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# ELECTRICAL ENGINEERING

## High Performance InGaAs/GaAs Strained Layer Superlattice Photodetectors Compatible with GaAs MESFET Technology

**Nacer Debbar**
*Electrical Engineering Department, College of Engineering,*
*P. O. Box 800, King Saud University, Riyadh 11421, Saudi Arabia*

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**Abstract.** A high performance long-wavelength interdigitated metal-semiconductor-metal (MSM) photodetectors is reported in this paper. The photoabsorbing layer consists of an InGaAs/GaAs strained layer superlattice designed for light absorption in the long wavelength region. The structure, grown on a GaAs undoped substrate, is fully compatible with the technology of the mature GaAs electronic devices. The MSM photodiodes exhibit a very low dark current, 26 nA at 10 V applied bias, a very fast pulse response with a deconvoluted full width at half maximum of about 13 ps at 10 V applied bias, corresponding to an intrinsic bandwidth of about 35 GHz.

### Introduction

Metal-semiconductor-metal (MSM) photodetectors (PD) are becoming increasingly attractive in optoelectronic communication systems. Due to their planar structure, they have a very small capacitance and are easily integrated with FET transistors. For the long-wavelength region, $1.0-1.6\mu m$, which is suitable for optical fiber communication, the photoabsorbing layer of the detector should be made of a low band-gap material such as InGaAs lattice matched to InP substrate. Moreover, because of its excellent transport properties, this material system has also been used to realize very high performance electronic devices. In the past decade, considerable efforts were devoted to integrate such optical and electronic devices to realize optoelectronic integrated circuits (OEIC) [1-4]. However, because of the material difficulties and immature processing techniques, these OEIC grown on InP comprise only few electronic devices. In contrast, large scale GaAs MESFET IC technology is well established and easily available. Therefore, by integrating long-wavelength photodetectors with the large scale GaAs MESFET IC, one can achieve long-wavelength OEIC's with desired performance and increased functionality. This require the growth of the photoabsorbing InGaAs layer lattice mismatched on a GaAs substrate. To date, limited number of attempts have been made to fabricate photodetectors on lattice mismatched layers [5-8]. In most cases, these detectors have cutoff wavelengths below 1.3 µm or suffer from relatively slow response speed and/or high dark currents.

In this paper, we present the realization of a high performance MSM PD using an InGaAs/GaAs strained layer superlattice (SLS) active layer grown on GaAs substrate. The Indium content and the well and barrier dimensions of the SLS are designed to efficiently absorb light in the long-wavelength region, a requirement for application in optical fiber communication systems. A thin GaAs/AlGaAs superlattice is grown on top of the SLS, its role is to smoothen the growth front and block the propagation of threading dislocations generated by the SLS [9]. Thus, enabling the subsequent growth of the active layer of the MESFETs with reasonably good quality. This layer will also be used as Schottky barrier enhancement layer for the MSM diodes.

### Device Description and Fabrication

The MSM PD is made by forming two Schottky contacts on an undoped semiconductor layer. The device has a planar configuration with interdigitated metal electrodes as shown in Fig.1. The electrodes typically have width and spacing in the range of 1 to 5 µm. The dark current of the device is principally determined by the height and quality of the Schottky barrier. Since this device has a planar structure, it has the advantage of low capacitance as compared to the p-i-n structure. Thus, reducing the RC time constant and leaving the response speed limited by the transit time of the photogenerated carriers. The latter can be made very small by reducing the electrode spacing.

For undoped and infinitely thick detector material, the capacitance of the MSM is given by [10,11]:

$$C = \varepsilon_0(1+\varepsilon_r)(N-1)L\frac{K(k)}{K(k^1)}$$

where $\varepsilon_r$ is the relative dielectric constant of the semiconductor, N is the number of fingers, and L is their length. K(k) is the complete elliptic integral of the first kind, it is given by:

$$K(k) = \int_0^{\pi/2} \frac{d\phi}{\sqrt{1-k^2\sin^2\phi}}$$

$$k = \tan^2\left(\frac{\pi}{4}\frac{w}{w+d}\right)$$

$$k^1 = \sqrt{1-k^2}$$

where w is the finger width and d is the finger spacing. Figure 2 shows the dependence of the MSM capacitance with the finger length L for three values of finger spacing d, the finger width w is maintained fixed at 2 μm. For L = 50 μm, w = 2 μm, and d = 2 μm, the dimensions of the presented MSM, a capacitance of about 36 fF is obtained. This value suggests a response time, in a 50 Ω system, of about 1.8 ps. The transit time of photogenerated carriers, on the other hand, are on the order of [(finger spacing)/(2 × saturation carrier velocity)]. An MSM with 2 μm finger spacing, and assuming an average saturation velocity of about 6 × $10^6$ cm/s [11], yield a transit time of photogenerated carriers of about 16 ps suggesting that the speed of response of such a device will be limited by the transit time of carriers.

