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Flip-Chip GaInAs/InP Quad PIN Photodiodes for Polarization-Diversity Coherent Optical Receivers

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A monolithic quad PIN photodiodes chip with flip-chip structure has been developed for the application to polarization-diversity coherent receivers. The chip consists of four elemental photodiodes having ultra-small junctions for back-illumination together with focusing lenses on the light entry surface. Fabricated chip has shown high-speed response exceeding 10 GHz and low common mode rejection ratio and crosstalk characteristics.

1. Introduction

One of the key issues in making coherent optical transmission systems practical is the development of coherent receivers which can compensate the polarization instability occurring in practical fiber systems. A polarization-diversity receiver involving two balanced pairs of photodiodes to be coupled to two mutually orthogonal polarizations is extremely useful for this purpose.[1] Such receivers used in previous system demonstrations, however, were constructed by using either four discrete photodiode chips or two twin-PIN photodiodes.[2,3] In this paper, we report on the fabrication of monolithically integrated quad PIN photodiodes for the application to compact, high-performance polarization-diversity coherent receivers. The adoption of flip-chip structure having lensed, back-illuminated PIN photodiodes provides both high receiver performance and simple and reliable packaging.

2. Structure and fabrication

A quad PIN photodiodes chip consists of four identical back-illuminated GaInAs/InP PIN photodiodes formed on an InP substrate. Figure 1 shows the cross section of elemental PIN photodiode, the pattern layout on the back surface and the circuit diagram of a monolithic quad PIN photodiodes chip. PIN photodiode was fabricated from an epitaxial wafer involving an n^+-InP ($n = 2 \times 10^{17}$ cm^{-3}, $t = 1.5\ \mu$m) contact layer, an undoped GaInAs ($n < 1 \times 10^{15}$ cm^{-3}, $t = 2.4\ \mu$m) photoabsorption layer and an n^--InP ($n = 1 \times 10^{16}$ cm^{-3}, $t = 1\ \mu$m) window layer, grown on

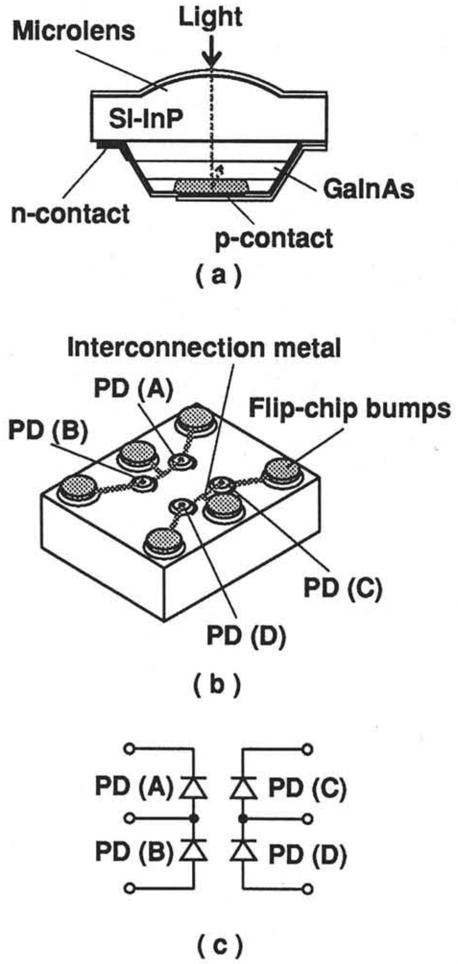

Fig. 1 Structure of quad PIN photodiodes. (a) cross section of elemental PIN photodiode (b)pattern layout on back-surface (c)circuit diagram

the (100) surface of a semi-insulating (SI) InP substrate. The thickness of the photoabsorption layer was determined by taking into account of both the quantum efficiency and the optical input power level.[3] A junction structure with a diameter of 20 μm was formed by using selective Zn diffusion into the InP window layer. Contacts were formed by Au/Zn/Au and Au/AuGe films on n- and p-type layers, respectively. An isolation mesa had gentle slopes enabling reliable interconnections with Au/Ti films. A monolithic lens was formed for generating a large fiber alignment tolerance by using ion-beam etching technique.[2] A symmetrical pattern layout as shown in Fig. 1 was adopted for obtaining well balanced output characteristics and minimizing crosstalks. Six solder bumps were prepared for chip bonding using Au-Sn/Pt/Ti metallization structure.[4] Figure 2 shows an SEM photograph of a chip bonded on a ceramic substrate. The separation among adjacent photodiodes was 125 μm from center to center and the chip size was 400 μm x 500 μm.

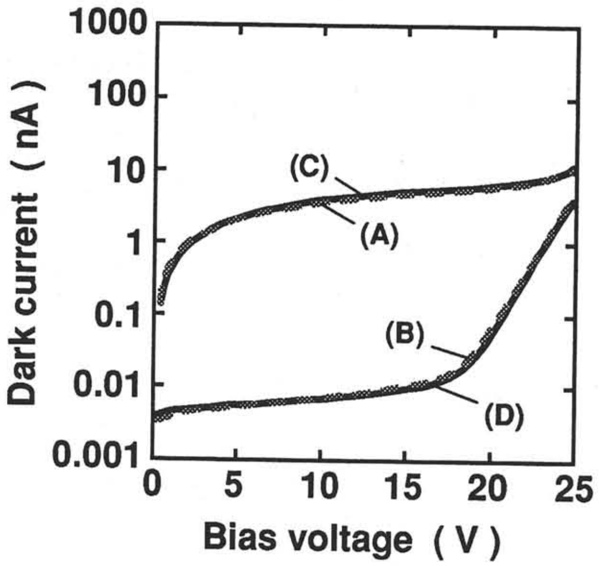

Fig. 3 Dark current versus bias voltage relationships for four PIN photodiodes.

