

Investigation of Electrochemically Etched GaAs (001) Surface with the Help of Image Processing

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Abstract: Surface morphology of GaAs (001) surface after electrochemical layer removal with the help of image processing was investigated. The surface pattern of GaAs shown fractal behaviour under non-selective etching conditions. The morphological surface study was carried out using digital image processing of scanning electron microscope data. The surface patterns were segmented by the so called grade of membership method. Fractal behaviour of the surface morphology was established using the box counting method.

Keywords: GaAs, surface morphology, electrochemistry, grade of membership fractal

1 Introduction and Experimental Preliminaries

GaAs (and related materials) – electrolyte interfaces are of great importance in their technology and measurement techniques. With the help of a transparent electrolyte, a Schottky-like contact can be created and an electrochemical process can be carried out at this contact. Therefore this junction can be used for wafer processing, for solar energy conversion devices and for different measurement techniques [1-9]. The kinetics of anodic dissolution is a very complex process. Its sophisticated nature and much of its properties and behaviour are not yet fully understood [3, 11]. This junction can be investigated not only by its dissolution kinetics, but the roughness and the pattern formation provides further information about the surface process, too.

In this work the non-selective etched GaAs (001) surface was investigated. The arrangement of our electrochemical measurement is the standard one used in electrochemical investigations. Different electrolytes were used varying polarization for selective anodic dissolution. For the investigation of the structure of the etched surface scanning electron microscopy (SEM) (JEOL JSM-20) were used. The typical SEM picture after layer removal (10 μm) (under anodic bias of 0.5 V) with electrolyte (36% HCL-methanol (1:99)) is shown in Fig. 1 (SEM-kep). Detailed description of the experiment is described in Ref. [11].

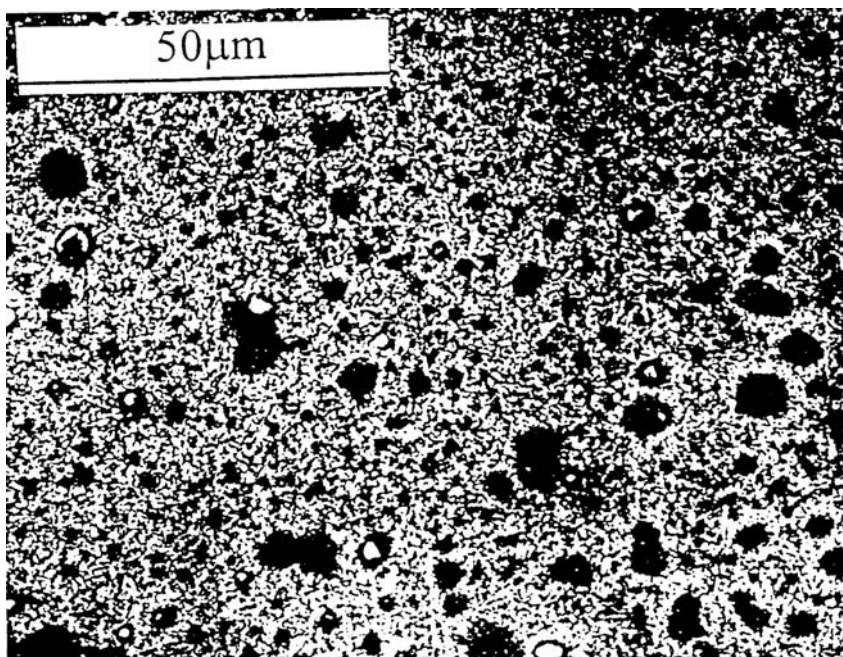


Figure 1

SEM picture of the morphology of GaAs surface after electrochemical layer removal (10 μm , 0.5 V anodic bias to SCE, (36% HCl: methanol (1:99)) electrolyte)

2 Image Processing of the Surface Pattern

The sample surface can be characterized not only by its roughness, but the pattern formation provides further information about the morphology, too. We will investigate the lateral distribution of the pattern formation of the surface. The surface morphology will be studied with the help of image processing, where the pattern recognition is carried out with the grade of membership method (GOFM).

One of the most important problems in analysis of the pictures is the segmentation of the clusters. The recognition of surface pattern formation is not a simple task. The etching pits are not deep, therefore the contrast is also weak and furthermore the background is generally non-uniform in the SEM pictures. This non-uniformity of gray shade on the pictures originates from the different secondary electron intensity, which depends on the surface morphology. These intensity differences have geometrical and material reasons, too. The deeper lying etched area has rougher surface and the surface state can be also different. The separation between the background and pattern formation is generally not possible with a simple choice of tonality threshold. This problem was solved by the help of GOFM [12].

The pictures were saved as bit map (bmp) files with 256 grayscale images. There were two or three patterns noticeable on the pictures. We have separated these patterns by the following so called GOFM function:

$$G_i(x) = \frac{1}{\sum_{j=1}^n \left(\frac{(x-v_j)^2}{(x-v_i)^2} \right)^{\frac{1}{m-1}}}$$

where variable x is the brightness value of pixel, v_i is the determined brightness at the cluster center of the i -th pattern. n is the number of clusters (usually two or three, in our case two $v_i = A$, $v_j = B$), m is the membership weighting exponent. The illustration of GOFM function is shown in Fig. 2. (GOFM-fv) If the function was greater then a p threshold, we said that the pixel belongs to the cluster.