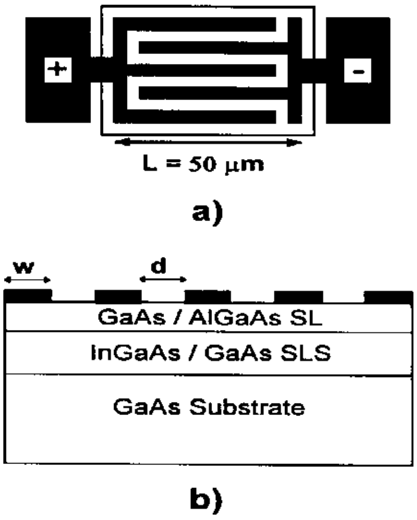

**Fig. 1.** Schematic view of interdigitated MSM photodetector a) top view and b) cross section.

The epitaxial layers, of the present structure, were grown by MBE on an undoped GaAs substrate. They consist of a 0.2 μm GaAs buffer layer, a 120 period InGaAs/GaAs SLS with total thickness of 0.84 μm to be used as the photoabsorbing layer of the MSM, and a thin 10 period GaAs/AlGaAs superlattice capping layer. The SLS, grown at 450 °C, barriers are 35 Å thick and the In content of the InGaAs wells is about 0.5.

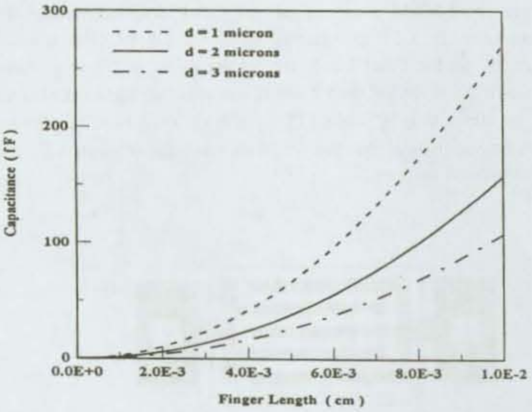

**Fig. 2. Capacitaance versus finger length of the interdigitated planar MSM diodes, for 1,2, and 3 μm finger spacing and 2 μm finger width.**

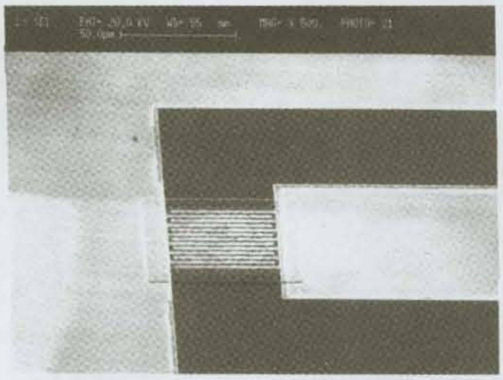

**Fig. 3. Photograph of interdigitated MSM photodetector with 2 μm finger spacing and 50x50 $\mu m^2$ active area.**

The fabrication starts with device isolation by mesa etching down to the substrate, then depositing a 0.5 μm thick polyimide insulating layer, which is developed away on top of the mesas. This layer prevents leaky contact between the exposed InGaAs/GaAs at the wall of the mesas and the metal electrode. The interdigitated contact structure (Fig.3) was realized by the evaporation of Ti/Pt/Au on the top surface of the mesas, using standard optical lithography and lift-off technique. The MSM photodiodes have an active area of 50x50 $\mu m^2$, with finger width and spacing of 2x2 μm.

## Results and Discussion

Figure 4 shows the measured dark current-voltage (I-V) characteristics of a typical MSM. The diodes exhibit a very symmetric I-V curves, with a very low dark current, less than 26 nA at 10 V bias, and a breakdown voltage in excess of 20 V. These results illustrate the high quality of the Schottky barrier height revealing the good quality of the GaAs/AlGaAs capping layer and the reasonable crystalline structure of the InGaAs/GaAs SLS photoabsorbing layer despite the strain caused by the lattice mismatch.

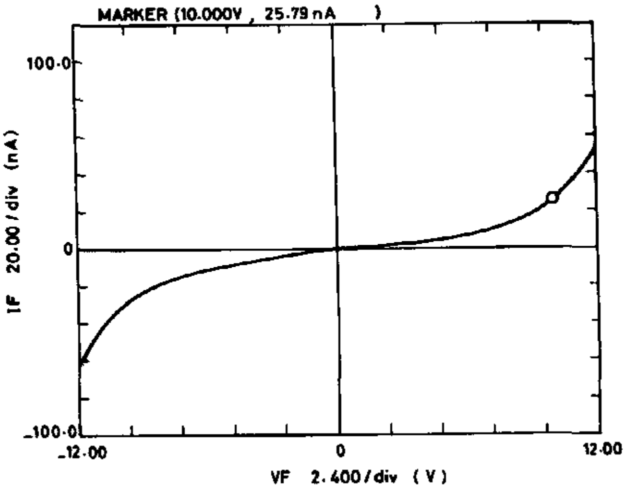

Fig. 4. Dark current-voltage characteristics of InGaAs/GaAs MSM photodetector.

