Semiconductor Physics, Quantum Electronics & Optoelectronics. 2001. V. 4, N 4. P. 298-300.

PACS 61.76.C, 73.40.K, 84.40

Ordering of lateral nonuniformity of TiB_x film and transition layer in the TiB_x-GaAs system

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Abstract. For TiB_x film ~50 nm thick formed by magnetron sputtering from a pressed target onto the <100> GaAs substrate we experimentally revealed lateral nonuniformity ordering at microwave irradiation (frequency of 2.45 GHz, illuminance of 1.5 W/cm^2). This correlates with improvement of the TiB_x-n-n^+-GaAs diode structure parameters after similar microwave treatment.

Keywords: microwave treatment, interface, TiB_x film, gettering.

Paper received 08.07.01 ; revised manuscript received 05.12.01; accepted for publication 12.12.01.

1. Introduction

Interactions between phases in metal-semiconductor contacts are studied in connection with the problem of reliability of a wide range of semiconductor devices. This problem is related to the properties of metal-semiconductor interfaces (primarily, transition layers). A number of papers, both theoretical and experimental, dealt with various external actions (thermal and radiation treatments) on the contacts, as well as with different technological procedures (conditions of treatment of initial surfaces and sputtering modes). It was shown that the above factors favor ordering of structural-impurity nonuniformities in contacts. They also result in banded contrast formation at metal-semiconductor interfaces and reduce intrinsic stresses in the systems studied [1–6].

Here we present some results of our investigation of the effect of microwave treatment on structural relaxation in TiB_x films on single-crystalline GaAs substrates, at TiB_x-GaAs interface and in the Au-TiB_x-n-n^+-GaAs surface-barrier structures.

2. Preparation of samples

The contacts were formed using TiB_x magnetron sputtering from a pressed target onto a single-crystalline n-GaAs substrate (concentration of tin impurity was 4×10^{17} cm^{-3}). The substrate was previously cleansed in hydrochloric acid and washed in deionized water. The TiB_x film thickness was 50 nm. The Au-TiB_x-n-n^+-GaAs diode structures were 500 μm in diameter. The n- (n^+-) layer thickness was 5 (300) μm; the free electron concentration in the n- (n^+-) layer was ~2×10^{17} (~2×10^{18}) cm^{-3}.

Some samples were exposed to microwave radiation (frequency of 2.45 GHz, illuminance of 1.5 W/cm^2) for 1–10 s. The morphological investigations were made using atomic force microscopy. The properties of transition layers were studied with surface-barrier electroreflectance (SBER). Both before and after microwave treatment we took the I–V and C–V curves for the barrier structures studied.

3. Results and discussion

The structural investigations have shown that the TiB_x films obtained were amorphous. The initial surface of films demonstrated weak periodic relief (of nonuniform height) as a set of parallel bands along the <111> direction (Fig. 1a). This resist indicated at some stress relaxation in the TiB_x film that occurred during deposition of quasi-amorphous TiB_x film and formation of a transition layer. This layer had a complex composition. It involved oxides of titanium, gallium and arsenic, as well as pure boron and B_2O_3. In [7] it was shown that it also involved solid solution $B_xGa_{1-x}As$. According to the Auger analysis, the initial TiB_x film contained, along with chemically bound boron (TiB_x), also pure boron and B_2O_3. The above factors led to nonuniform relief for the initial structures. Microwave irradiation of the initial samples for 10 s resulted in a uniform height of the banded relief (see Fig. 1b).

In the earlier paper [4], such banded contrast was observed for the transition layer of the AuGe-GaAs ohmic contact. The radiation-field treatment of that contact resulted in ordering of lateral nonuniformity and enhancement of banded contrast. The authors of [4,6] have advanced a model for partial relaxation of intrinsic strains due to appearance of periodic structure and radiation-induced Ge mass transport in the elastic stress field. It seems to us that in the present work we observed similar effect for the TiB_x-GaAs contact. This effect was enhanced by the microwave treatment and, possibly, radiation-induced boron mass transport. In our case (contrary to [4,6]), separation into layers was observed for the TiB_x film, thickness of which was 50 nm. It should be noted that possibility of boron mass transport into the GaAs near-contact layer due to rapid thermal annealing of the TiB_x-GaAs contact was noted in [8].

