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A study on the distribution of stress in thin epitaxial GaN on patterned silicon substrate

Tasnia Hossain[1*], M. J. Rashid[2], M. R. Alam[3]

[1]Department of Electrical and Electronic Engineering, University of Asia Pacific, Dhaka, Bangladesh
[2]Department of Electrical and Electronic Engineering, University of Dhaka, Bangladesh
[3]Department of Electrical and Electronic Engineering, Hamdard University, Narayanganj, Bangladesh

*Corresponding Author, Email: tasnia@uap-bd.edu

Abstract: The stress distribution of thin epitaxial GaN on patterned silicon substrate is studied here. The calculation is made according to the acknowledged model of Fischer and Richter for stress relaxation of thin film. Here the stress distribution of thin GaN layer on patterned silicon from one edge to another edge as a function of distance is shown. To study the stress distribution on the GaN layer we have varied the width of the stripe, GaN film thickness and trench height of the stripe. A large influence on the stress distribution has been observed due to the variation of the width and trench height of the stripe but the film thickness considered here does not show significant effect on the stress distribution of the stripe.

Keywords: GaN epitaxy, patterned silicon substrate, stress distribution, thin film.

Introduction

In semiconductor devices, epitaxial layers are mostly grown on non-native substrate and it is well known that, the grown layers are under either in tensile or compressive stress. Depending on their stress state, the device performance can be varied significantly in different region of the same sample. This effect can make the devices unreliable to the users. Therefore the study of the stress state of the epitaxial layer is very important, specially to understand the behavior of the device. Devices based on group-III nitride are of strong interest to develop light emitting diodes and laser diodes due to their visible and near UV spectral range [1,2,3]. However due to the lack of native substrates, GaN epilayers are mostly grown on foreign substrates. Silicon as a substrate is very attractive due to its relatively low cost, availability of large diameter wafer, the existence of well developed Si-removal process and potential integration between GaN based devices and Si technology. However, the disadvantage to grow GaN on Si is the large lattice mismatch of GaN with silicon (17%) and their large difference in thermal expansion co-efficient (~56%). The large lattice mismatch leads to the formation of dislocations and their difference in thermal expansion co-efficient induces a large tensile stress while cooling down to room temperature from the growth temperature. Due to the large tensile stress, cracks occur over critical thickness. In order to grow crack free GaN on Si, several works have been done [4-9]. Use of patterned substrate is one of the approaches to reduce the stress to obtain crack free GaN [6-9]. However, due to the different geometry of the patterned devices, the edge effect can induce local stress. Therefore, stress analysis is very important for the patterned devices. A large number of works has been done on the stress analysis. Some analytical model has been developed to simulate the stress on the patterns [10-13]. Among these we will use Fischer and Richter's model which was developed to see the effect of stress for stripes of thin films. This model is mainly based on Hu's model [10] which describes the edge effect of the patterns. In this paper, we will calculate the normalized stress of GaN grown on stripe pattern of silicon substrate using the model of Fischer and Richter [13]. The calculated stress distribution will be shown for different widths of the stripe, film thickness on the patterned stripe and trench heights of the stripe.

Analytical model

The analytical model of Fischer and Richter presents the stress distribution of a stripe pattern. It is mainly based on Hu's model [10] which describes the stress effect of edges of the patterned samples. Here the stripes are of infinite length. According to the model of Fischer and Richter [13], the stress distribution across the stripe of width A (in-plane axis a) is obtained and it can be written as,

$$f(a)=\frac{\sigma_1}{\sigma_x}=1-\exp\left\{-\left[\frac{2Ka}{\pi(h+KH)}\right]^{\frac{1}{2}}-\exp\left\{-\left[\frac{2K(A-a)}{\pi(h+KH)}\right]^{\frac{1}{2}}\right\}\right\} \qquad (1)$$

Here the normalized stress is derived for the film on the patterned stripe (Fig. 1) where σ_1 and σ_x are the stress across the stripe and the maximum stress of the stripe, respectively. Film thickness is *h* and trench height of the patterned substrate is *H*. Here, *K* is the relative rigidity between the film and the substrate which is represented as,

$$K = \frac{E_s(1-\nu_f^2)}{E_f(1-\nu_s^2)} \qquad (2)$$

where E is the Young's modulus and ν is the Poisson's ratio where the subscript f and s mean the film and the substrate, respectively.

