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Study of Groove Formation in InP Surface During Zn Diffusion

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Zn diffusion is commonly used for p-n junction formation in InGaAs/InP technology for short-wave infrared imaging devices. InP surface degradation during the diffusion process can lead to low device performance and fabrication yield. InP degradation is usually manifested as macroscopic etch-pits and In hillocks and is a consequence of preferential evaporation of P [1]. Other investigations have attributed the InP degradation during Zn diffusion to the chemical reaction between Zn and InP that results in the formation of In hillocks and crystalline Zn_3P_2 inclusions [2] or a Zn_xP_2 film [3]. This paper presents a different type of InP deterioration in InGaAs/InP P-i-N photodiodes occurring during Zn diffusion. It presents the microanalysis performed in finding the cause for this type of deterioration and the solution.

The InP and lattice matched $In_{0.53}Ga_{0.47}As$ thin film were grown on (100) InP wafer by MOCVD. The p-n junction was produced by opening diffusion windows by conventional Reactive Ion Etching (RIE) methods and the diffusion process was carried out in a semi-closed system. The morphological and compositional analysis of the defected InGaAs/InP layers was performed by dual beam Focused Ion Beam (FIB),Versa 3D, and Transmission Electron Microscopy (TEM), Titan Themis G2.

After diffusion, different widths and lengths of oriented grooves were observed on the degraded InP surface as shown in figure 1. FIB analysis combined with Energy Dispersive Spectroscopy (EDS) analysis revealed that the depth of these grooves is less than 0.3µm, i.e. they are present only in the InP layer. Their vicinity is enriched with Zn, the dark areas marked in figure 1(b). This phenomenon leads to an increase in the lateral diffusion and degradation of the photodiode performance. For the TEM microanalysis site-specific cross section lamella was prepared. The lamella was oriented perpendicular to the grooves and the challenge was to include a wide range of grooves with a variety of sizes on the same lamella. These sizes correspond to different stages of formation, from the initial stage to continued growth. The initial stage assisted in identifying the cause of its formation and the more advanced stage helped us determine its orientation and the processes that occurred with its growth. Figure 2 presents an example of the TEM lamella that includes 3 grooves at different stages of growth. The grooves are formed along the {111} crystal planes, see figure 2(a). Dislocation or any other related defects were not observed. EDS line scan of the marked line in figure 2(b) is presented in figure 2(c). Two amorphous layers are seen at the InP surface; $Zn(PO_x)_y$ is the outer layer and the inner one adjacent to the InP crystal is Zinc Phosphide with a composition close to Zn_3P_2. The outer $Zn(PO_x)_y$ layer is present thoughout the diffusion window and has a uniform thickness of 4nm, except for the area in which the groove starts to develop. The inner Zn_3P_2 film does not have a defined thickness and length, and it depends on the groove size, see figure 2(a) and figure 3.

To understand the cause for the formation of these amorphous layers, TEM analysis was performed on wafers before diffusion. Figure 4(a) presents the TEM image of such a wafer and figure 4(b) the EDS line scan of the marked line in figure 4(a). The analysis reveals the formation of a thin amorphous layer of $In(PO_x)_y$, with a thickness of 4 nm, similar to that of $Zn(PO_x)_y$. The formation of this layer is related to the damage formed during the process for the diffusion window opening. By etching this layer [4] as presented in figure 4(c) surface degradation of the InP could be diminished.

The $In(PO_x)_y$ layer plays an important role in the degradation of the InP surface during Zn diffusion. Zn can replace In and react with P to form a $Zn(PO_x)_y$ layer. We assume that the grooves are formed as a result of a stress relief mechanism. The formation and the growth of the Zn_3P_2 layer are related to the grooves formation and subsequent growth. This layer grows and progresses with the groove.

In summary, this work presents the use of TEM microanalysis for understanding the source and finding the solution for grooves formation that cause degradation of the InGaAs/InP photodiodes [5].

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[5] The authors acknowledge Y. Kauffmann and Galit Atiya from the Technion, Israel, Department of Materials Science and Engineering for their contribution in the TEM anlysis on Titan Themis G2.

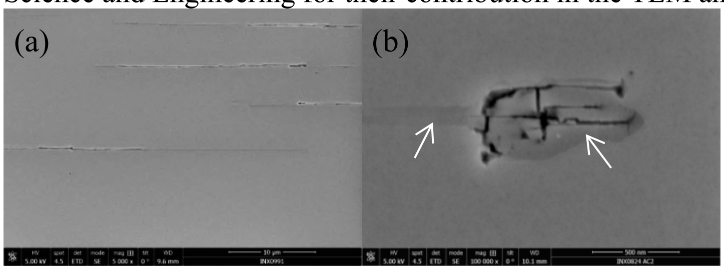

Figure 1. SEM images of typical grooves (a) low magnification and (b) higher magnification.

