Extended Abstracts of the 1992 International Conference on Solid State Devices and Materials, Tsukuba, 1992, pp. 220-222 **PC1-3**

A Subpicosecond Heterobarrier MSM-Photodetector

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Interdigital metal-semiconductor-metal diodes based on an $InP/Ga_{0.47}In_{0.53}As$ heterostructure are proposed as extremely fast and effective photodetectors for the visible spectral range. We electro-optically measure the intrinsic speed of diodes incorporated into coplanar transmission lines. The diodes respond to 100 fs optical excitation pulses with the generation of subpicosecond electrical pulses. At a bias voltage of 1.0 V and an optical pulse energy of 10 pJ the measured voltage swing amounts to 40 percent of the bias voltage.

INTRODUCTION

Planar interdigitated metal-semiconductor-metal (MSM) diode structures are promising devices for high-speed photodetection. In recent years, the approach to further reduce the speed limit of such devices has diversified. Formerly, the main effort has been devoted to improving the sweep-out rate of the photogenerated charge carriers by reducing the separation of the metal fingers.[1] More recently, researchers complementarily explore the use of new material systems to rapidly remove the carriers from the contacts even at the expense of a reduced collection efficiency. This led to the development of MSM-diodes based on low-temperature-grown (LT) GaAs,[2,3] the fastest photodetectors to date. Extremely rapid carrier trapping at arsenic precipitates is the mechanism responsible for the fast intrinsic response of such diodes in the range around 1 ps.

We test another approach towards subpicosecond MSM-photodiodes for the visible spectral range by utilizing an $InP/Ga_{0.47}In_{0.53}As$ heterobarrier. MSM-diodes based on $Ga_{0.47}In_{0.53}As$ have been explored extensively in the past for applications in long wavelength communication systems.[4-8] To obtain diodes with low dark current in spite of the low Schottky barrier height of $Ga_{0.47}In_{0.53}As$, a thin layer of a high-bandgap material such as InP is usually introduced between the $Ga_{0.47}In_{0.53}As$ layer and the metal contacts. This InP layer does not absorb light in the long wavelength regime but strongly absorbs in the visible spectral range.

We show that for applications in the visible one may take advantage of (i.) the light absorption in the InP layer and (ii.) the subsequent rapid transfer of the photogenerated charge carriers from the high-bandgap InP into the low-bandgap $Ga_{0.47}In_{0.53}As$ to increase the speed of an MSM-photodetector. The basic idea is to make use of the charge transfer to very quickly turn off the current flow in the MSM-diode after excitation by a short optical pulse. This requires that the electrical bias of the MSM-diode should be moderate to reduce carrier escape from the $Ga_{0.47}In_{0.53}As$ layer back over the InP barrier to the metal contacts. The carriers trapped in the $Ga_{0.47}In_{0.53}As$ layer recombine on a time scale much longer than the transfer time.

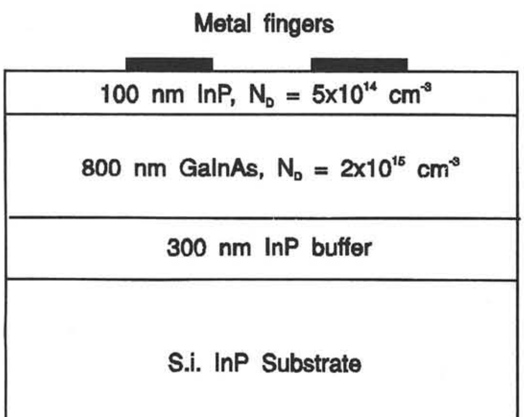

Fig. 1: Schematic of our device: Cross-section through the layer sequence

DEVICE FABRICATION

Fig. 1 shows the layer sequence of our diode. The basic heterostructure consists of a 800 nm thick $Ga_{0.47}In_{0.53}As$ layer and a 100 nm thick InP film on top of it. Both layers are nominally undoped. The layers are grown by low-pressure metal-organic-vapor-phase-epitaxy (LP-MOVPE) on a semiinsulating InP substrate. A Ti/Pt/Au film is then deposited on top of the wafer. A 20×20 μm^2 area of the metal film is patterned by electron beam lithography into an interdigitated finger structure with 0.5 μm wide fingers separated by 0.5 μm gaps. We use the same patterning step to form a several mm long coplanar electrical waveguide with 20 μm wide lines separated by 20 μm. One end of the waveguide contacts the active interdigital area of the device, the other end widens into contact pads for wire bonding. Fig. 2 shows a top view of the interdigital area of the diode. The capacitance of this area is extimated to be 25 fF.

