Polysilicon Slice Dislocation Defects Segmentation and Area Statistics based on Curve Fitting

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Abstract—**The quality of the polysilicon slice affects the efficiency of polysilicon solar cells directly, dislocation defects exist in the polysilicon generally, a large number of dislocation defects have a greater impact on efficiency of solar cells. On the basis of photoluminescence defects detection, this paper proposes a new method that progressive scan image to obtain the grayscale curve of each row, and do curve fitting for each grayscale curve to achieve defect segmentation, by comparing the segmentation results obtained by quadratic curve and Gaussian curve fitting, proves that the quadratic curve fitting can be better for defects segmentation. At last, get the proportion of defective area in total slice area. Experiments show that the method of quadratic curve fitting is efficiency and accuracy for dislocation defects segmentation and counting defects area ratio.**

Keywords: ***Curve Fitting, Defect Segmentation, Area Statistics, Dislocation Defect.***

I. INTRODUCTION

In the case of global energy shortage, the development and utilization of new energy catch the attention of the global community. Solar energy gets a widespread development and utilization as a pollution-free and widely exist energy. Photovoltaic industry has a rapid development, manufacturing and production of solar cells are the key link in the photovoltaic industry. Quality and efficiency of power generation of solar cells are important factors which are affecting the reliability and efficiency of the photovoltaic system. Polysilicon slice as an important part of solar cells, its quality affects the conversion efficiency of the solar cell directly, so quality testing for polysilicon slice is very important in the process of solar cell production.

This paper studies the method for polysilicon slice dislocation defects automatic segmentation and defects area ratio statistics based on photoluminescence defect detection and digital image processing technology. On the basis of analysis of photoluminescence image (PL image) and dislocation defects characteristics of polysilicon slice, completes dislocation defects segmentation and defects area statistics by curve fitting, achieves dislocation defects automatic detection.

II. IMAGE ACQUISITION

By the photoluminescence detection principle that silicon slice acquires energy by laser irradiation to generate infrared fluorescence whose wavelength is between 1100nm to 1200nm, then acquire image data by infrared-sensitive devices and transport data to computer to process. The schematic diagram of device for silicon slice photoluminescence defect detection is shown in figure 2.1, the device includes image display and processing module, image acquisition module and laser module. The laser module consists of a laser and dodging piece, responsible for generating laser, the dodging piece before laser can homogenizes the intensity distribution of laser irradiated on silicon slice; image acquisition module consists of infrared-sensitive lens and ray filter, responsible for image acquisition, the ray filter before lens can prevent light entering the lens whose wavelength is not between 1100nm and 1200nm; image display and processing module consists of computer and software, responsible for the display and processing of the image.

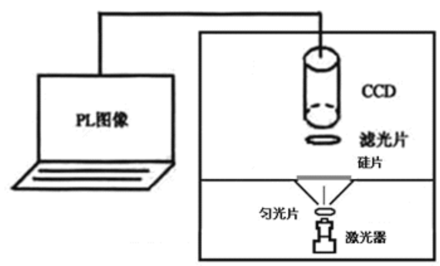

Figure 2.1 The schematic diagram of silicon slice photoluminescence detection device.

III. ANALYSIS OF PL IMAGE AND DISLOCATION DEFECT

A. PL Image Features

By photoluminescence principle, the intensity distribution of the PL image is affected by the intensity distribution of laser. In order to get the intensity distribution features of the PL image, first let the laser irradiate on the silicon slice without defects, then get the PL image after denoising as shown in figure 3.1, the PL image of the silicon slice without defects can reflect the intensity distribution of laser. Get the grayscale distribution curved surface of image by MATLAB as shown in figure 3.2. Plot the grayscale curve of the middle row pixels in image as shown in figure 3.3. By PL image grayscale distribution curved surface and grayscale curve of row pixel, this paper can't determine the distribution of grayscale curve of each

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row pixels in PL image is quadratic curve or Gauss curve, so determine the better distribution by comparing the results of two methods.

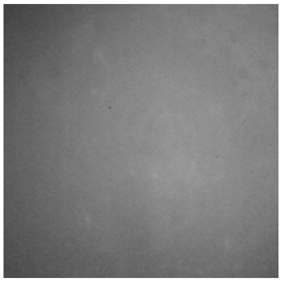

Figure 3.1 PL image of silicon slice without defects.