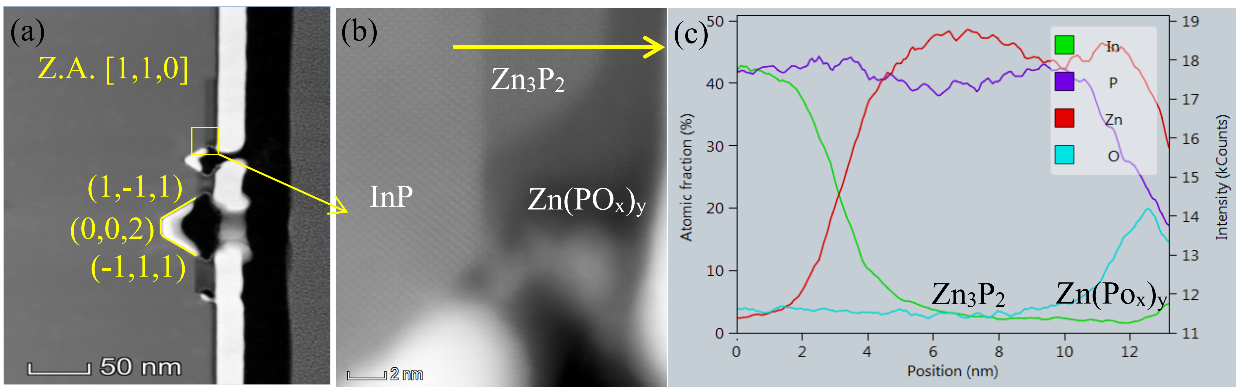

Figure 2. STEM High-angle annular dark field (HAADF) images presenting grooves of different sizes, crystalline structure and composition. (a) Cross section of 3 grooves, (b) higher magnification of the highlighted area in figure (a) and (c) EDS line scan across the marked line in figure (b).

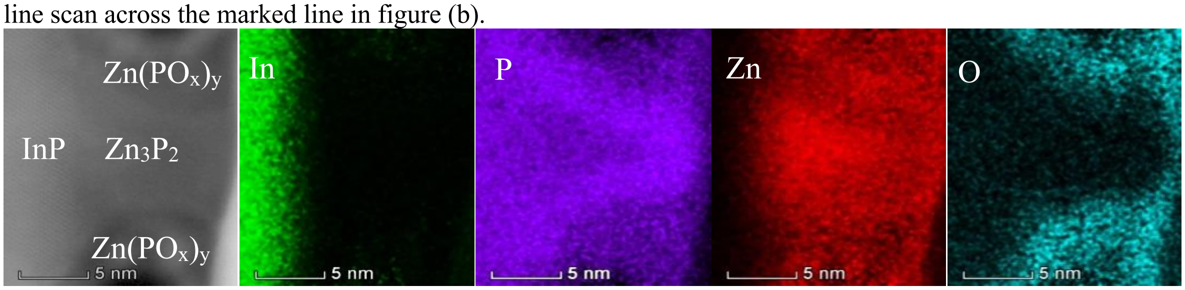

Figure 3. STEM HAADF image and EDS mapping analysis showing the structure and composition between 2 adjacent grooves.

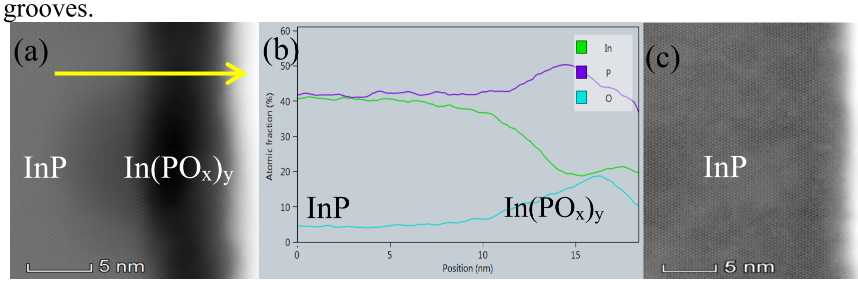

Figure 4. STEM HAADF images and composition of InP layer (a) after the process for diffusion window opening, (b) EDS line scan across the marked line in figure (a) and (c) after etching.

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