2].

Fabrication of the normal MSM-PD is done by the formation of Schottky contacts over the undoped GaAs layer. Here, we call this type of MSM-PD as the surface MSM-PD. Due to the structure of the surface MSM-PD, the detection area is partially shadowed by the electrodes [3]. If we embed the Schottky electrodes inside the GaAs layer, the entire light sensitive area would be used. Fig. 1.b shows the schematic diagram of the proposed detector. However, there should be some trade off between the transit time of carriers and the thickness of the GaAs layer over the embedded electrodes. The carriers are generated at the surface and the electric field is largest at the bottom of the GaAs layer. The overgrown area is $57\mu m \times 60\mu m$, and the Schottky electrodes of $3\mu m$ spacings are interdigitated inside the area. The overgrowth is done by the selective LPE [4]. First, SiO_2 masking layer is deposited except the window area. Second, the tungsten is deposited and defined by the lift off process over the window area. After this, the lateral growth of GaAs over W is undertaken by LPE.

II.2 Back Gated Photoconductive detector

Another proposed photodetector based on the embedded Schottky electrode is the back gated PCD (BPCD). The PCD is simple to fabricate and has internal photoconductive gain and exhibits high speed operation. But due to the low velocity of minority holes, the long tail in the impulse response is shown. To decrease the long tail, the ion implantation or the noncrystalline layers are used. Because of the reduced optical gain due to the small mobility, detectors made from these materials are not suitable for optical communication. The long tail can also be reduced by the use of the reverse biased back gate to drain the minority holes [5]. Here, as a back gate, we used the embedded W electrode on S.I.GaAs substrate. Fig.2 shows the shematic diagram of the detector. The BPCD is fabricated as follows:

First, SiO_2 is deposited except the light sensitive area ($117\mu m \times 120\mu m$) . Second, the W finger is defined by the lift off process. The deposition is done by rf sputtering. Third, lateral overgrowth is done by LPE. Fourth, the interdigitated ohmic electrode is formed over the active area ($60\mu m \times 60\mu m$) and the direction of the ohmic finger is normal to that of W finger. The ohmic contact is patterned by the lift off process and alloyed at 420°C for 2min 30sec.

III. Results and discussions

After fabrication, the device is mounted on the package. Fig.3 shows the scanning electron micrograph of the embedded MSM-PD. The salient in the middle of the figure is the overgrown GaAs and the thick metal over the W pad is the plated Au. From the figure we can see the W fingers under the grown GaAs layer. The current voltage characteristics of the embedded MSM-PD is shown in Fig.4. The carrier concentration of the GaAs layer is $5\times10^{16}cm^{-3}$. We have a large leakage current and the breakdown voltage is lower than expected. The reasons are thought to be as follows:

a) the organic residual impurities remain after the lift off;
b) the edges of the embedded Schottky junction are susceptible to breakdown,
c) the possible thermally inverted surface can cause leakage current because the LPE is undertaken at high temperature (800°C).

To improve these, the low temperature process such as MOCVD or MBE, and the modified electrode strucrure are suggested. The optical characteristics of the embedded MSM-PD is measured using the focused light from an AlGaAs laser (λ=780nm). The PD is biased at 3V. The bias voltage is set low because of the fairly high doping concentration. The epitaxial thickness of the GaAs layer is 6μm. Fig.5 shows the characteristics of the photodetector. From the figure, we can see that the rise time of the light pulse is 180ns and that of the detector is 200ns. But the rise time of the bipolar transistor used in the amplifier is nearly 20ns so that the exact rise time of the detector is not clear at present. The response of the embedded MSM-PD will be improved by reducing the thickness of the epitaxial layer. For the BPCD, Fig.6 shows the scanning electron micrograph.

IV. Conclusion

The embedded MSM-PD and the BPCD are proposed for use in OEIC. Two detectors are based on the embedded Schottky electrode. The Schottky diode is formed by the selective LPE. The electrical and optical characteirstics would be improved by using the low temperature process and the modified electrode structure.

References

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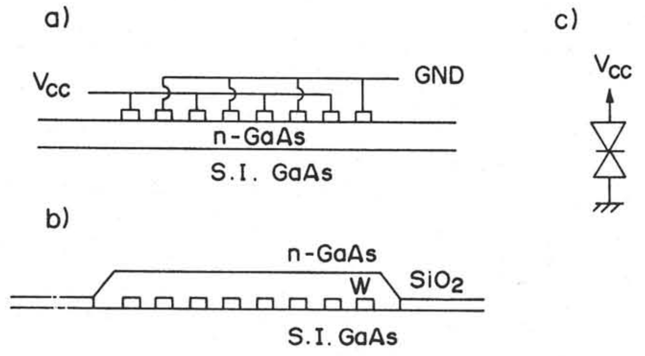

Fig.1 Schematic structure of MSM-PD.
a) Conventional MSM-PD.
b) Embedded MSM-PD.
c) Equivalent circuit.

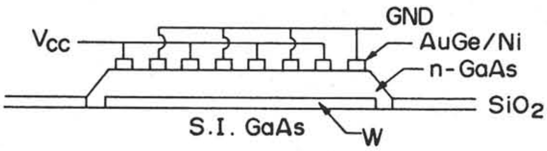

Fig.2 Schematic structure of BPCD.

