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Highly Reliable Operation of InGaAlAs Waveguide Photodiodes for Access Network Systems

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1. Introduction

Recently, much attention has been directed towards low-cost optical modules that use optical hybrid integration on a silicon optical bench or a planar lightwave circuit (PLC) platform and can be used in optical access networks [1-4]. A side-illuminated waveguide photodiode (WG-PD) is a key component in these optical modules, because it can directly couple to planar waveguides without requiring any optical components such as lenses or mirrors [5, 6]. We have demonstrated the WG-PD with the responsivity of 0.95 A / W and vertical coupling tolerance of 2.6 μm to a dispersion shifted fiber at a light wavelength of 1.31 μm using symmetric double core InGaAlAs waveguide structure [7]. In this paper the long-term reliability of the WG-PDs is confirmed by the aging tests for 8500 hours and a carrier injection model which could explain the degradation of IV characteristics is also shown.

2. Experiment

A schematic structure of the WG-PD is shown in Fig. 1. The waveguide consists of an InGaAlAs (λ g = 1.4 μm) absorption layer and two InGaAlAs (λ g = 1.1 μm) second-core layers sandwiched between two InAlAs cladding layers. These layers were grown by solid-source molecular beam epitaxy. The mesa waveguide was formed by chemical etching, then its surface was passivated with SiN and planarized with a polyimide. Finally, a passivation that also works as an anti-reflection film was deposited on a cleaved facet. The waveguide was 40 μm wide and 100 μm long. This WG-PD typically had a responsivity of more than 0.9 A / W at a wavelength of 1.3 μm and a dark current of less than 1 nA at a bias voltage of 2 V at room temperature [6,7]. For long-term aging tests, WG-PDs were bonded junction-up to TO18 stems.

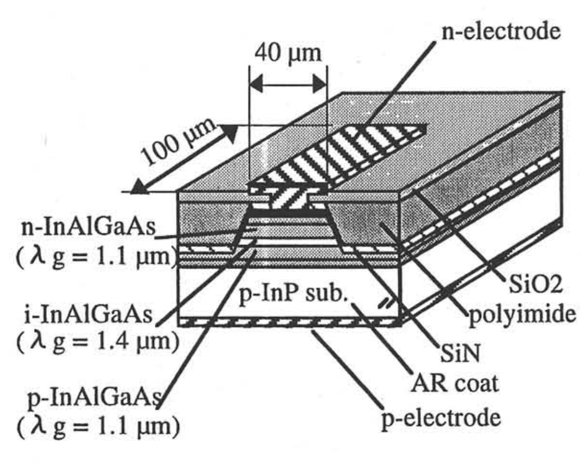

Fig. 1. Schematic structure of the InGaAlAs mesa-waveguide photodiode with a double-core structure.

3. Results and discussions

Figure 2 shows an example of long-term aging test results under a bias voltage of 10 V at temperature of 200℃ in a nitrogen atmosphere. None of the devices were eliminated by the screening tests. Stable operation was observed without any drastic change in the dark current after 8500 hours of testing.

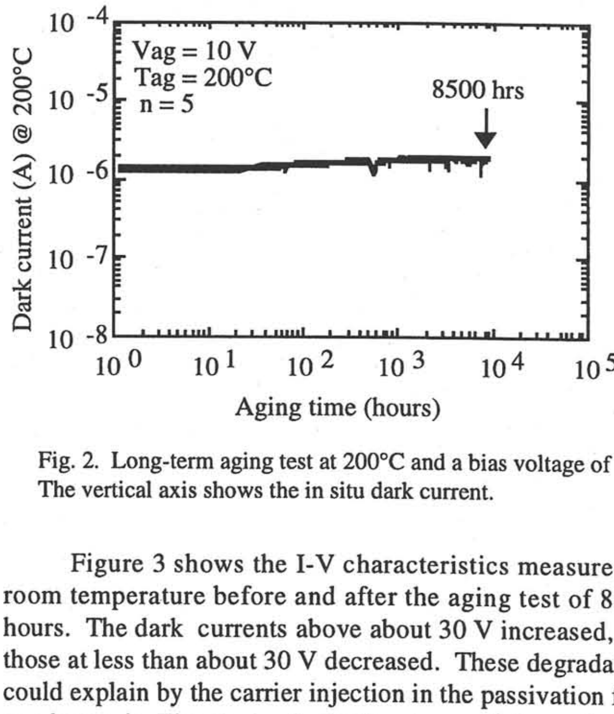

Fig. 2. Long-term aging test at 200°C and a bias voltage of 10 V. The vertical axis shows the in situ dark current.

