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Automatic Detection of Dislocation contrasts in Birefringence Image of SiC Wafers Using Variance Filter Method

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Abstract

Birefringence imaging attracted great attention as a nondestructive characterization method of defects in next generation power device materials such as SiC and GaN. However, due to the complicated and unclear contrasts of dislocations in the birefringence image, it is almost impossible to automatically detect the position of the dislocation contrasts by the conventional image thresholding. In the present study, we demonstrated the automatic detection of dislocation contrasts in the birefringence images of the commercial SiC wafers using variance filter method.

1. Introduction

In semiconductor devices, particularly power devices, the dislocations in the crystal adversely affect device properties, reliability and yield. In the case of silicon (Si), a method for manufacturing a dislocation-free wafer has been established[1]. However, a lot of dislocations exists in the next generation power device materials such as silicon carbide (SiC) and gallium nitride (GaN) compared to Si[2),3] Therefore, it is important to evaluate the positions of the dislocations in SiC and GaN wafers. Birefringence imaging using a polarizing microscope is one of the method to characterize the dislocations in crystals[4)–6]. Recently, it was reported that the threading dislocations (TDs) in SiC and GaN were possible to detect by the birefringence imaging[7),8]. However, because of the complicated and unclear contrast of the dislocation, and the contrast modulation due to the macroscopic stress field, it is almost impossible to automatically detect the position of the dislocations by the conventional image thresholding. In the present study, we propose an algorithm to detect the position of the dislocation contrasts in birefringence image using variance filter.

2. Experimental

Commercial 3-inch 4H-SiC (0001) wafers with 4 degrees tilted toward [11-20] was used for the birefringence observation. The Si face was planarized by chemical mechanical polishing (CMP) and the C face was planarized by mechanical polishing (MP), which is the same as a normal SiC wafers for manufacturing power devices. In this case, the contrast of the dislocation was unclear compared to the wafer which was planarized by CMP on both sides. A birefringence microscope (XS-1: Mipox) was used for observation. Detail of the observation setup was described in Ref. 7.

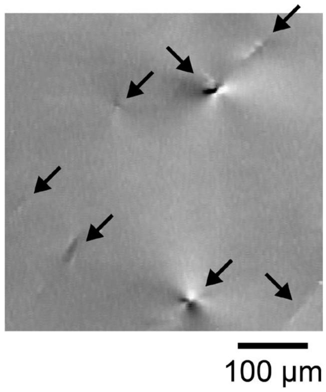

Fig.1 Birefringence image of the 4H-SiC wafer. The positions of the dislocation contrast is indicated by the arrows.

Figure 1 shows the birefringence image of the SiC wafer. The contrast of the dislocation in birefringence image depends on the Burgers vector and the propagation direction of the threading dislocations. Although the contrast level and the shape of the contrast was different from each other, every dislocation contrast was combination of the bright and dark contrast. This is because the dislocation always accommodating both compressing and tensile strain. Therefore, we focused on the fact that the change in the contrast level becomes large near the dislocation contrast.

3. Algorithm

The key concept of algorism for the detection of dislocation contrasts is that the variance filter is used to detect the position where the contrast level largely changes. The variance filter method was sometimes used for the edge detection of the photographic images[9]. Figure 2 shows the flow of the algorism for the detection of the dislocation contrasts. Firstly, the 8-bit birefringence image was linearly normalized so that the averaged pixel values of a normalized image became 128 (the center of the dynamic range) and the variance of pixel values became certain value ($v_0 = 16$). The normalization process makes it possible to detect the dislocation contrasts with

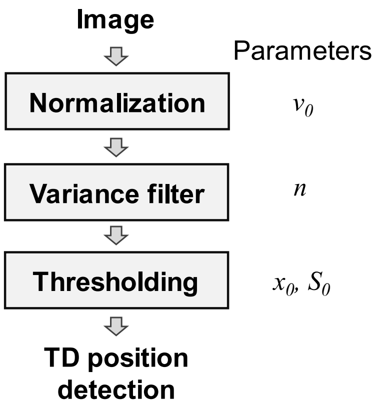

Fig. 2 Flow and the parameters of the algorism for the detection of dislocation contrasts.

good reproducibility even for the images having different contrast levels. Then, the variance filter was applied to the normalized image. The variance filter algorithm consists of replacing a central pixel values with the variance of a square set of *n* by *n* (*n* is an odd number) pixels values surrounding it. In this time we set the value of *n* as 5. The values of the variance are large at the position where the contrast level is changing. Therefore, the values of the variance are expected to be large near the dislocation contrasts. Finally, when the number of connected pixels above a certain value (x_0 = 24) is larger than threshold values (S_0 = 10), the rectangle bounding box is set. By this algorithm, the dislocation contrasts in the images are automatically bounded by the box.

3. Results and discussion

Figure 3 shows the results of the variance filter and the automatic detection for the birefringence image shown in Fig. 1. The variance of the position near the dislocation contrast is large and almost all dislocation contrasts were detected by the current algorism. When the dislocation contrasts were too adjacent to be connected, they are counted as one defect by this algorism. Therefore, this algorism tends to slightly underestimate the density of the dislocation contrasts. Table 1 summarizes the density of the dislocation contrasts measured manually and automatically. Owing to the normalization process in the algorism, it seems that the accuracy of the automatic detection was not largely depending on the individual images. The averaged deviation of the density was as low as 4.4% and it was revealed that the defect density was estimated relatively accurately. The density of defect contrasts in birefringence images are almost corresponding to the typical threading dislocation density of the commercial wafers. Therefore, the threading dislocation density of the wafer is possible automatically measured by this algorism as well as the birefringence microscopy.

4. Conclusions

In the present study, we proposed an algorism using valiance filter method to automatically detect the position of the unclear and complicated dislocation contrasts in birefringence images of a SiC wafer. We successfully detected the position of the dislocation contrasts by this algorism and the accuracy was as low as 4.4%. It is expected that the threading dislocation density in SiC wafers can be estimated by this algorism and the birefringence microscopy.

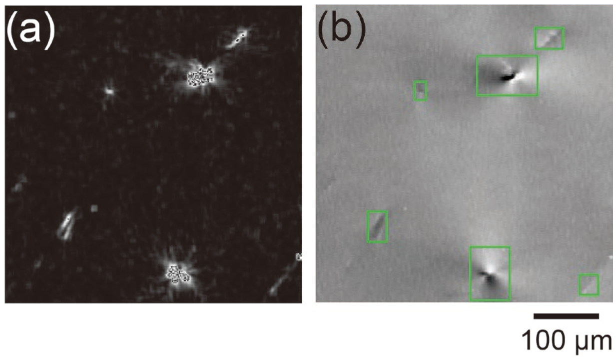

Fig. 3 (a) The images after normalization and variance filter process and (b) the result of the automatic detection for the birefringence image shown in Fig. 1.

Table 1 Density of dislocation contrasts in the birefringence images with the different area (1920 μm x 853 μm) measured by the automatic detection algorism.

	Density (cm^{-2})		
Area #	Manual	**Automatic**	Deviation (%)
1	5493	**4944**	10
2	4120	**4120**	0
3	2747	**2930**	6.7
4	5676	**5859**	3.2
5	4303	**4211**	2.1
Ave.	4467	**4412**	4.4

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