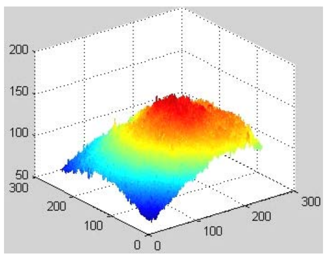

Figure 3.2 Grayscale distribution curved surface of figure 2.1.

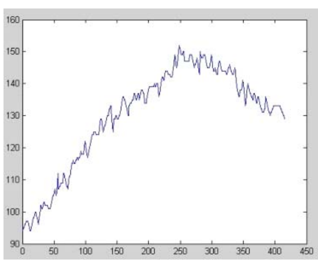

Figure 3.3 Grayscale curve of the middle row pixels of figure 2.1.

B. Dislocation Defect Features

In silicon slice photoluminescence defect detection, the intensity of excited light is proportional to the minority carrier density. Due to the low minority carrier density of the defect region, the intensity of excited light from defect region is low, so the defect region in the PL image has lower gray value. The PL image of polysilicon slice with dislocation defects after denoising is shown in figure 3.4. The grayscale curve of the middle row pixels in image of figure 3.4 is shown as figure 3.5. By the analysis of PL image and grayscale curve of row pixels, the existence of dislocation defects makes pixels of defective region grayscale values lower, and forms hollows in the grayscale curve of row pixels. This feature can be used as a basis for dislocation defects segmentation.

Figure 3.4 PL image of polysilicon slice with dislocation defects after denoising.

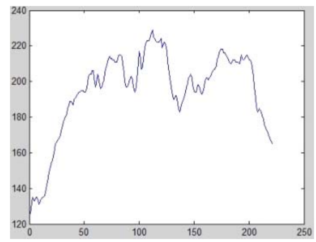

Figure 3.5 Grayscale curve of the middle row pixels of figure 2.4.

IV. DISLOCATION DEFECT DETECTION

According to the above analysis, the paper proposes a method that progressive scan image, get grayscale curve of each row pixels, then do curve fitting for grayscale curve of each row, calculate segmentation threshold for each pixel base on the fitting value, at last, achieve dislocation defects segmentation by threshold, and statistics of defects area.

A. Image Denoising

In the process of image acquisition, because of the environmental factors and the equipment, the image will be taken into some noise. The image in this experiment has salt and pepper noise and Gaussian noise. The salt and pepper noise is randomly appeared granular noise, the Gaussian noise is the noise whose intensity obeys the Gaussian distribution.

In this paper, the median filter combined with Gaussian smoothing filter has been used for image denoising, median filtering has a good inhibition for salt and pepper noise, Gaussian smoothing filter has a good effect on the removal of Gaussian noise, and also has a good effect on other types of noise in a certain extent. The image of polysilicon slice before denoising is shown in figure 4.1 and the image after denoising is shown in figure 3.4, the contrast result shows that the salt and pepper noise is suppressed, and the image becomes smoother.

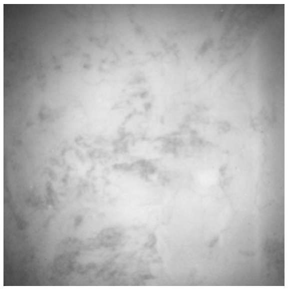

Figure 4.1 PL image before denoising

B. Curve Fitting and Defect Segmentation

According to the above analysis, in order to compare the two distributions, quadratic curve and Gaussian curve. This paper does quadratic curve fitting and Gaussian curve fitting respectively for grayscale curve of each row pixels by the method of least squares, calculates segmentation threshold based on the fitted value of each pixel to achieve defects segmentation. Decide which method is better by comparing the results of defects segmentation.

The least squares method seeks the best function match for data by minimizing the deviation square summation between the data obtained and the origin data.