Figure 3 shows the I-V characteristics measured at room temperature before and after the aging test of 8500 hours. The dark currents above about 30 V increased, but those at less than about 30 V decreased. These degradation could explain by the carrier injection in the passivation film as shown in Figure 4. A similar type of degradation mechanism was observed on photodiodes with polyimide thin film [8, 9]. Open circles in Figure 3 show the calculated results of the dark current after aging by this model assuming the injected sheet hole concentration of 1.2×10^{11} cm^{-2}. They agree well with the experimental results in the whole voltage region. The injected holes cause the increase of the electric field of the depletion layer near the passivation film, which results in the increasing dark current at higher voltage, but cause the decrease the width of depletion, which brings the decreasing dark current at lower voltage (Figure 4).

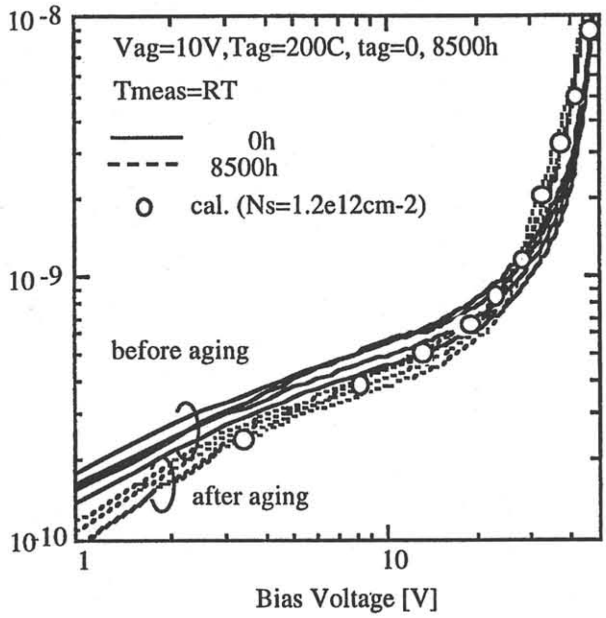

Fig. 3 I-V characteristics of WG-PDs before and after 8500-hr aging at 200 ℃ and calculated degradetion by carrier injection model.

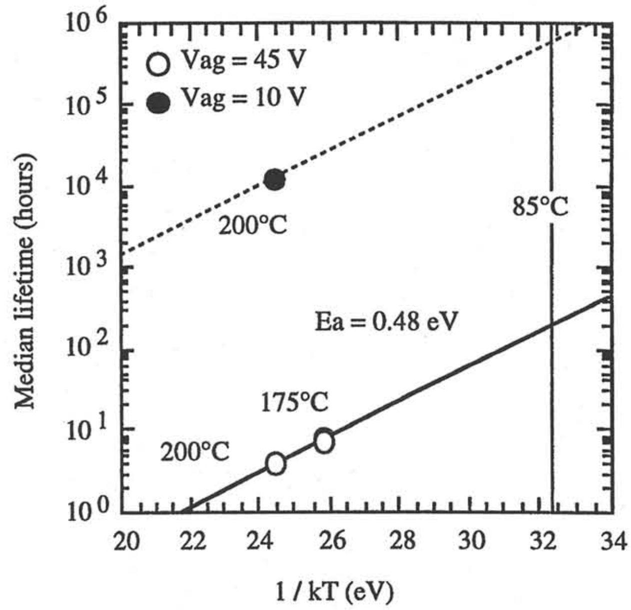

Fig. 5 Arrhenius plot of median lifetime versus temperature with aging voltage as a parameter.

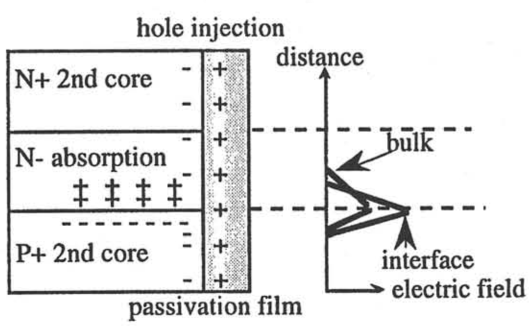

Fig. 4 Carrier injection model

Figure 5 shows an Arrhenius plot of median lifetime at the bias voltage versus aging temperature. Failure criteria was defined when the room-temperature dark current rose by 10% compared its primary value at a bias voltage of 10 V. The median life of aging at 10 V and 200℃ was estimated to 10,000 hours by interpolating the results of above tests. The aging tests at 45 V were also carried out to estimate the activation energy of the WG-PDs. The I-V characteristics after aging test at 45 V were similar to those at 10 V except the degradation rate. This result could mean that the degradation modes between the aging bias voltage of 45 V and 10 V are equivalent. The activation energy for the aging of the bias voltage of 45 V was 0.48 eV, which is the energy of the hole injection in the passivation film according to the our carrier injection model. From above discussion, the median life over 40 years of the WG-PDs operating at 10 V and 85℃ is estimated as shown in this figure.

4. Conclusion

We have investigated the reliability of mesa WG-PDs through long-term aging tests. The median lifetime at a bias voltage of 10 V at 85℃ is estimated to about 40 years. This demonstrates that the WG-PDs well-suited to surface-hybrid integration is sufficiently reliable for use in low-cost optical modules.

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