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Effect of microwave radiation on optical transmission spectra in SiO_2/SiC structures

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Abstract. We investigated the effect of microwave radiation on absorption spectra (in 400–800 nm range) and curvature radius of SiO_2/SiC structures obtained using traditional thermal oxidation in water vapor at the temperature of 1373 K and rapid thermal annealing in dry oxygen at 1273 K. From an analysis of the sample optical density and radius of curvature variations with total duration of microwave action, we concluded that the structures obtained using rapid thermal annealing are more stable against microwave action.

Keywords: SiO_2/SiC, rapid thermal annealing, traditional thermal oxidation, optical density, microwave action, radius of curvature.

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1. Introduction

Presence of localized states in an insulator layer and at insulator/semiconductor interface determines, to a great extent, stability and reliability of devices based on metal-insulator-semiconductor structures. This factor becomes of particular importance for the silicon-carbide-based device structures, because they are intended for operation at higher temperatures than those based on silicon and gallium arsenide. Therefore, search for ways to exert control over the SiO_2/SiC interface properties is urgent.

In this work we used microwave annealing as a factor acting on the properties of the SiO_2/SiC interface.

2. Sample preparation and investigation technique

We studied the optical transmission spectra and radii of curvature of SiO_2/SiC structures obtained by oxidation of Lely-grown *n*-6H-SiC. The free electron concentration was ~10^{18} cm^{-3}. The following two techniques were used for silicon carbide oxidation: (i) traditional thermal oxidation in water vapor for 30 to 180 min. at the temperature T = 1373 K, and (ii) rapid thermal annealing (RTA) in dry oxygen for 60 to 180 s at T = 1273 K. The obtained SiO_2/SiC structures were exposed to repeated microwave annealing in a magnetron processing chamber (frequency f = 2.45 GHz, irradiance of 1.5 W/cm^2).

The transmission spectra in the 400–800 nm range were registered with a SDL-2 plant at the room temperature. A spectral lamp SIRSH-200 served as a continuous spectrum source.

3. Experimental results and discussion

Table 1 presents radii of curvature R (measured on the (0001) face side) of different SiO_2/SiC structures as a function of total time of exposure to microwave radiation t_T. The structures obtained with traditional thermal oxidation in water vapor at 1373 K (samples-I) appeared to be more sensitive to microwave radiation; the degree of R changing with t_T is proportional to duration of initial sample oxidation. Contrary to this, for the samples obtained using RTA in dry oxygen at T = 1273 K (samples-II) the radii of curvature practically did not depend on t_T.

A typical dependence of optical density (OD) of SiO_2/SiC structure (the initial sample) on the wavelength at T = 300 K is presented in Fig. 1. SiO_2 films are transpar-

Table 1. Radii of curvature R (measured on the (0001) face side) of different SiO_2/SiC structures as a function of total time of exposure to microwave radiation t_T.

Sample preparation and their number	Total time of exposure to microwave radiation t_T, s	Radius of curvature R, m
traditional thermal oxidation for 30 min., #1	0	9
	10	9
	30	8
	40	8.6
traditional thermal oxidation for 60 min., #2	0	1.4
	10	1.2
	30	3.35
	40	1.3
traditional thermal oxidation for 120 min., #3	0	4.1
	10	1.4
	30	1.5
	40	1.9
traditional thermal oxidation for 180 min., #4	0	16.8
	10	14.7
	30	31
	40	8
RTA for 60 s, A	0	0.5
	10	0.6
	30	0.5
	40	0.5
RTA for 180 s, B	0	0.6
	10	0.7
	30	0.75
	40	0.8

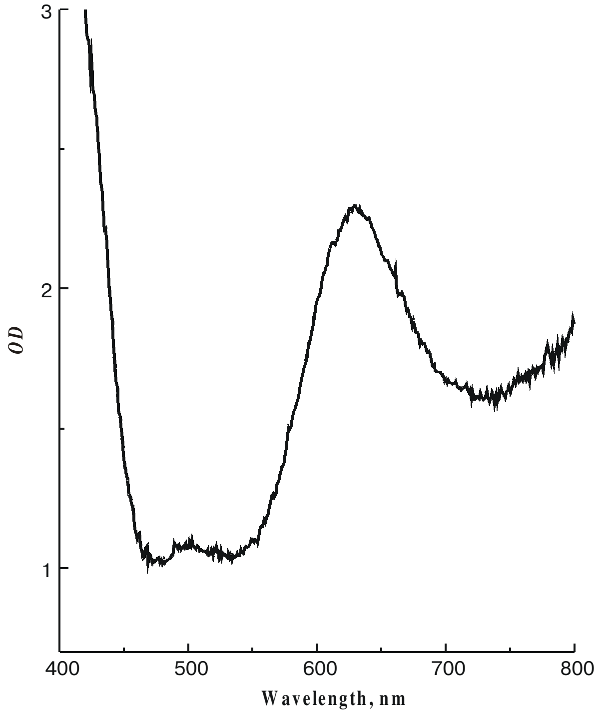

Fig. 1. Typical OD dependence on wavelength for the initial SiO_2/SiC sample taken at T = 300 K.

