ELECTRICAL AND PHOTOLUMINESCENCE PROPERTIES OF BULK GaAs AFTER SURFACE GETTERING

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ABSTRACT

The successful results on surface gettering of background impurities and defects in 1.6 mm thick (111) GaAs wafers have been obtained. For the gettering, the wafers were coated by a 1000 Å thick yttrium film either on one side or on both sides followed by a heat treatment. It has allowed the electron concentration to decrease from (1–2)´10^{15} *cm*$^{-3}$ *down to* 10^{8}–10^{10} *cm*$^{-3}$ *and the mobility to increase from 1500–2000 cm*^{2}*V*$^{-1}$*s*$^{-1}$ *up to 7000 cm*^{2}*V*$^{-1}$*s*$^{-1}$ *at 300 K. The distribution profiles of the electron concentration and of the hole effective lifetime throughout the wafer thickness as well as photoluminescence spectra at 2 K have been presented.*

INTRODUCTION

For the last decades the development of power devices, optoelectronic integral circuits, irradiation (X- and γ-rays) and particle (including solar neutrino) detectors has been stimulating widespread investigations of undoped and semi-insulating bulk GaAs. To improve the device characteristics, the GaAs wafers are required with the low carrier concentration below 10^{13} cm^{-3} and with the uniform carrier distribution throughout volume.

For this purpose, ultra-high pure gallium and arsenic with purity of 99.99999 are generally used (Markov et al (1)) to increase both resistivity and charge carrier mobility in GaAs wafers. However, even so, an uniform distribution of these characteristics in bulk GaAs crystals is not always obtained. Their spread is 30 percent from crystal to crystal. The non-reproducibility is associated with native defects, which determine electrical and optical properties, when the concentration of background shallow impurities is less than 10^{15} cm^{-3}.

In the present paper the surface gettering technique (Shmidt et al (2), Vlasenko et al (3,4)) has been applied to obtain the ultra-high pure (111) GaAs wafers with thickness of 1.6 mm.

EXPERIMENT

The undoped (111) GaAs crystals with the electron concentration of (2–3)×10^{15} cm^{-3} and the electron mobility of 1500–2000 cm^{2}V^{-1}s^{-1} at 300 K, which were grown by the LEC Czochralski method (Markov et al (1)) from gallium and arsenic with the 7N purity, were used as an initial material. In this case Shmidt et al (2) and Vlasenko et al (3) showed that the carrier concentration was determined by the shallow donor level with the activation energy (E_a) of 10–12 meV and of the deep donor level with $E_a \sim 150$ meV. The compensation degree was 40 percent and was likely to depend on the concentration of native defects and of their complexes.

For gettering, the wafers were coated by a 1000 Å thick yttrium film either on one side (the one-side coating – OSC) or on both sides (the two-side coating – TSC) using the vacuum deposition technique. Thereafter the wafers were heat treated in ambient pure hydrogen in various temperature-time regimes. The Y films were etched in plasma after the heat treatment (HT).

The carrier concentration in the gettered wafers was determined both by the C–V method using a Hg-GaAs Schottky barrier and by the Van-der-Pauw measurements. The distribution of the carrier concentration was obtained with a use of both *C-V* electrochemical (Reichman (5)) and photoelectrochemical (Andrievskii (6)) profiling. The solution of H_2SO_4:H_2O_2:H_2O (1:8:1) was applied as the electrolyte-etchant. Under illumination of the GaAs-electrolyte interface with the light at hν>E_g, the photocurrent, which was proportional to the hole effective lifetime (Sze (7)), arose in the system. Therefore, the relative distribution of the hole effective lifetime throughout the wafer thickness was obtained from the photocurrent data. The photoluminescence investigations at 2 K were carried out using the conventional technique.

RESULTS AND DISCUSSION

A preliminary investigation on the carrier concentration distribution was carried out using the C-V method with the layer-by-layer etching in the etchant H_2SO_4:H_2O_2:H_2O (1:8:50). The etching rate was 1000 Å min^{-1}. The investigation showed that, after HT at 800 °C in 0.25 h followed by the plasma removal of the Y film, the wafer had a 0.5 μm thick near-surface layer of p-type conductivity with $p \cong 10^{16}\,cm^{-3}$. At the same time in the case of the OSC-gettering, the uncoated GaAs surface had the near-surface layer of p-type conductivity with $p \cong 10^{17}\,cm^{-3}$. The thickness of the layer was several microns. At more depth, the inversion of the type conductivity took place from both sides of the wafer. As the result, the electron concentration was about 10^{13} cm^{-3} and below.