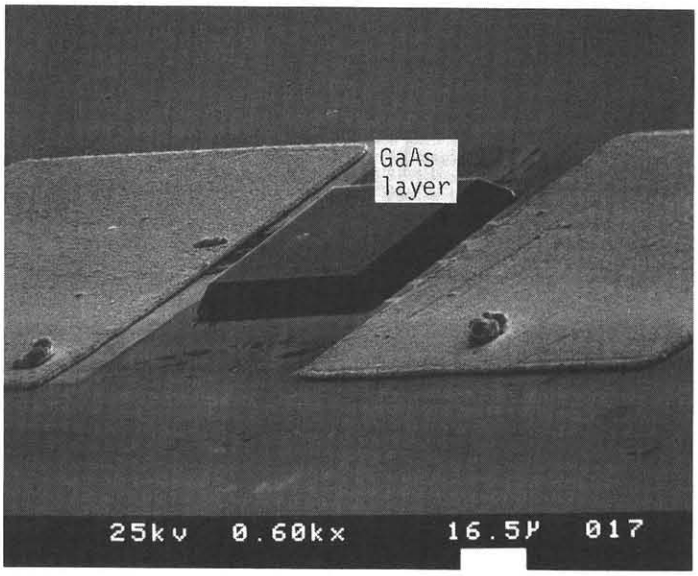

Fig.3 Scanning electron micrograph of the embedded MSM-PD: The salient in the figure is the overgrown GaAs.

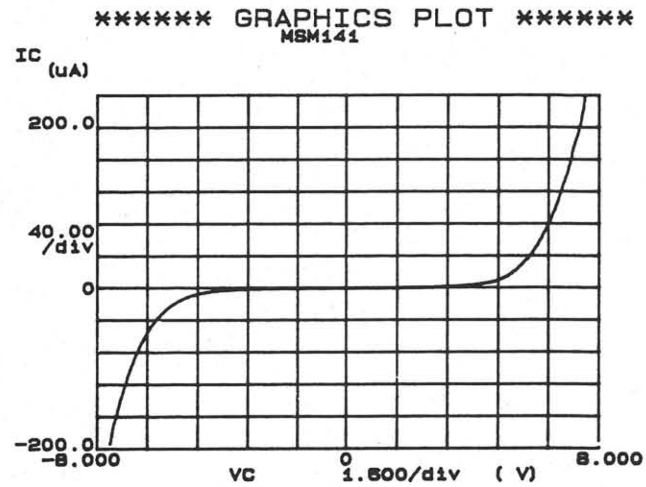

Fig.4 Current-voltage characteristics of the embedded MSM-PD. (hor.: 1.6V/div., vert.: 40μA/div.)

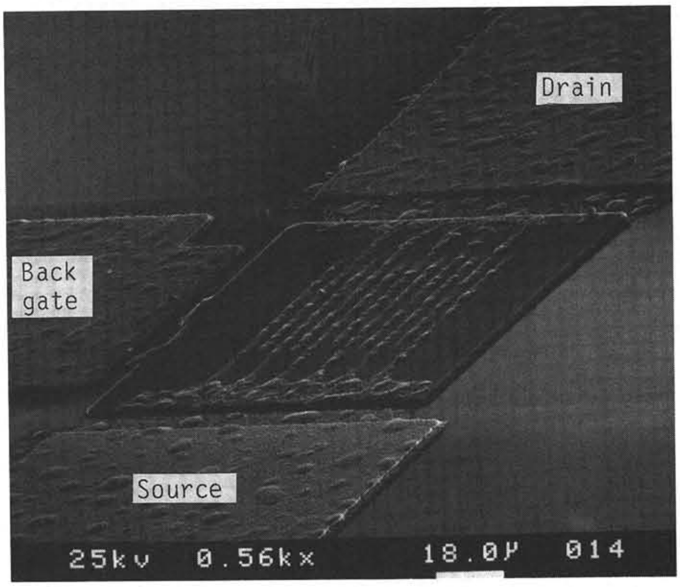

Fig.6 Scanning electron micrograph of BPCD.

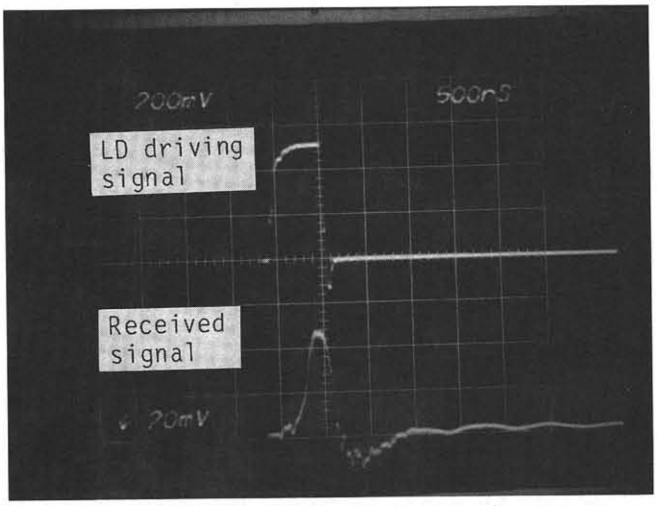

Fig.5 Oscillogram of the received light signal.