The function of conic is shown as formula 4.1, a_0, a_1, a_2 are the coefficients. And the function of Gaussian curve is shown as formula 4.2, α, β, γ are the coefficients.

$$f(x) = a_0 + a_1 x + a_2 x^2 \tag{4.1}$$

$$f(x) = \alpha e^{-(x-\beta)^2 / \gamma^2} \tag{4.2}$$

For example, to do curve fitting for the grayscale curve shown in figure 3.5 by quadratic curve fitting and Gaussian curve fitting respectively, the result of quadratic curve fitting is shown as figure 4.2, and the result of Gaussian curve fitting is shown as figure 4.3， the contrast of two results is shown as figure 4.4.

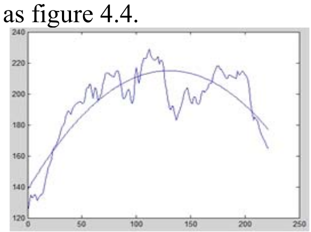

Figure 4.2 Result of quadratic curve fitting

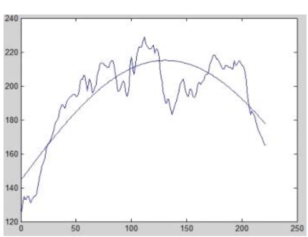

Figure 4.3 Result of Gaussian curve fitting

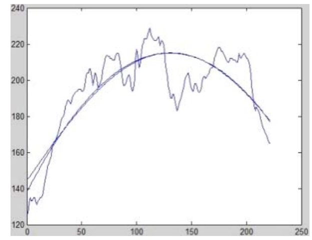

Figure 4.4 Contrast of two results

It is difficult to judge the two methods by the contrast of two results of curve fitting for grayscale curve of the middle row pixels. So judge the two methods by the results of defects segmentation.

In this experiment, the region whose minority carrier density is below the 90% of normal level will be identified as defect. Due to the presence of noise, and the gradation value fluctuation brought by the changes of minority carrier density, the fitted values can reflect the normal level of minority carrier density to a certain extent. Calculate the segmentation threshold for each pixel by the fitted value, the segmentation threshold for each pixel is got by the corresponding fitted value multiplies a scaling factor k , k equals 0.9. The function of threshold calculation is shown as equation 4.3, $threshold(i, j)$ is the segmentation threshold for the pixel whose coordinate is (i, j) , and $F(i, j)$ is the fitted value of the pixel.

$$threshold(i, j) = F(i, j) \times k \tag{4.3}$$

For example, respectively complete dislocation defects segmentation for the PL image in figure 3.4 by the two methods. The result of quadratic curve fitting method is shown as figure 4.5, and the result of Gaussian curve fitting method is shown as figure 4.6.

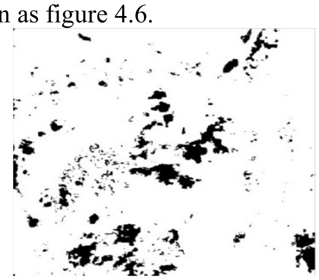

Figure 4.5 Result of segmentation by quadratic curve fitting method

Figure 4.6 Result of segmentation by Gaussian curve fitting method

By comparing the two results of segmentation with the image shown in figure 3.4, this paper determines the quadratic curve fitting method is better for dislocation defects segmentation, because of its more ideal result.

V. Dislocation Defects Area Proportion

In order to detect polysilicon slice is eligible or not and achieve the classification of polysilicon slice, the proportion of the dislocation defects area in silicon slice needs to be counted. For binary image of dislocation defect after segmentation, the proportion of dislocation defects area is the proportion of dislocation defects pixels amount in the image. This paper counts defects pixels number by scanning counting method based on the binary image of dislocation defects, then calculates the ratio of dislocation defects pixels number in the total pixels number to obtain the proportion of dislocation defects area.

VI. Conclusions

Based on the silicon slice photoluminescence defect detection, and the analysis of photoluminescence image and dislocation defects, this paper proposes a method for defects segmentation based on curve fitting, progressive scan image to get grayscale curve of each row pixels, do curve fitting for the grayscale curve, then calculate segmentation threshold for each pixel based on each pixel corresponding fitted value to achieve the dislocation defects segmentation. Proves the quadratic curve fitting method is better by comparing the segmentation results of quadratic curve fitting and Gaussian curve fitting. Finally count the proportion of the defects area in silicon slice area by scanning counting method in the dislocation defect binary image, achieve the polysilicon slice dislocation defects automatic detection, and make the detection more accurate and efficient.

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