A periodic banded nonuniformity is known [1–3,5] to change the intrinsic strains in the metal-GaAs system. They relax along some direction; this is accompanied by change in the system curvature. Indeed, as was shown in our investigations, the initial system curvature was essentially nonuniform. It was not possible to perform a correct estimation of it. After microwave treatment for 10 s the system curvature was ~14.5 m^{-1} (its initial value was ~7.5 m^{-1}). The above-said is confirmed by Fig. 2. It presents the profiles for the TiB_x-GaAs system both before and after microwave irradiation for 10 s.

According to [5], minimum of free energy could be achieved at periodic distributions of impurity concentration and strain. Therefore, the separation into layers that we observed in the TiB_x film exposed to microwave irradiation could be preferable from the energy viewpoint.

On the other hand, the relaxation processes enhanced by microwave treatment occur at the TiB_x-GaAs interface, too. This is evidenced by the surface-barrier electroreflectance (SBER) spectra presented in Fig. 3. One can see that the initial spectrum (curve 1) is substantially smeared. It seems to result from disordering of the interface and transition layer localized in the GaAs near-contact region. Microwave treatment leads to a considerable increase in the band intensity and makes the spectrum structure substantially simpler. This is characteristic of structural-impurity ordering.

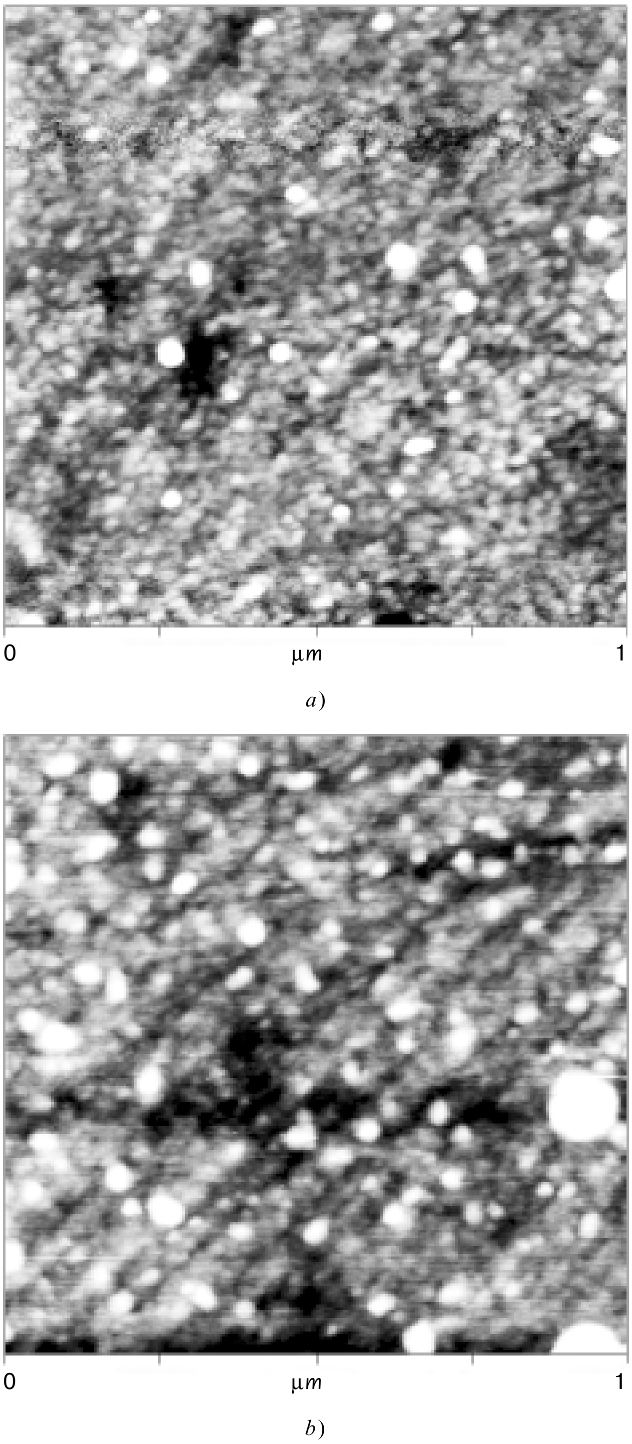

Fig. 1. Surface morphology of TiB_x film: *a* – initial; *b* – after microwave treatment for 10 s. The height range is 5 nm.