ent in the 400–800 nm wavelength range. So, the absorption spectrum of SiO_2/SiC structure is due mainly to absorption in SiC bulk and at the SiO_2-SiC interface. An absorption peak observed at 630 nm (Fig. 1) may be related to the ground state of donor centers resulted from presence of nitrogen impurities in silicon carbide crystals [1-4].

It was found that SiO_2/SiC demonstrated different dependences of the OD spectra on t_T, depending on the technique used for structure oxidation. For the samples-I, the OD dependence on t_T is shown in Fig. 2 (for the band with a peak at 630 nm). One can see that for all the samples studied the intensity of the above absorption band decreased after exposure to microwave radiation during 10 s. At recurrent microwave action the intensity of the 630 nm absorption band practically did not change for the samples whose oxidation times were 30, 60, and 180 min. (Fig. 2, curves 1, 2, and 4), while for the sample whose oxidation time was 120 min. (Fig. 2, curve 3) the absorption band intensity decrease continued.

Next stage of microwave treatment results in increase of the absorption band intensity practically up to the initial value. For the sample whose oxidation time was 120 min. the absorption band intensity after total exposure to microwave radiation for 30 s becomes even higher than its initial value. Further t_T increase up to 40 s results in

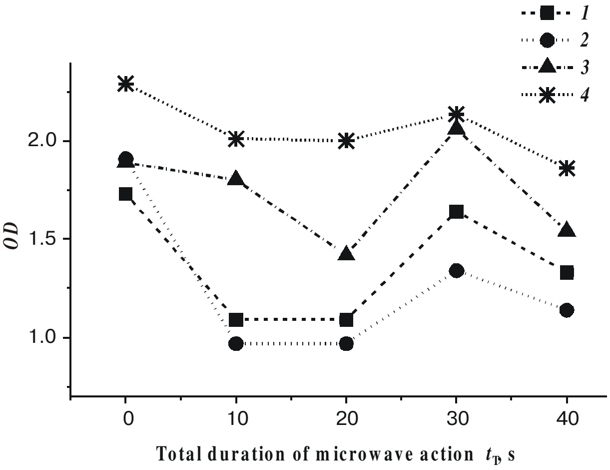

Fig. 2. OD dependence on total duration of microwave action t_T (the 630 nm absorption band) for the samples-I. Oxidation duration: *1* – 30 min., *2* – 60 min., *3* – 120 min., *4* – 180 min.

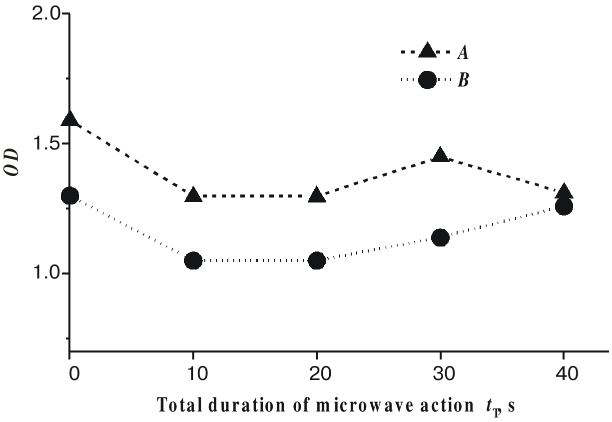

Fig. 3. The same as in Fig. 2 but for the samples-II. Annealing duration: A – 60 s, B – 180 s. (total duration of microwave action t_T, s – OD)

decrease of the absorption band intensity, which becomes comparable to that after $t_T = 20$ s. One can see from Fig. 2 that the smallest departure of the absorption band intensity from its initial value is observed in the case when oxidation duration for the SiO_2/SiC structures-I was 180 min.

The OD dependences (for the 630 nm band) on total duration of microwave action for the samples-II shown in Fig. 3. One can see that the dependence observed at $t_T \leq 30$ s is similar to that for the samples-I oxidized during 180 min. at $T = 1373$ K (Fig. 2, curve 4): a small OD decrease (increase) at total duration of microwave action of 10 and 20 s (30 s).

