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LOW EPD AND HIGH AVALANCHE GAIN OF LATTICE-MISMATCHED $In_{0.52}Ga_{0.48}As$ DIODES ON InP SUBSTRATE

Y. Takeda and A. Sasaki

Department of Electrical Engineering, Kyoto University

Kyoto 606, Japan

INTRODUCTION A great interest has been focused on the APD material, fabrication, and operation for long distance and large capacity optical communication at the 1.55 μm wavelength. $In_{0.53}Ga_{0.47}As$ has been thought as one of the best suited materials for this APD. However, the breakdown characteristic is not "hard" and the avalanche gains obtained are not greater than ∿20, except for the early report of Pearsall *et al.*[1]. Very recently, it has been proposed that the electron effective mass of $In_{1-x}Ga_xAs$ ($x \simeq 0.5$) is too light to start avalanche breakdown prior to tunneling at higher electron concentrations than $\sim 10^{15}$ cm^{-3}[2]. On the other hand, it has been believed that a close lattice-matching of InGaAs with InP is essential to obtain a low EPD wafer for APD applications. However, we have shown that the EPD is lower in $In_{1-x}Ga_xAs$ ($0.474 < x \lesssim 0.48$) lattice-mismatched with InP at room temperature[3].

In this paper, we describe a low EPD and a high purity $In_{0.52}Ga_{0.48}As$ wafer, and high avalanche gain of the $In_{0.52}Ga_{0.48}As$ mesa-diodes.

DECREASE OF EPD IN LATTICE-MISMATCHED InGaAs $In_{1-x}Ga_xAs$ is grown by LPE at 625°C on (100)-oriented InP substrates. It has been common to grow $In_{0.53}Ga_{0.47}As$ lattice-matched with InP to obtain high quality alloy layers. However, the EPD of $In_{0.52}Ga_{0.48}As$ which is lattice-mismatched with InP by a factor of 7.7×10^{-4} is lower than that of $In_{0.53}Ga_{0.47}As$. The variation of EPD in $In_{1-x}Ga_xAs$ is shown schematically in Fig. 1. This phenomenon is well interpreted from the difference of thermal expansion coefficients between InGaAs and InP. $In_{0.52}Ga_{0.48}As$ is almost lattice-matched with InP at the growth temperature of 625°C[1] and there would be no misfit dislocations in $In_{0.52}Ga_{0.48}As$ at the growth temperature. $In_{1-x}Ga_xAs$ ($x \leq 0.47$) has misfit dislocations, because of the lattice-mismatch greater than 7.7×10^{-4} at the growth temperature. $In_{1-x}Ga_xAs$ ($x > 0.48$) involves line imperfections, since the tensile stress in the alloy layer is large enough to form cracks. Thus, there should be an optimum composition between 0.47 and 0.48. In our experiments, $In_{0.52}Ga_{0.48}As$ is used for the APD applications.

HIGH AVALANCHE GAIN IN $In_{0.52}Ga_{0.48}As$-APD Very high purity $In_{0.52}Ga_{0.48}As$ is grown on (100)-oriented InP substrates using the temperature cycle shown in Fig. 2. The thicknesses of 7 μm for non-doped n-type layer and 2 μm for the p^+ layer are grown. The lowest impurity concentration measured with the C-V method is 3.8×10^{14} cm^{-3}, so that the avalanche can be the dominant process at the breakdown[2].

Mesa-shaped diodes with a diameter of 100 or 150 μm are formed by the photolithographic

technique. Monochromatic light with a spot diameter of 50 μm is focused on the InGaAs surface to eliminate an anomalous photoresponse at the diode edge. Lock-in technique is used, and thus the increase in the DC dark current is eliminated from the measurement of the avalanche gain.

A sharp breakdown characteristic is observed as shown in Fig. 3 at a reverse voltage as high as 110 V. Avalanche multiplication versus reverse voltage is shown in Fig. 4. Multiplicaion of 85 and 30 are obtained at the wavelengths of 0.9 and 1.30 μm, respectively. There appears to be a wavelength dependence of the multiplication. However, we consider that the dependence is not on the wavelength itself, but on the intensity of the excitaion light. The light intensity at 1.30 μm is one order of magnitude higher than at 0.9 μm in our measurement system.

SUMMARY It has been believed that a close lattice-matching of the epitaxial layer with the substrate at room temperature is essential to obtain high quality layers. However, lattice-matching at the growth temperature is important, even if the lattice is mismatched at room temperature. Decrease of EPD has been observed in $In_{0.52}Ga_{0.48}As$ lattice-mismatched with InP. High avalanche gains have been obtained in the $In_{0.52}Ga_{0.48}As$-mesa diodes which have high breakdown voltages of 110∿120 V.

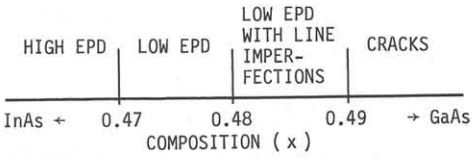

Fig. 1 Variation of EPD in $In_{1-x}Ga_xAs$ on InP with relation to composition.

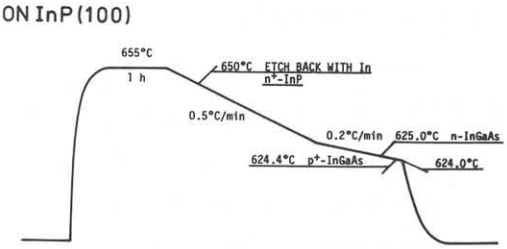

Fig. 2 Temperature cycle for the growth of InGaAs diode on InP. In, InAs and GaAs are baked at 800°C for 3 h before this temperature cycle.

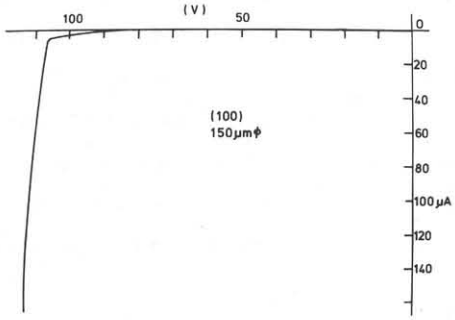

Fig. 3 Sharp breakdown characteristic is obtained in $In_{0.52}Ga_{0.48}As$ APD.

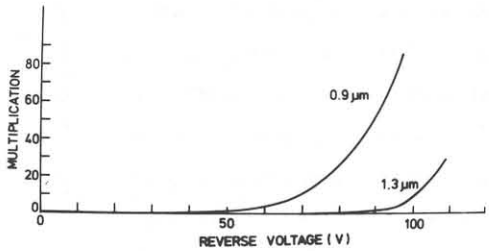

Fig. 4 Avalanche multiplication vs. reverse voltage of $In_{0.52}Ga_{0.48}As$ APD.

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[1] T. P. Pearsall and R. W. Hopson, Jr., J. Electron. Mater. 7, 133 (1978)

[2] Y. Takanashi, M. Kawashima and Y. Horikoshi, Rep. Tech. Group Opt. and Quan. Electron., IECE Japan, OQE79-90, 1979(in Japanese)

[3] Y. Takeda, K. Noda and A. Sasaki, Spring Meet. of Jpn. Soc. Appl. Phys. 29a-H-6, 1979 (in Japanese)