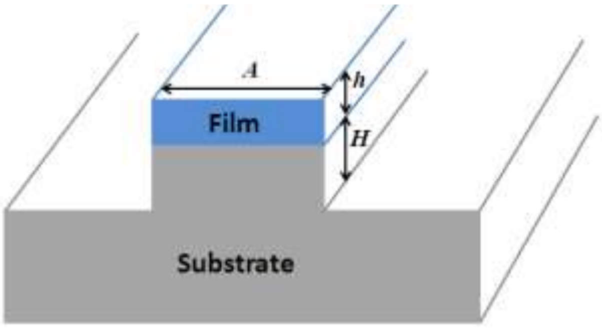


Figure 1. The thickness of the film is *h* shown on the patterned stripe whose height is *H*.

In this paper, the stress distribution of GaN on patterned silicon stripe is calculated using equation (1). The relative rigidity K is calculated from equation (2) using the values of E and ν for GaN and Si as given in Table-1.

Table-1: Values of E, ν and K

	E	*N*	*K*
GaN	196 [14],[15]	0.53 [15]	0.71
Si	169 [16]	0.36 [16]	

Results and Discussion

Normalized stress is calculated for GaN grown on Si stripes (Fig. 2) for different widths of stripe, different thickness of GaN film and different trench heights. In Fig. 2 the stress distribution from one edge to another edge of different widths (A) of stripes such as 5 µm, 10 µm, 20 µm, 40 µm, 100 µm are shown.

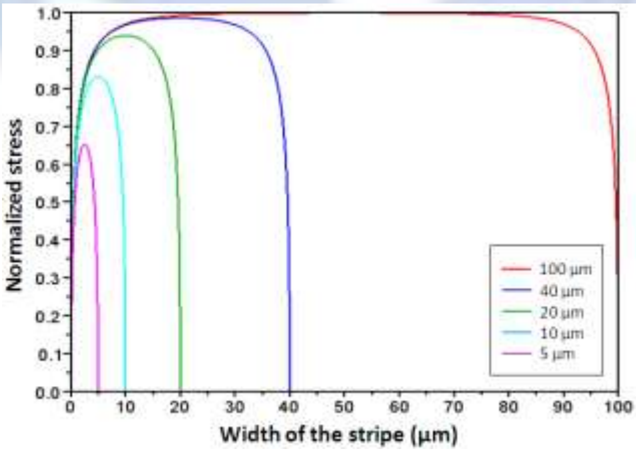
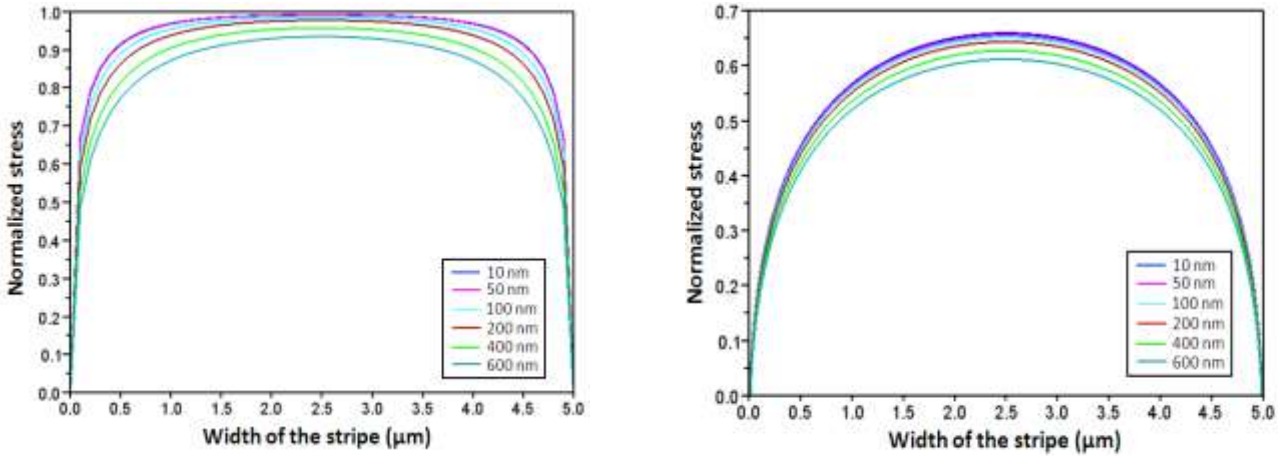


Figure 2. Stress distribution of different widths of stripes (Trench height of Si: 5 µm and GaN film thickness: 100 nm).