The above results are supported by the fact of improvement of the TiB_x-n-n^+-GaAs diode structure parameters due to microwave treatment (see Table 1). One can see that even exposure to microwave irradiation for 0.5–

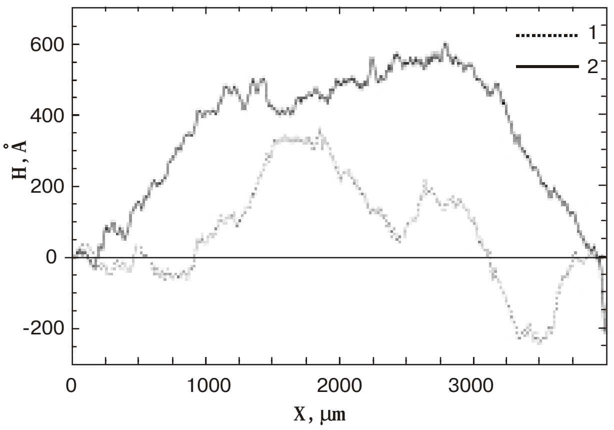

Fig. 2. Profiles of TiB_x-GaAs structure: *1* – initial; *2* – after microwave treatment for 10 s.

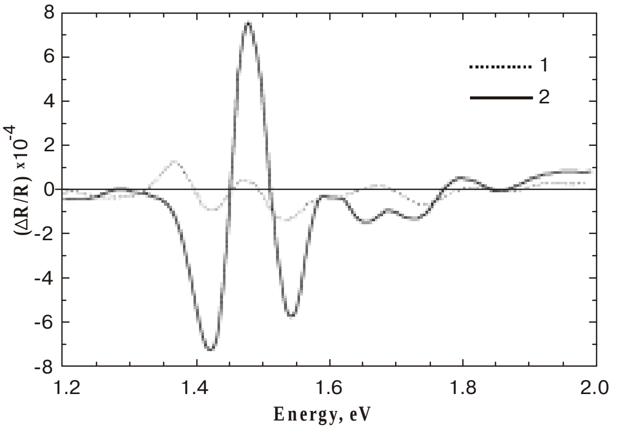

Fig. 3. SBER spectra of TiB_x-GaAs structure: *1* – initial; *2* – after microwave treatment for 10 s.

1 s is sufficient for reduction of the reverse current of thermal-generation nature (that varies in inverse proportion to the minority charge carrier lifetime). Microwave treatment enhances gettering; as a result, the collision line-broadening decreases. This serves as evidence for both decrease of the scattering center concentration in the semiconductor near-surface layer and, correspondingly, increase in the effective lifetime of the minority charge carriers. When duration of microwave treatment is increased to 3–10 s, then the reverse current drops by more than an order of magnitude. In this case the Schottky barrier height φ_b somewhat grows and ideality factor n decreases.

Conclusion

The presented experimental data enable one to conclude that microwave treatment induces stressed state relaxation in the TiB_x-GaAs and TiB_x-n-n^+-GaAs systems through separation into layers of the TiB_x film and structural-impurity ordering of uniformities in the transition layer and GaAs near-contact region.

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Table 1. The surface-barrier structure parameters before and after microwave treatment.

Parameters	Duration of microwave treatment, s							
	0	0.5	1	2	3	5	6	10
Barrier height φ_b, V	0.78	0.81	0.79	0.8	0.82	0.82	0.82	0.82
Ideality factor n	1.3	1.27	1.3	1.2	1.15	1.15	1.15	1.15
Reverse current I_R, A	2×10^{-8}	10^{-8}	10^{-8}	7×10^{-9}	10^{-9}	10^{-9}	10^{-9}	10^{-9}
Radius of curvature R, m	7.5	8.0	6.0	12.2	12.0	15.0	∞	∞