Some distinctions are observed in characteristics of different samples-II at $t_T = 40$ s. For the sample annealed during 60 s (Fig. 3, curve A) the intensity of absorption band somewhat drops, while for that annealed during 180 s (Fig. 3, curve B), it is practically the same as the initial one.

One can see from Figs 2 and 3 that samples-II demonstrate maximal tolerance for microwave action (Fig. 3, curves A and B). The samples-I, oxidation duration of which was maximal, demonstrate the highest stability against microwave action (Fig. 2, curve 4). It can be seen from their optical transmission spectra.

The dependence of the 630 nm band half-width on total duration of microwave action is presented in Fig. 4. Contrary to the situation with the same dependence of the band intensity, here one cannot name some trend that would be common for all the samples studied. For the samples-I oxidized during 30 and 60 min. (Fig. 4, curves 1 and 2) the above dependence quantitatively resembles a similar dependence of intensity: first, some decrease of the band half-width with t_T is observed, then it slightly grows, and, at further t_T increase up to 40 s, the band half-width decreases again. For the samples-I oxidized during 120 and 180 min. (Fig. 4, curves 3 and 4), the dependence of the 630 nm band half-width on total duration of microwave action is somewhat different. When $t_T = 10$ s, then the band half-width slightly grows; at further t_T increase up to 30 s it goes down, and at $t_T = 40$ s the band half-width slightly increases again. For the samples-II oxidized during 60 s (Fig. 4, curve A) and 180 s (Fig. 4, curve B) the above dependence of the band half-width is non-monotone.

According to [1-4], the 630 nm band stems from photoionization of three nonequivalent nitrogen donors nearest neighborhood coordinations of which are hexagonal and cubic. This band actually involves three close bands that merge into a single broad band [4]. Microwave action can lead to fluctuations of nonuniformity of dopants and defects distribution at the structure surface and in the bulk [5]. Variation of nitrogen impurities distribution over the silicon carbide crystal bulk may result in changing the character of inter-impurity interaction

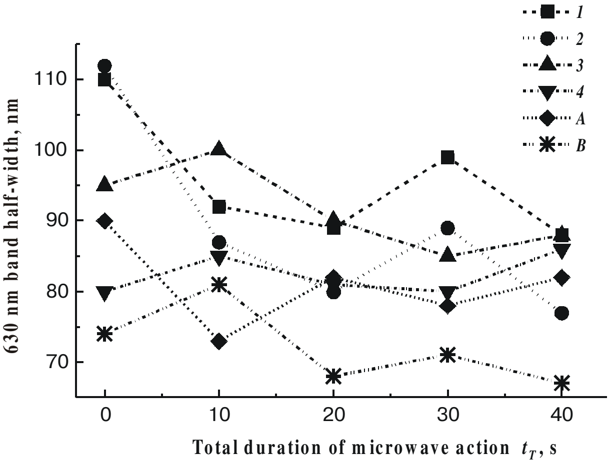

Fig. 4. Dependence of the 630 nm band half-width on total duration of microwave action t_T. *1–4* – for structures-I; oxidation duration: *1* – 30, *2* – 60, *3* – 120, *4* – 180 min. A, B – for structures-II; annealing duration: A – 60, B – 180 s.

for centers of absorption [6] and, consequently, changing intensity of the observed absorption band. Variation of defects distribution over the sample exposed to microwave radiation can result in changing the absorption band half-width, similarly to the case of the diffraction reflection curves [7]. Besides, (dis)appearance of structural defects under microwave action may be accompanied with changes in symmetry of the nearest neighborhood of single nitrogen atoms thus, resulting in redistribution of intensities of the individual bands that make the 630 nm band. This, finally, will cause changes in both half-width and intensity of the resulting band.

Presence of three nonequivalent absorption centers enables one to assume that they will demonstrate different degrees of tolerance for microwave action. Nonmonotonic character of the absorption band intensity and half-width dependences on total duration of microwave action may result from redistribution of donors due to their different interactions with microwave radiation. It is believed that most stable against microwave radiation are the samples containing predominantly the donors whose interaction with microwave radiation is the weakest. The character of dependences of the 630 nm band intensity and half-width on total duration of microwave action evidences that such samples are those obtained using RTA in dry oxygen at $T = 1273$ K.

4. Conclusion

We investigated the effect of microwave radiation on radii of curvature, as well as on intensity and half-width of the 630 nm band, of the SiO_2/SiC structures obtained using silicon carbide oxidation in two different ways: (i) traditional thermal oxidation in water vapor at a temperature of 1373 K and (ii) rapid thermal annealing in dry oxygen at 1273 K. From the experimental results obtained, one can conclude that the structures prepared using technique (ii) are more stable against microwave action.

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