The analogous investigation were carried out after HT at 700 °C in 0.25 h. In this case both surfaces after the Y film removal (the TSC gettering) as well as the uncoated surface (the OSC gettering) had the n-type near-surface layer with $n \cong 10^{13}$–$10^{14}\,cm^{-3}$. The thickness of the layer was several microns. At more depth, the electron concentration decreased to 10^{12} cm^{-3} and below depending the HT duration.

The in-depth distributions of the N_d-N_a concentration and of the hole effective lifetime were studied by the photoelectrochemical profiling from the side of both coated (after the Y film plasma removal) and uncoated surfaces. The distribution profiles of the N_d-N_a concentration are presented in Fig. 1 after the TSC and OSC gettering at 800 °C and 700 °C. The corresponding distribution profiles of the hole effective lifetime (τ_{eff}) are shown in Fig. 2.

Surprisingly, all profiles (both N_d-N_a and τ_{eff}) are nearly constant after the TSC and OSC gettering. Therefore, the gettering is of volume character, even though one surface is coated with the Y film. The uncoated surface is likely to make its own contribution to the effect. As evident from Fig. 2, τ_{eff} after HT at 700 °C is more than the one after HT at 800 °C by 30 percent.

The results given above allow the conclusion to be made that the HT temperature of 700 °C is the threshold of the efficient gettering beginning. Moreover, anti-site defects As_{Ga} and Ga_{As} as well as perhaps various native defects (V_{Ga}, V_{As}, I_{Ga}, and I_{As}) are generated during the gettering process.
The spatial separation of the anti-sites and the complex formation with their participation play the significant role in the gettering rather than their direct annihilation. These effects result in a decrease in the electron concentration from $10^{15}\,cm^{-3}$ down to $10^{8}\,cm^{-3}$. It should be noticed that the gettering decreases the compensation degree down to 30 percent and increases the electron mobility up to 7000 $cm^2V^{-1}s^{-1}$ at 300 K. In this case the temperature dependence of the carrier concentration was determined by the donor level with E_a = 430 meV.

The low-temperature (2 K) photoluminescence spectra (Fig. 3), which were obtained after the TSC gettering at 800 °C both in 0.5 h and in 3 h followed by the film plasma removal and by etching of the 50 μm thick GaAs layer, testify the purification of the GaAs wafers. The gettering resulted in disappearance of the impurity band with $h\nu \sim 1.45$ eV, which was likely to be associated with the native defects. An prolongation of HT simultaneously caused a decrease in the intensity of the band with $h\nu \sim 1.49$ eV, which was related to acceptor levels (Pavesi (8)) and an increase in the intensity of the edge band with $h\nu \sim 1.512$ eV, which was due to exciton bond to neutral acceptor (A^0x). The wider FWHM of the band was caused by the high compensation degree (~30 %) of the material (Shmidt et al (2) and Vlasenko et al (3)).

The photoluminescence spectra of GaAs after the OSC gettering are shown in Fig. 4 for both coated (after the Y film plasma removal) and uncoated surfaces after HT at 700 °C and 800 °C. (The distribution profiles of N_d-N_a and τ_{eff} have been presented for these wafers in Figs. 1 and 2, respectively.) The acceptor-related impurity band prevails in the spectra of the uncoated surfaces for both temperatures, while the exciton-related edge band dominates in the spectra of the coated surfaces. The edge band is most pronounced for the coated surface of the wafer after HT at 700 °C. Therefore, it follows from the Figs. 2 and 4 that the lower temperature gettering (700 °C) is preferable.

CONCLUSION

– It was established that the surface gettering of GaAs with the Y films was of volume character for both one- and two-side coating.
– It was shown that the gettering at 700 °C and 800 °C allowed the electron concentration to be reduced in GaAs; in so doing HT at 700 °C was preferable.
– The near-uniform distributions both of N_d-N_a and of the hole effective lifetime in depth were an unique result.
– The effects observed during gettering process were likely to be associated with the generation of the anti-site defects (As_{Ga} and Ga_{As}). The spatial separation of the anti-sites and the complex formation with their participation play the significant role in the gettering rather than their direct annihilation.
– The material obtained can be promising in development of high-power devices, X-ray and particle (including solar neutrino) detectors, as well as of ultra-speed optoelectronic VLSIC.