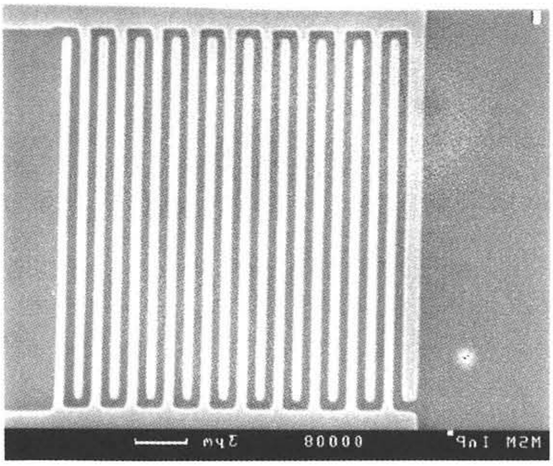

Fig. 2: SEM micrograph showing a top view of the MSM finger structure. Active area of the diode: 20×20 μm^2, finger width: 0.5 μm, finger separation: 0.5 μm.

HIGH-SPEED DEVICE CHARACTERIZATION

For high-speed characterization, we excite the diode by 100 fs pulses from a self-modelocked Ti:Sapphire laser operating at 750 nm and trace the electrical response by electro-optic sampling in a $LiTaO_3$ crystal positioned on the coplanar transmission line as closely to the interdigital area as possible. Fig. 3 shows the detected electrical signal at a bias voltage of 1.0 V for energies of the incident optical pulses ranging from 3 pJ to 26 pJ (corresponding carrier density in the InP layer: 2-15×10^{17} cm^{-3}). The response of the diode is extremely fast. We measure a full width at half maximum of the detected electrical pulses of 0.6 ps. This width is nearly independent of the energy of the optical pulses. The observed voltage swing ranges from 0.2 V to 0.6 V and does not depend linearly on the pulse energy. At low energy, the shape of the electrical pulse is unipolar. At high energy, the electrical waveform develops a bipolar characteristics.

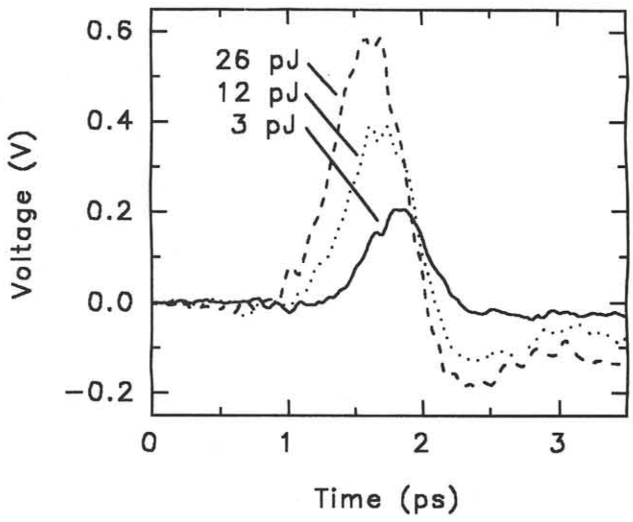

Fig. 3: Electro-optically measured response of the MSM-diode (bias: 1.0 V) to a 100 fs optical pulse with pulse energy ranging from 3 pJ to 26 pJ (density of photogenerated carriers in the InP layer: 2-15×10^{17} cm^{-3}).

DISCUSSION

The measured speed of the diode is similar to that of LT-GaAs MSM-photodetectors.[2,3] The speed is much higher than that reported in other publications on $Ga_{0.47}In_{0.53}As$-based heterostructure diodes. Earlier measurements at visible wavelengths could not reveal the extremely high intrinsic speed because of insufficient time resolution and missing integration of the device into a transmission line. Such experiments, however, proved already that $Ga_{0.47}In_{0.53}As$-based heterostructure diodes are much faster in the visible than in the long wavelength range where carriers are photogenerated only in the $Ga_{0.47}In_{0.53}As$ layer.[6,7]