The processed picture depends on the choice of the parameters A , B , m , p , so we have to determine these parameters. Change of the surface morphology can be shown in Fig. 2. The intelligent observer can distinguish the pattern from the background. We have made three independent attempts. Three researchers selected the clusters with a mouseclick, which determination was carried out with the help of computer program. (The characteristic grayscale in many places on the picture has been measured and have been to calculated their average for the determination of the tone value of background and pattern formation.) The three selected values were averaged for further data processing. (However the fractal dimensions which were determined one by one with these three values were very close to each other.) The determined average values were $A = 35$, $B = 119$. This determination was similar to that described in Ref. [13].

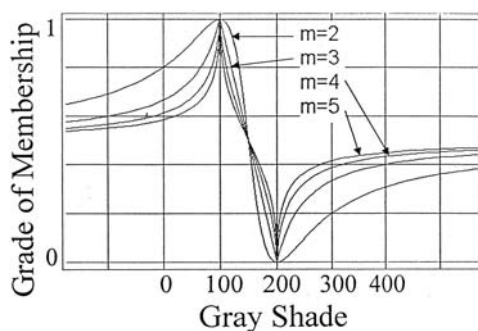


Figure 2

Illustration to the grade of membership method. Grade of membership versus gray shade (A = 100, B = 200) with the different values of parameter m .

The determination of the appropriate parameter m is a more simple problem. The pictures derived by GOFM under different p and m values were also compared visually to the original ones. We have compared the processed and the original pictures, and choose the most similar ones. The number of black pixels versus p at different values of the parameter m can be shown in Fig. 3. (threshold) In our case the most similar derived picture was using parameters $m = 2$ (p is about 0.4 which is determined exactly later), where is in saturation and does not change any more, while the picture obtained at different values remains parameter dependent. (This is a recursive process with the determination of the gray shade.)

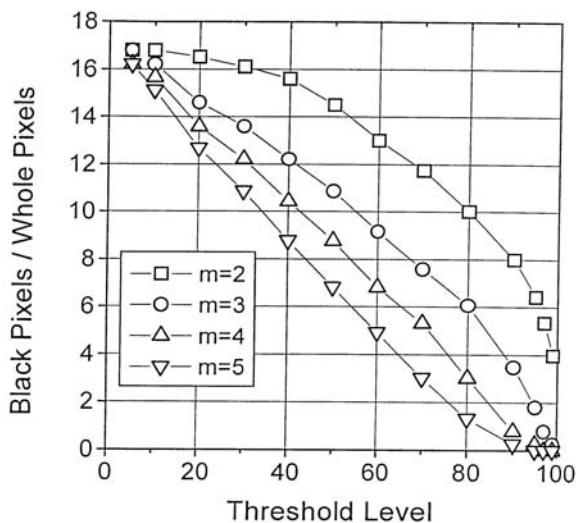


Figure 3

Choice of appropriate parameters for recognition of pattern formation. The number of black pixels versus threshold value p at different values of shape parameter m .

The accurate determination of the threshold value p was carried out with the help of segmentation. The histogram for number of pixels vs. gray shade can be shown in the upper left diagram in Fig. 4. (Segmentation) The segmentation and the quality of the picture can be characterized with the product of the histogram and the GOFM function. The GOFM function for our case ($A = 35$, $B = 119$, $m = 2$) can be seen in the upper right diagram in Fig. 4. In the ideal case for the determination of threshold value the function of segmentation must be two narrow Gaussian peaks, and the mean values equal with maximums [12]. Fig. 6 shows our resultant function of segmentation, from which can be determined the threshold value as $p = 0.5$. The peak which represents the pattern is not broad and the place of mean value (58) and the place of maximum value (57) are close. The square root of the variance of the segmentation function is 45. The GOFM and segmentation processed picture correspond also visually very well with the original picture.

