Evaluation of 4” Fe-doped InP wafers using a scanning photoluminescence technique

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Commercially-available 4’’ Fe-doped InP (100) wafers grown by liquid-encapsulated Czochralski (LEC), vapor-controlled LEC (VCZ), and vertical gradient-freezing (VGF) methods are examined by a scanning photoluminescence (sPL) technique at both microscopic and macroscopic scales. The sPL map of LEC-grown wafer measured at room temperature shows a circular symmetric distribution with striation patterns at the macroscopic scale, and network structures at the microscopic scale. The VCZ-grown wafer also reveals the circular symmetric distribution with striation patterns and network structures, although they are much weaker than those in the LEC-grown ones. On the other hand, the VGF-grown wafer reveals an asymmetric distribution over the whole wafer. The sPL results at microscopic and macroscopic scales shown here can be associated to comparatively evaluate the growth methods for 4’’ Fe-doped InP crystals at industrial production level.

Keywords: InP, liquid-encapsulated Czochralsky (LEC), vapor-controlled Czochralsky (VCZ), vertical gradient freezing (VGF), photoluminescence, room temperature

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1. **Introduction:**

A scanning photoluminescence (sPL) technique has been widely employed to characterize a variety of semiconducting and semi-insulating wafers used for fabricating optoelectronic and electronic devices [1-3]. Specially in Fe-doped InP crystals, the sPL measurements is useful in investigating their semi-insulating characteristic connected to deep levels caused by native defects, unknown impurities, and Fe-dopants, since the intensity of PL due to the band edge emission is strongly influenced by the density of deep levels. For instance, Longére *et al.* examined a large number of Fe-doped InP wafers and found that the sPL intensity distribution is associated with the defects and the non-uniformities such as Fe-decorated dislocations and striations in the wafer [2]. From the viewpoint of device fabrication, Miner *et al.* also found that the bright-line pattern in the sPL map of Fe-doped InP wafer is correlated to the slip-like defects in the InGaAs epitaxial layer [3]. Those studies were performed with the 2” Fe-doped wafers grown by liquid-encapsulated Czochralski (LEC) method. Even if the same crystal growth method is employed, the semi-insulating characteristic may be changed by increasing the crystal size, because the thermal environment during crystal growth is reasonably modified. It is, therefore, worthwhile to characterize the semi-insulating InP wafers currently used. The wafer size of up to 4” is commercially produced in response to the strong market demand. Concerning crystal growth, several methods have been newly introduced at the industrial production level to replace the conventional LEC method. One of them is a vapor-controlled LEC (VCZ) method [4] and another is a vertical gradient-freezing (VGF) method [5,6].

In this paper, we will present the sPL results measured in commercially-available 4” Fe-doped InP (100) wafers grown by the three different methods. The sPL results measured at both microscopic and macroscopic scales are discussed in conjunction with the difference between their crystal growth methods.
2. Experimental

The samples used here are commercially-available 4” Fe-doped InP (100) wafers grown by the LEC, VCZ, and VGF methods. In our sPL measurements, a He-Ne laser with the wavelength of 632.8 nm is used as excitation source. The spot size of laser beam is approximately 10 µm at the sample surface. Without scanning a monochromator, the PL spectra corresponding to band-to-band transitions at room temperature were detected at once by a multi-channel linear sensor. The integrated intensity and the full width at half maximum (FWHM) were calculated from the recorded PL spectra. The scanning measurement was done both with the 20 µm step for microscopic observation of a part of the wafer and with the 500 µm step for macroscopic one covering the whole area of wafer.

3. sPL measurement results

Figure 1 shows typical maps of sPL intensity measured in the LEC-, VCZ-, and VGF-grown wafers. The sPL measurement was done on 2mm×2mm areas at the center and the near the [0 1 1] orientation flat (OF) for each wafer. It is clearly found from the sPL maps of the LEC-grown wafer that there are several bright-lines forming network structures with the size of several hundred microns. The density of the network structure is not varied both at the center and at the OF areas. The network structures observed here are typically found in microscopic sPL observation in commercial LEC-grown InP wafers and are considered as a variation of Fe concentration due to dislocations [2,3]. The VCZ-grown wafer as well as the VGF-grown wafer also exhibits network structures but the intensity is much weaker than that of the LEC-grown wafer, which may reflect the difference in the dislocation density between these wafers.