The response speed of the photodetectors was measured on wafer by the pulse method, using a Cascade Microtech Probe station with 26.5 GHz bandwidth. Short optical pulses (FWHM ( 200 fs ) at 890 nm from a Titan-Sapphire laser Coherent Mira 900 provide the light excitation. The pulse response, shown in Fig.5, was recorded by a Tektronix S4 sampling head with 25 ps rise time. The total system response width is about 40 ps. The measured FWHM, rise time and fall time, at 10 V applied bias, are 42 ps, 28 ps and 66 ps, respectively. The absence of an extended tail in the response time, a desirable feature in high speed digital communication, shows that there is no significant charge trapping at the heterointerfaces which would screen the external field [12]. Deconvoluting for the system response, the actual detector pulse response FWHM is expected to be about 13 ps, corresponding to an intrinsic device bandwidth of about 35 GHz. It should be noted that the measured FWHM is in good agreement with the transit time of about 16 ps estimated earlier. These results are comparable to the best results published in the literature [5]-[7], [13]-[14 ].

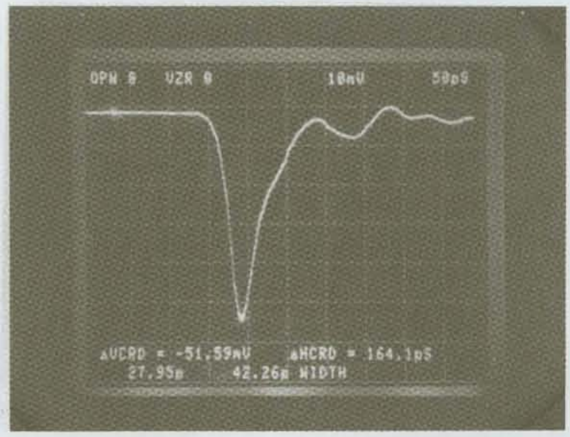

**Fig. 5. Optical pulse response of InGaAs/GaAs MSM photodetector with 2 μm finger spacing at 10 V applied bias.**

The high performance of these structures as evidenced by the very low dark current, the symmetric I-V characteristics, and the very fast speed of response indicates that the superlattice structure and the thin capping layer are of sufficient crystalline quality for detector applications despite the strain in the SLS. These results make this structure a promising candidate, in the realization of high speed long wavelength monolithically integrated photoreceiver using the mature GaAs technology, for applications in optical fiber communication systems.

## Conclusion

A long wavelength, high performance MSM PD, was realized using an InGaAs/GaAs SLS grown on GaAs substrate. The diodes have a very symmetric I-V characteristics, a very low dark current of 26 nA at 10 V bias, and a very fast impulse response of 42 ps FWHM. The photodetectors are fully compatible in growth and processing with the mature GaAs MESFET. Thus, promising for the realization of long-wavelength OEIC with desired performance and increased functionality.

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# كاشف ضوئي ذو كفاءة عالية، منسجم مع تقنية ترانزستور GaAs ذو التأثير المجالي، مكوّن من شبكية InGaAs/GaAs متوتّرة

**نصر دبار**
*قسم الهندسة الكهربائية، كلية الهندسة، جامعة الملك سعود، ص.ب ٨٠٠،*
*الرياض ١١٤٢١، المملكة العربية السعودية*

(أستلم في ١٩/٥/١٩٩٦م ؛ وقُبل للنشر في ٩/٤/١٩٩٧م)

**ملخص البحث.** يقدّم هذا البحث كاشفاً ضوئياً للموجات الطويلة يتكون من معدن شبه موصل ومعدن آخر متداخلة فيما بينها (MSM). وتتكون الطبقة التي تقوم بامتصاص الضوء من شبكية متوترة مكونة من (InGaAs/GaAs). وهذه الشبكية مصممة كي تمتص الضوء ذي الموجات الطويلة. والتركيبة المشيّدة على قاعدة من (GaAs) غير مشوبة بحيث تكون منسجمة تماماً مع تقنية النبائط الإلكترونية من (GaAs) المستقرة.

وفي حالة الظلام، يبدي الكاشف الضوئي ـ قيد البحث ـ تياراً منخفضاً مقداره ٢٦ نانو أمبير عند جهد دعم مقداره ١٠ فولت، واستجابة نبضية سريعة جداً بعرض تام بعد إزالة الالتفاف وعند نصف القيمة القصوى بحوالي ١٣ بيكو ثانية (13 ps) عندما يكون جهد الدعم ١٠ فولت وهذا يناظر عرض نطاق داخلي يقارب ٣٥ ميغاهيرتز.