Here the GaN film thickness is 100 nm and the trench height of silicon substrate is 5 µm. In Fig. 2, we can see the inverted U shape stress distribution of different widths of stripes where the maximum stress occurs at the center of each stripe and it relaxes near the edges. It is also observed that with the increase in the width of the stripe the maximum stress increases and the relaxation length decreases. In the case of smaller size stripe, the stress is reduced more through the edges than the larger size stripes. Therefore, in the case of 5 µm width of stripe the stress at the center is reduced more through the edges than the 100 µm width of stripe.



(a) **(b)**

Figure 3. (a) Stress distribution of the stripes for different GaN film thickness (a) Width of the stripe: 5 µm and trench height of Si: 0.5 µm, (b)) Width of the stripe: 5 µm and trench height of Si: 5 µm

In Fig. 3(a) and 3(b), the stress distributions across the width of the stripe for different thickness of GaN are shown. In Figure 3(a), width of the stripe is 5 µm and trench height is 0.5 µm and in Figure 3(b), trench height is increased to 5 µm. In both cases, the film thickness is varied from 10 nm to 600 nm. In Figure 3(a) and (b) we can see the inverted U shape stress distribution of the stripe where the maximum stress occurs at the center and with the increase of the thickness of GaN, a small amount of stress is reduced. However, we do not see significant variation in the stress level due to the variation of GaN film thickness from 10 nm to 600 nm. This is also true for the case of 5 µm trench height. But in this case, the maximum stress level is reduced compared to 0.5 um trench height. Therefore, it is clear that the trench height has large influence on the reduction of stress.

In order to see the effect of trench heights, we have considered 100 nm thick GaN and the width of the stripe is 100 µm. In Fig. 4, we can see the stress distribution of the stripe for different trench heights (such as 100 nm, 200 nm, 500 nm, 1 µm and 5 µm) of the stripe. In this case also, we can see the similar inverted U shape stress distribution. The maximum stress reduces with the increase in the trench height. This is likely due to the fact that, the increase in trench height leads to more free areas at the edge of the silicon substrate. Therefore, the free areas of the edge existing around the patterned Si substrate effectively release the stress of the substrate as well as the film.

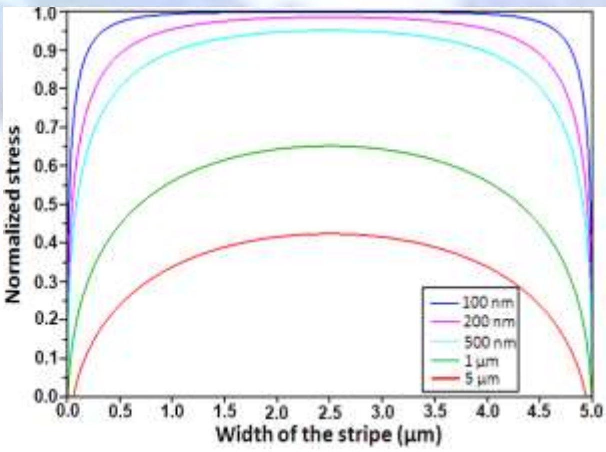


Figure 4. Stress distribution of the stripe for different trench heights (Width of the stripe: 5 µm and GaN film thickness: 100 nm).

Conclusion

The stress distribution on a GaN film on a stripe pattern of silicon substrate is studied here and the inverted U shape stress distribution is observed. It is found that the maximum stress occurs at the center of the stripe and the stress near the edge is relaxed. It is also observed that the size of the stripe and the trench height of the stripe have a large influence on the stress of the stripe. With the increase in the width of the stripe, the stress increases and a large amount of stress can be reduced by increasing the trench height of the stripe. However, it is also observed that the increase in film thickness has small effects on the stress of the GaN film.

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