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B—4—4 High Gain Metal-Semiconductor-Metal Photodetectors for High-Speed Optoelectronic circuits

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A new metal-semiconductor-metal photodetector(MSM-PD), which has large photocurrent gain and high speed due to the tunnel current from the cathode of the reversed-biased Schottky barrier contact, is proposed and investigated experimentally as well as theoretically. Photocurrent gain greater than 50 has been obtained at a bias voltage less than 15 V. Several applications of the MSM-PDs to the optoelectronic logic circuits are demonstrated at switching speeds of less than 200 ps for GaAs/GaAlAs laser pulses.

Typical MSM-PD consists of a photo-sensing region of within 5 μm or 10 μm between two interdigital Al metal contacts, and a coplanar stripline as the output electrode on the semi-insulating GaAs substrate. Fig.1 shows the cross sectional view of this MSM-PD. The MSM-PD is biased such that one Schottky contact(cathode) is reversed-biased and the other(anode) is forward-biased. The potential energy diagram under the biased condition is shown in Fig.2.

Most of electrons and holes are generated within the light penetration depth which is about the inverse of the absorption coefficient. For GaAs, such penetration depth is less than 1 μm below the 0.87 μm spectrum range. Photogenerated electrons are swept out from the gap by the bias field and contribute to the primary photocurrent. However, Photogenerated holes are accumulated at the cathode since there is a barrier against holes at the cathode due to the thin non-artificial insulating layer. Such hole accumulation layer makes a high electric field near the cathode and then induces the tunnel injection current which gives the photo-current gain. The small temperature dependence of the photocurrent gain confirms the tunnel injection current mechanism.

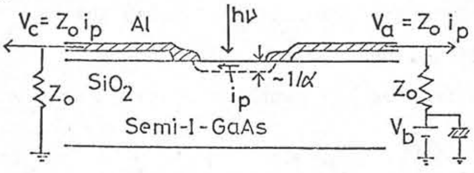

Fig.1 A cross sectional view of the fundamental structure of a MSM-PD

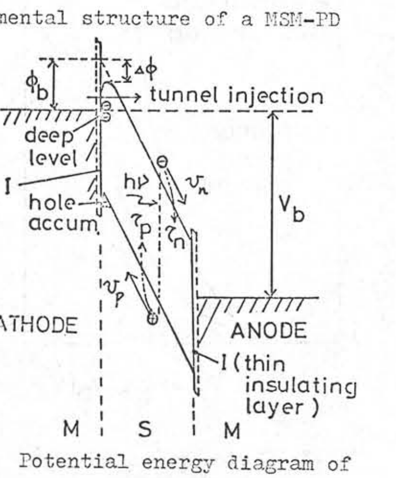

Fig.2 Potential energy diagram of a MSM-PD under the biased condition

In Fig.3, the photocurrent gain has been obtained to be more than 50 at the bias voltage less than 15 V for a MSM-PD with 5 μm gap. The primary photocurrent without gain i_0 is estimated as that due to the light power into the semiconductor taking the reflection from the metal and the semiconductor surface into account. The photo-response is flat in 0.45 μm to 0.87 μm spectrum range.

The amplified photocurrent due to the tunnel current through the lowered barrier at the cathode is calculated and compared with experiments, taking the photoconducting current, surface leakage velocity, image force barrier lowering, carrier recombination and carrier diffusion into account. There is an evidence that some deep traps are existing and affect the transient response. The deep traps have also an influence on the proposed tunnel injection calculation. The details will be given at the meeting and the qualitative agreement is obtained with experiment.

The proper combinations of MSM-PDs, essentially incorporated in coplanar striplines on the semi-insulating GaAs substrate, offer important optoelectronic pulse processing functions such as AND/OR gates(M1 and M2) and INHIBITOR/NOT gates(M1/M2 and M3) for optical input pulses as shown in Fig.4. Such integrated optoelectronic circuits have been operated at switching speeds of less than 200 ps for GaAs/GaAlAs laser pulses as shown in Fig.5. The speed is apparently limited by the input laser pulse. MSM-PDs in coplanar striplines have most promising structure for high-speed optoelectronic integrated circuits on GaAs substrate, since there is no parasitic element except for the gap capacitance between the two metal contacts, which can be decreased to under 0.1 pF. The advantage originates from the lateral structure, which is easy in fabricating stripline layouts. This MSM-PD is also suitable for ultrafast optoelectronic switching and sampling systems for picosecond laser pulses.

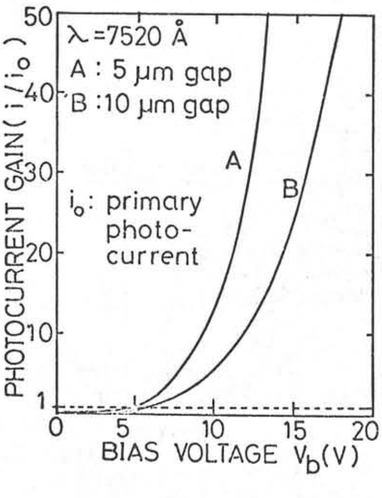

Fig.3 Photocurrent gain vs. bias voltage

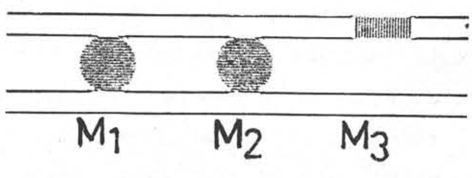

Fig.4 AND/OR gate and INHIBITOR/NOT gate

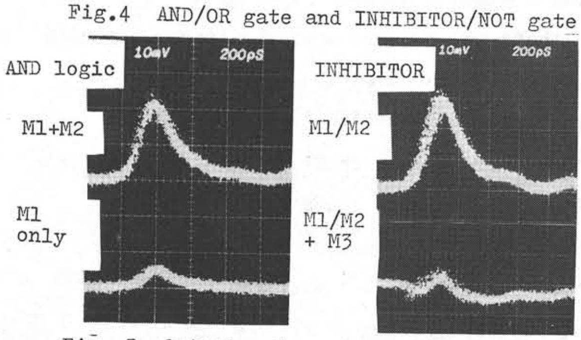

Fig. 5 Output pulses for GaAlAs laser input pulses