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Defect Observations of GaAs-$Al_xGa_{1-x}As$ Heterostructures by Transmission Infrared Microscopy

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GaAs-$Al_xGa_{1-x}As$ epitaxial multilayers used in optical devices have various defects at the interfaces, some of which have been observed by selective etching.[1] Such interface defects in the heterostructure composed of the crystals of different optical indices are thought to be detected by the optical transmission observation without use of any decorative procedure. The infrared transmission microscopy has been successfully applied for the evaluation of GaAs bulk crystals,[2] but few is reported for GaAs-$Al_xGa_{1-x}As$ epiwafers. If the infrared method is applicable to the epiwafers, this method will be very useful because one can evaluate wafers nondestructively before or during device processing. In this note, emphasis is placed on demonstration of usefulness of this technique for epiwafers: it is shown that several sorts of interface defects can be detected, some of which induce dark photoluminescence. However, details of the nature of the observed defects are out of scope of this note.

The sample in Fig. 1 is a four-layer DH epiwafer composed of an *n*-GaAs (001) substrate, *n*-$Al_{0.4}Ga_{0.6}As$, *p*-$Al_{0.04}Ga_{0.96}As$, *p*-$Al_{0.4}Ga_{0.6}As$ and *n*-GaAs cap layers. (a) is an IR transmission photograph of the as-grown wafer. The speckled pattern was observed uniformly thoughout the whole area. (b) and (c) are the reflection and IR transmission photographs of the same sample after selective etching.[3,4] From these figures, it is obvious that the speckled pattern observed in Fig. 1(a) arises from interface roughness at the 1st epilayer-substrate boundary which leads to the light scattering. Heavy arsenic vaporization from the substrate surface before contact with As-saturated Ga melt may be responsible for this interface roughness. In fact, this type of defect was much reduced by using an appropriate growth apparatus. Therefore, defect observation in what follows was carried out for samples with improved interfaces.

Other examples of defects are shown in Figs. 2 and 3. Apparently, the observed defects are different, at least in its shape, size and distribution, from those shown in Fig. 1. Figure 2 shows the defects observed for the $Al_{0.3}Ga_{0.7}As$ single epitaxial wafer. In the IR transmission photograph (Fig. 2(a)), [110]-oriented oval defects were observed. After removal of the epilayer with AB etchant,[5] a corresponding feature appeared on the GaAs substrate (Fig.

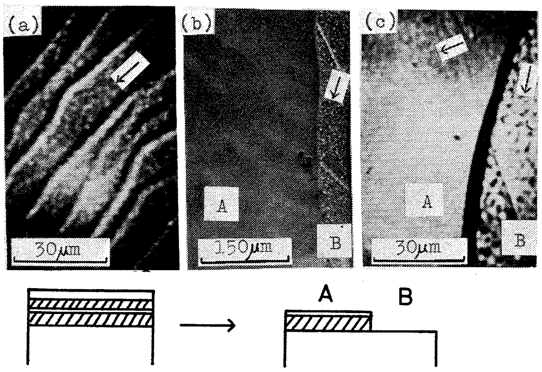

Fig. 1. Interface roughness in 4-layer DH epiwafer observed by IR transmission (a), (c) and reflection (b). (a) as-grown and (b), (c) after selective etching. Arrows indicate the speckled pattern. Line features in (a) are the growth terraces, and the line-shaped defects in (b) and (c) are due to scrathes introduced during preparation of the substrate.

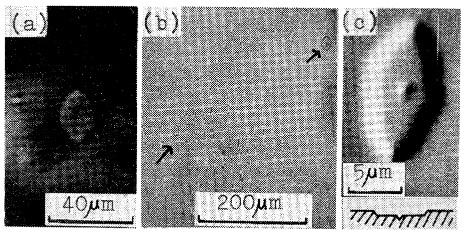

Fig. 2. Oval defects in single-layer $Al_{0.3}Ga_{0.7}As$ epiwafer. (a) as-grown IR transmission. (b) reflection and (c) an SEM image after AB etching.

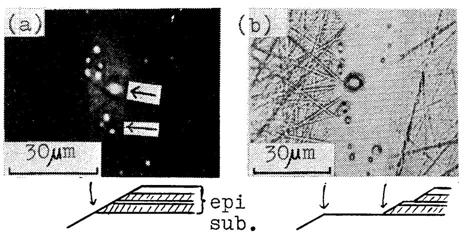

Fig. 3. Rod-shaped defects and round defects in 4-layer DH epiwafer after angle-lapping. (a) IR transmission (as lapped) and (b) etched feature with the AB etchant.

2(b) and (c)). Figure 2(c) shows the fine structure of this oval defect observed by an SEM. The depths of the oval pits range from 0.03 μm to 0.15 μm.

In Fig. 3, [110]-oriented rod-shaped defects and round defects which are different from those shown in Fig. 2 are seen. In this case, IR transmission and reflection microscopic observations were made on the angle lapped and AB etched epiwafer respectively. The result of Fig. 3 indicates that these defects lie at the substrate interface.

Yet another example of defect is given in Fig. 4 where line-shaped defects (Fig. 4(a)) on the back surface of the 1st $Al_{0.3}Ga_{0.7}As$ layer are seen in the IR transmission photograph (Fig. 4(b)). The photograph (Fig. 4(a)) was taken after removing partly the GaAs substrate with PA etchant. The line-shaped defects may be related with morphology of the substrate surface etched back by Ga melt before epitaxial growth, and this defect can be observed by X-ray topography.[6] Figure 4(b) was obtained after stripe formation by selective diffusion.[7]

Finally, we will show in Fig. 5 that the IR transmission observation can detect another type of line-shaped defects which induce dark

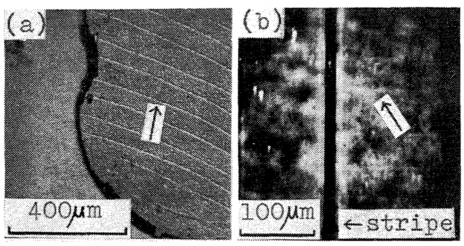

Fig. 4. Line-shaped defects in 4-layer DH epiwafer. (a) etched feature observed after removing off the substrate and (b) IR transmission pattern observed after selective diffusion. The stripe structure is not essential.

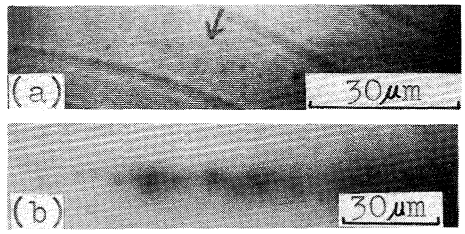

Fig. 5. The relation between IR transmission observation and PL measurement. (a) IR transmission pattern and (b) PL pattern at the same site in 3-layer DH epiwafer.

PL. However, the defects accompanied with dark PL are not always detected by the IR transmission observation. The PL pattern method is a powerful tool for evaluation of epiwafers,[8] but application of this method to DH wafers is limited due to the presence of the GaAs cap layer. This limitation is removed to some extent by the use of IR transmission microscopy.

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