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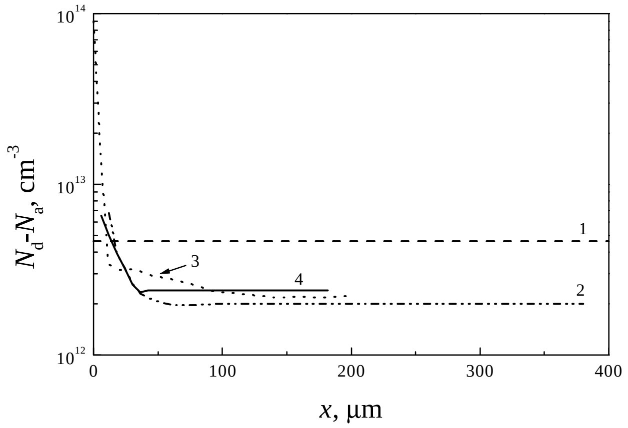

Fig. 1. Distribution profiles of the carrier concentration (N_d-N_a) obtained after the TSC gettering at 800 °C in 0.5 h (1) and after the OSC gettering at 800 °C in 0.5 h (2,3) and at 700 °C in 0.25 h (4): the coated surface after the Y film removal (1,2,4) and the uncoated surface (3).

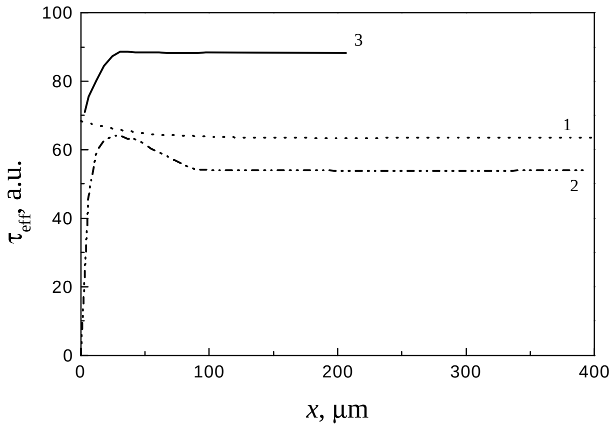

Fig. 2. Distribution profiles of the hole effective lifetime obtained after the TSC gettering at 800 °C in 0.5 h (1) and after the OSC gettering at 800 °C in 0.5 h (2) and at 700 °C in 0.25 h (3) for the coated surface after the Y film removal.

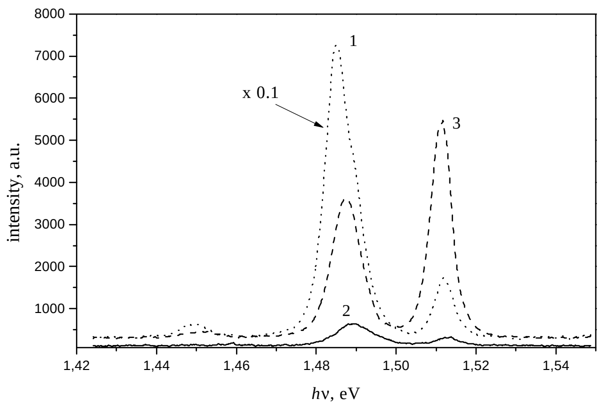

Fig. 3. Photoluminescence spectra of GaAs at 2 K after the TSC gettering from the coated surface after the Y film removal : 1 – initial; 2 – after HT at 800 °C in 0.5 h; and 3 – after HT at 800 °C in 3 h.

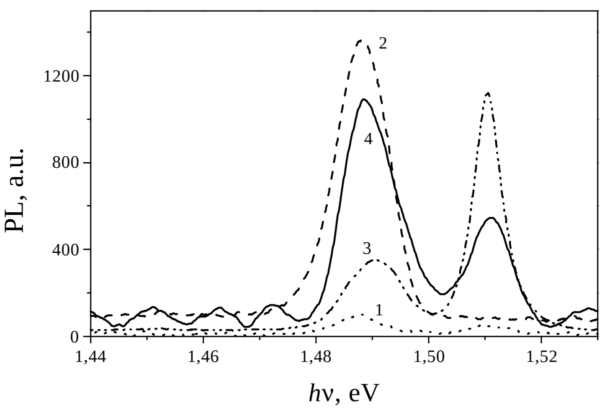

Fig. 4. Photoluminescence spectra of GaAs at 2 K obtained after the OSC gettering at 800 °C in 0.5 h (1,2) and at 700 °C in 0.25 h (3,4) from the coated surface after the Y film removal (1,3) and the uncoated surface (2,4).