High-Speed 1.3-μm GaInAs Detectors Fabricated on GaAs Substrates

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Abstract—**High-speed interdigitated metal-semiconductor-metal (IMSM) detectors have been fabricated on non-lattice-matched, semi-insulating, GaAs substrates using two GaInAs layers of differing indium concentrations to accommodate most of the lattice mismatch via interface misfit dislocations. Bandwidths as high as 3 GHz were measured with none of the detrimental low-frequency gain usually observed in this type of device. This is attributed to the inhibition of the surface trapping of photoinduced carriers by means of a graded pseudomorphic layer at the surface.**

I. Introduction

Although much encouraging work has been done recently to show that high-performance detectors can be fabricated on the same chip with complex electronics circuits [1], [2], GaAs has been used as the active region of the detectors making them only useful for optical wavelengths less than about 0.9 μm. Long-distance fiber-optic systems, however, operate at wavelengths of 1.3 or 1.5 μm where the fiber loss and dispersion is low. In general, semiconductor materials that absorb light at these wavelengths are not lattice matched to material systems such as silicon and GaAs for which the integrated circuit technology has been well developed. Good quality InGaAs p-i-n diode detectors have been fabricated on non-lattice-matched GaAs substrates but have relied on rather thick epitaxial layers of InP interposed between the GaAs substrate and the GaInAs diode [3], making optoelectronic integration difficult. For these reasons most attempts at electo-optic integration have relied on the use of lattice-matched substrates such as InP for which the integration technology is less developed, or have used photoconductive detectors that are more compatible with the dislocations created due to lattice mismatch.

Until about five years ago, nearly all heterojunction, optoelectronic, and high-speed devices were fabricated with lattice-matched epitaxial layers. Recently, with the very encouraging work done on pseudomorphic MODFET's [4], it has become evident that non-lattice-matched heterojunctions can be used in high-performance electronic devices. Optoelectronic devices, such as a photodetector, however, require non-lattice-matched semiconductor layers with thicknesses exceeding the requirements of pseudomorphic growth. It was suggested by Matthews *et al.* [5], and later observed at Cornell [6], that the misfit strain-induced dislocations in large lattice constant layers grown on sphalerite type crystals could be Frank–Read centers. These are a loop type of dislocation which grow due to slip as the layer becomes thicker and eventually bend over and reside at the buried heterojunction interface resulting in a relatively dislocation-free layer. In order for this to happen the total amount of misfit must be limited to reduce the generation of other types of dislocations, and the layer thickness must exceed a minimum in order to generate enough misfit strain to cause the generation and glide of the dislocations to the buried layer. Using the above growth mechanism as a model, an interdigitated metal–semiconductor–metal (IMSM) detector was fabricated on an epitaxially grown InGaAs layer in which an attempt was made to encourage the glide of dislocations to buried layers.

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II. Device Fabrication and Design

As shown in Fig. 1, a total of four layers were grown using MBE. All of the layers were not intentionally doped. The first layer was a 0.5-μm GaAs buffer layer followed by a 0.5-μm $In_{0.25}Ga_{0.75}As$ layer. This layer was grown at 550°C and its thickness was chosen to facilitate the collapse of loop dislocations at the buried interface. The next layer was a 1-μm $In_{0.40}Ga_{0.60}As$ layer grown at 500°C, also grown thick enough to facilitate collapse of the loop dislocations as well as to provide enough thickness to insure the nearly complete absorption of 1.3-μm wavelength light before reaching the buried layers where interface misfit dislocations might adversely affect the detector performance. Subsequent TEM cross sections revealed the presence of some threading dislocations propagating perpendicular to the interface indicating that the lattice mismatch was not entirely accommodated by interface misfit dislocations.

The last layer was a 500-nm-thick layer graded in indium concentration linearly back to GaAs at the surface. This layer served two purposes: 1) to provide a high Schottky barrier at the detector electrodes, and 2) to provide a barrier to prevent the photo-generated electrons and holes from being trapped at the surface causing the undesirable low-frequency gain frequently associated with the IMSM detector [7]. Gold detector electrodes were then fabricated using a lift-off stencil. Although other geometries were fabricated, for the results presented here, the detector fingers were 1.5 μm wide with a space of 2.5 μm between fingers. The detector's interdigitated pattern covered a region of 100 μm on a side.