Figure 2 shows the sPL maps of (a) intensity and (b) FWHM, and (c) the intensity histogram measured in the whole area of the LEC-grown wafer. It is clearly found in Fig.2 that there are concentric circles over the whole wafer, which are well known as striations [1]. The distribution of
FWHM is almost flat except for the OF area. Figure 3 shows the sPL maps and intensity histogram measured in the VCZ-grown wafer. The VCZ-grown wafer also exhibits the striation patterns, but their intensities are weaker than those in the LEC-grown wafer. The FWHM decreases at the specific wafer peripheral regions, which forms a distorted four-fold symmetric distribution. On the other hand, it is found in Fig. 4 that the sPL map of VGF-grown wafer reveals an asymmetric distribution extremely skewed to a certain pattern. The asymmetric distribution is also found in the FWHM map. The intensity histogram shows broad variation than those of the LEC- and VCZ-grown wafers, which means the great variation of the Fe concentration over the VGF-grown wafer.

From the viewpoint of device fabrication, it is desirable to suppress the variation of Fe concentration not only at the microscopic scale but also at the macroscopic one because it may cause several problems such as the slip-like defects in the InGaAs epitaxial layer [3] and the out-diffusion of Fe into epitaxial layers [7,8]. The obvious differences of sPL results between the VCZ- and VGF-grown wafers are primarily connected with the difference in their crystal growth methods, especially in the thermal conditions. Since the cylindrical crystal is rotated without contact with the crucible during the LEC and VCZ growth processes, the thermal conditions can easily exhibit circular symmetry. The sPL results of VCZ-grown wafer shown here, including circular symmetry, weak striations and network structures, agree with the features. On the other hand, the growth condition of the VGF method is primarily dominated by the crucible structure and the growth direction. Since the sPL intensity of VGF-grown wafer revealed asymmetric but almost monotonous variation, it may be reflected not only by the temperature inhomogeneity in the furnace but also by the specific condition to the VGF method such as the growth direction with an offset to the crystallographic 〈100〉 direction.

4. Conclusion

Commercially-available 4” Fe-doped InP (100) wafers grown by the LEC, VCZ, and VGF methods are examined by a sPL technique at room temperature. The sPL map of the LEC-grown
wafer shows the circular symmetric distribution with striation patterns at the macroscopic scale, and network structures at the microscopic scale. The VCZ-grown wafer also reveals the circular symmetric distribution with striation patterns and network structures, but their intensities are much weaker than those in the LEC-grown ones. On the other hand, the VGF-grown wafer reveals the asymmetric distribution over the whole wafer. The sPL results in microscopic and macroscopic scales shown here can be associated to comparatively evaluate the growth methods for 4” Fe-doped InP crystals at industrial production level.
References:


Figure captions:

Fig. 1 Two-dimensional maps of sPL intensity in 2mm×2mm areas at the center and near the orientation flat of the LEC-, VCZ-, and VGF-grown wafers.

Fig. 2 Two-dimensional maps of (a) intensity and (b) FWHM map, and (c) the histogram of intensity in sPL measurement of a Fe-doped InP wafer grown by the LEC method.

Fig. 3 Two-dimensional maps of (a) intensity and (b) FWHM map, and (c) the histogram of intensity in sPL measurement of a 4” Fe-doped InP wafer grown by the VCZ method.

Fig. 4 Two-dimensional maps of (a) intensity and (b) FWHM map, and (c) the histogram of intensity in sPL measurement of a 4” Fe-doped InP wafer grown by the VGF method.
Fig. 1. M. Fukuzawa, et. al.
Fig. 2. M. Fukuzawa, et. al.
Fig. 3. M. Fukuzawa, et. al.
Fig. 4. M. Fukuzawa, et al.