There are two possible mechanisms that may contribute to the observed high intrinsic speed, (i) ultrafast field screening by the photogenerated carriers (displacement current mechanism) and (ii) current disruption by ultrarapid carrier transfer from the InP layer, where most of the carriers are generated, to the $Ga_{0.47}In_{0.53}As$ layer. A hint that the first mechanism, ultrafast field screening, cannot be neglected is given by the fact that the switched voltage is high. At a bias of 1.0 V and an optical pulse energy of 12 pJ (26 pJ), we measure a voltage swing of 40 % (60 %) of the applied bias voltage. At such a high switching efficiency screening effects are expected to be important. On the other hand, the strong difference in speed for short and long wavelength excitation suggests that fast field screening is not the only mechanism responsible for the high speed of the device. We expect very effective field screening also when carriers are photogenerated exclusively in the $Ga_{0.47}In_{0.53}As$ layer. We assume that rapid transfer of carriers from the InP layer into the $Ga_{0.47}In_{0.53}As$ layer increases the speed of the device by disrupting the carrier collection in the metal contacts. It is known that charge carriers can be transferred extremely rapidly (1 ps time scale) from a high-bandgap to a low-bandgap material over distances on the order of 100 nm.[9,10] The band-offset between $Ga_{0.47}In_{0.53}As$ and InP is high enough (0.6 eV) that, at low bias voltages, the current flow back to the InP layer and into the metal contacts may be suppressed effectively. Evidence for this interpretation of our experiment is the observed low time-integrated photocurrent. We calculate from our data that only a few percent of all photogenerated carriers are collected in the contacts. The majority of the carriers seems to recombine in the $Ga_{0.47}In_{0.53}As$ layer on a time scale long compared to that of interest here. It is interesting to point out, that the trapping of carriers in the low-bandgap material, which is undesirable if one aims at a high quantum efficiency of the photodetector, is actually helpful to reduce the response time of our device. To study the fast carrier transfer process we plan to perform luminescence upconversion experiments in the future.

CONCLUSION

In summary, we have demonstrated that heterostructure InP/$Ga_{0.47}In_{0.53}As$ MSM-diodes can be extremely fast photodetectors for photon energies above the bandgap of InP. Our experiment suggests that the observed subpicosecond response time of the diodes may result largely from an extremely fast carrier trapping process in conjunction with a fast transfer of carriers from the InP layer into the $Ga_{0.47}In_{0.53}As$ layer. As a consequence, the device has a modest carrier collection efficiency. The switched voltage, on the other hand, is very high. For applications in the visible, if speed is more important than quantum efficiency, this device may be an interesting alternative to other photodetectors.

REFERENCES

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1.) Y. Liu, P. B. Fischer, and S. Y. Chou, in *Picosecond Electronics and Optoelectronics*, T. C. L. Sollner, J. Shah, eds., Optical Society of America, vol. 9 (1991) 97.

2.) Y. Chen, S. Williamson, T. Brock, F. W. Smith, and A. R. Calawa, Appl. Phys. Lett. 59 (1991) 1984.

3.) M. Klingenstein, J. Kuhl, R. Nötzel, K. Ploog, J. Rosenzweig, C. Moglestue, A. Hülsmann, J. Schneider, and K. Köhler, Appl. Phys. Lett. 60 (1992) 627.

4.) O. Wada, H. Nobuhara, H. Hamaguchi, T. Mikawa, A. Tackeuchi, and T. Fujii, Appl. Phys. Lett. 54 (1989) 16.

5.) J. B. D. Soole and H. Schumacher, IEEE J. Quantum Electron. QE-27 (1991) 737.

6.) F. Buchali, I. Gyuro, F. Scheffer, W. Prost, M. Block, W. Wendorff, G. Heymann, F. J. Tegude, P. Speier, and D. Jäger, in *Proc. 4th Int. Conf. on InP and Related Materials*, Newport, RI (1992) 596.

7.) F. Hieronymi, D. Kuhl, E. H. Böttcher, E. Dröge, T. Wolf, and D. Bimberg, in *Proc. 4th Int. Conf. on InP and Related Materials*, Newport, RI (1992) 561.

8.) J. H. Burroughes, M. S. Milshtein, G. D. Pettit, N. Pakdaman, H. Heinrich, and J. M. Woodall, IEEE Photon. Technol. Lett. 4 (1992) 163.

9.) R. Kersting, X. Q. Zhou, K. Wolter, D. Grützmacher, and H. Kurz, Superlatt. Microstruc. 7 (1990) 345.

10.) R. Kersting, R. Schwedler, K. Leo, and H. Kurz, in *Proc. 4th Int. Conf. on InP and Related Materials*, Newport, RI (1992) 565.