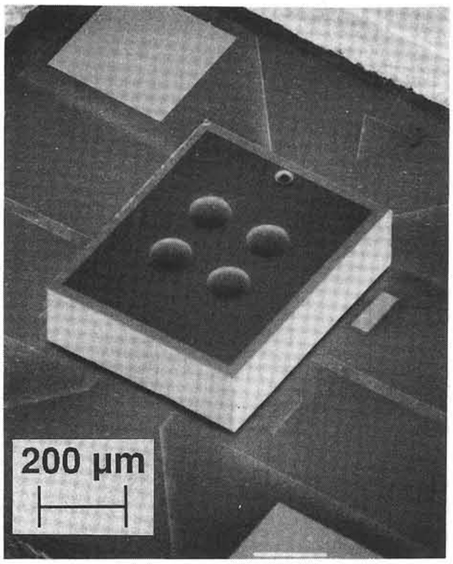

Fig. 2 SEM photograph of flip-chip bonded quad PIN photodiodes.

3. Characteristics

Figure 3 shows the dark current versus bias voltage relationships for four photodiodes. Diodes B and D as indicated in the equivalent circuit show extremely low dark currents of the order of pA untill the tunneling current dominates beyond 18 V. Comparatively higher currents for diodes A and C are due to leak paths in and/or at the surface of the substrate. However, the dark current is still less than several nA below 20 V for all diodes and this is sufficiently low for practical receiver circuits operating at gigabit rates. Capacitances were measured to be 66 fF for diodes A and C and 61 fF for B and D, respectively, at a bias voltage of 10 V. This capacitance consists of the depletion layer capacitance and the stray capacitance (approx. 20 fF) due to the interconnection line crossing over the n^+-InP layer. The quantum efficiency was determined to be in a range of 90% +/- 1% at a wavelength of 1.55 μm for all four diodes. The fiber alignment tolerance, being defined for 0.5 dB degradation in the coupling efficiency, was as large as 70 μm owing to the introduction of monolithic lenses. This provides very simple and reliable chip packaging.

Figure 4 shows the response of diode, the common mode rejection ratio (CMMR) for balanced diode pair and the crosstalk between two pairs monitored as functions of the signal modulation frequency at a wavelength of 1.54 μm. The bias voltages used were +10 V and -10 V and the diodes were loaded by 50 Ω. All diodes showed a cutoff frequency around 13 GHz. This is presumed to be limited, predominantly, by the CR product due to that the capacitance is doubled for a balanced diode pair. CMMR indicates the performance in suppressing intensity noise caused by a local oscillator laser. A value of CMMR of -30 dB was observed below 10 GHz. For evaluating the crosstalk, the outputs were compared between two diode pairs while only one diode had an optical input. An excellent crosstalk as low as -40 dB was achieved up to 14 GHz. This indicates that electromagnetic interference between two circuit pairs is well suppressed by the symmetric layout. Also this crosstalk is certainly sufficient for processing two polarization signals in a receiver. It is worth while to note that

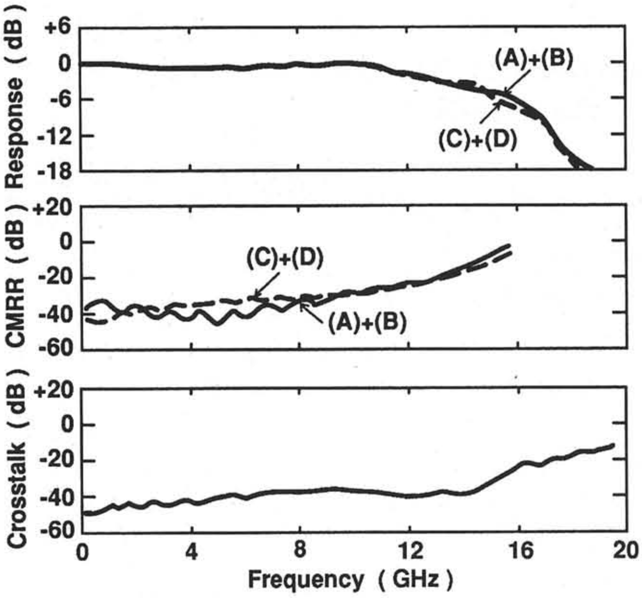

Fig. 4 Response and common mode rejection ratio of balanced pairs and crosstalk between pairs as functions of frequency.

the frequency response characteristic same as that in Fig. 3 was confirmed at an input optical power level of 5 mW. This suggests that an allowable local oscillator power for this quad PIN photodiodes chip is at least 20 mW, sufficient for practical application.

4. Conclusion

A quad PIN photodiodes chip with flip-chip structure was developed for the application to polarization-diversity coherent receivers and excellent performance was demonstrated at a frequency beyond 10 GHz. This chip will be useful for the development of practical coherent receivers for their easy-to-package structure and excellent performance.

References

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