III. Device Results

Photoluminescent spectra were taken on similar samples with a 35-percent indium concentration in the active region and

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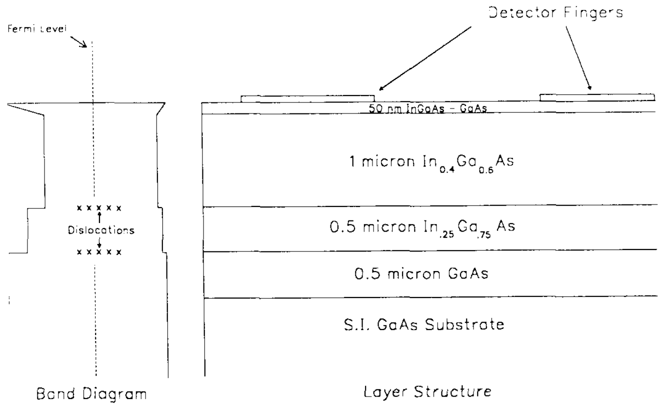

Fig. 1. The layer structure of the photodetector.

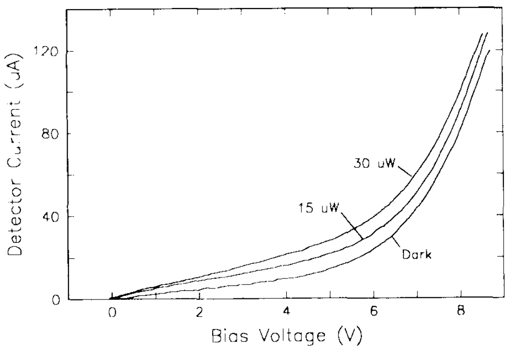

Fig. 2. Responsivities of the IMSM detector at 0, 15, and 30 μW.

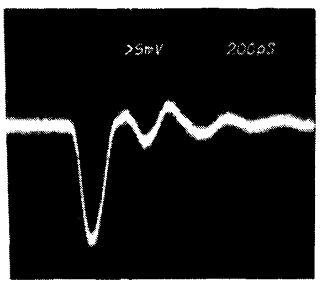

Fig. 3. Optical pulse response of the detector. FWHM = 140 ps and bandwidth = 3.2 GHz.

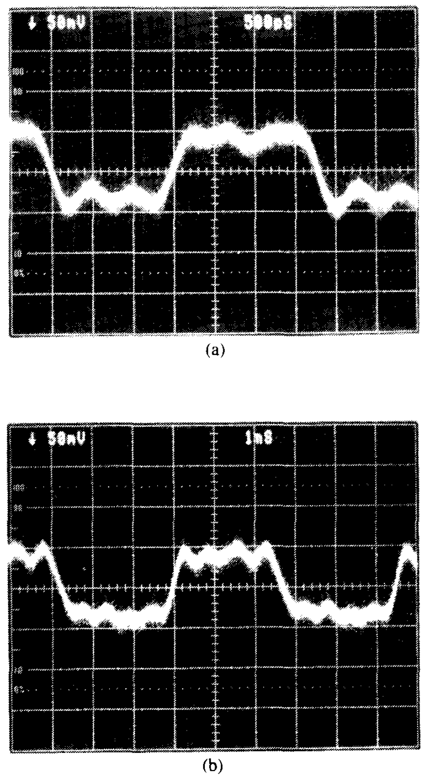

Fig. 4. Low-frequency response. Horizontal scale is 500 ps/div for (a) the 0.83-μm wavelength and 1 ns/div for (b) the 1.3-μm wavelength.

showed a line width of 20 nm at 4 K, which is comparable to that obtained in lattice-matched layers.

Fig. 2 shows typical *I–V* characteristics for the detector in the dark and with 15 and 30 μW of incident optical power. A dc responsivity of about 0.5 A/W at the 1.3-μm wavelength is observed from about 4 to 8 V. The responsivity corresponds to internal quantum efficiency of close to 100 percent when taking into account the light reflected from the fingers and the surface of the semiconductor. We believe that the large dark current is due to tunneling at the electrode edges and may be reduced by proper design of the pseudomorphic top layer.

Fig. 3 shows the response of the detector to a 50-ps optical pulse of 820-nm wavelength at an applied bias voltage of 7 V. The FWHM of the detector pulse is about 160 ps, which corresponds to a bandwidth of about 3 GHz.

In order to investigate the presence of low-frequency gain the response of the detector to a lower frequency square wave was observed and is shown in Fig. 4 for both 840- and 1300-nm wavelengths. Notice that after each transition the response is relatively flat indicating very little low-frequency gain. The ringing in the response was due to the signal generator. This lack of low-frequency gain was also confirmed by comparing the dc and ac responsivities which agreed to within 10 percent.

IV. Conclusions

A high-speed detector has been fabricated on non-lattice-matched InGaAs layers grown on a GaAs substrate. This provides evidence that the optoelectronic properties of photoactive devices may be decoupled from both substrate quality and lattice-mismatch constraints previously required for high-performance photodetector devices. We believe that the high performance in this non-lattice-matched system is a result of relieving strain in the photoactive layer via a buried array of misfit dislocations optoelectronically isolated from the photoactive layer. Hence the future integration of longer wavelength photodetectors with LSI GaAs circuitry may be possible.

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