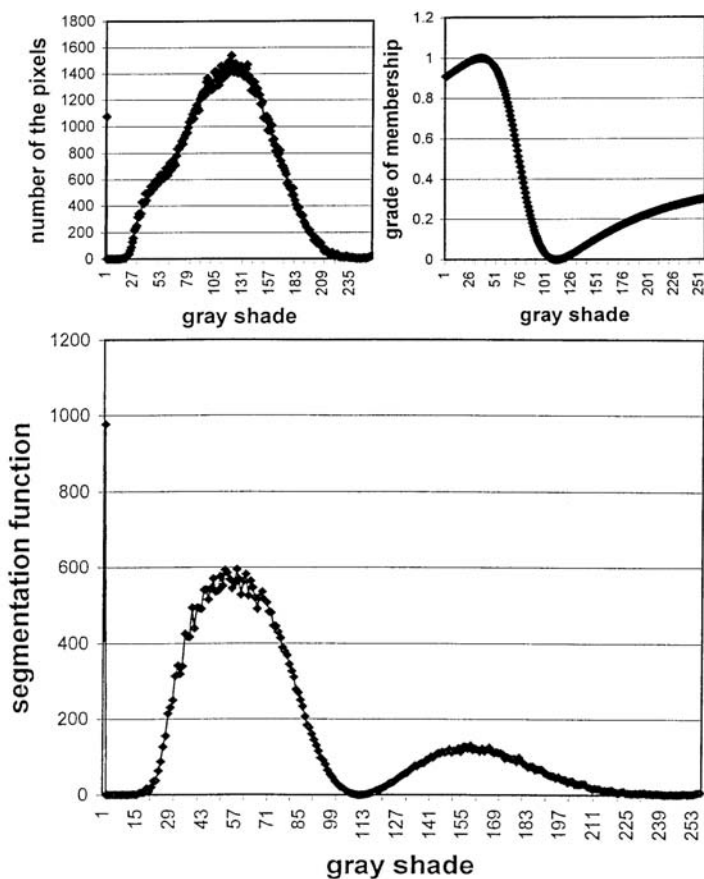


Figure 4

The threshold value p is determined with the help of segmentation. The function of segmentation originates from the product of histogram (upper left insert) and GOFM function (upper right insert).

3 Evaluation of the Processed Picture

We evaluated the surface pattern properties using the box counting method [14]. SEM was used for the investigation of the structure of the etched surface. The pictures of the surface patterns were digitised and analysed using high resolution bitmap. The size of the box ranged from two to hundred pixels. The self-similar behaviour was established using the processed image. This figure has the following parameters: background, pattern threshold and the value m are 35, 119, 0.5 and 2 respectively. The resolution was 1141x1489 pixels. These patterns showed a self-similar behaviour, because the curve of the average site number versus box size was found very closed to be linear. (The diagram has a light break point at larger box sizes.) The slope of the line (under break point) gives the actual fractal dimension $D = 1.59$. The error is 0.0631 and the correlation coefficient is 0.9987. Every etched surface exhibited fractal behaviour irrespective of the used three electrolytes and even under nonselective etching conditions. The fractal dimensions in these cases were about $D = 1.6$. The observed pattern formation shows self similarity through several orders of magnitude, but the behaviour of this self similarity at the larger box sizes slowly changes, which appears in the box diagram as a weak changing of slope. The slope of the line to the box size 30 is 1.59 (Figure 5). Up the box size 32 the slope of the line approach as two, which refers to the homogeneity of the picture. The reason of this behaviour comes from this method. The picture was processed with the help of periodic boundary conditions. If the box hang out from the picture, the picture is continued with its replica, so we can say that the picture from a far view is homogenous, which means two dimension.

The application of the novel GOFM method for the recognition of the surface pattern formation demonstrates that the surface morphology after non-selective electrochemical layer removal shows fractal behaviour. In this case the generation of dissolution centers is not in correlation with the crystal defects like in the case of low and high current. But their generation is random. This etching mode is just the reverse process of the crystal growth of the stepless surface, which also exhibits fractal behaviour.

Conclusion

The obtained electrochemically etched GaAs (001) surface pattern formation was investigated by GOFM method and the self-similar behaviour was investigated by box counting method. The generation of dissolution centers is randomly distributed (and not correlated with the crystal defects), which is inverse of the stepless growth mode, so the surface pattern shows self similarity. Both the composition and the decomposition of the crystal develop fractal features.

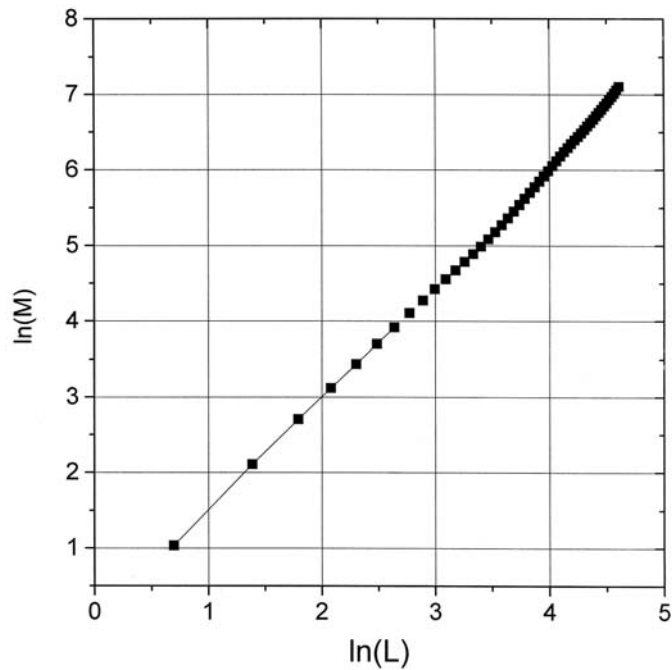


Figure 5

The average site number vs. box size curve at GaAs surface. The slope of the line gives the fractal dimension, actually $D = 1.59$.

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