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Peculiarities of defect and impurity behaviour in gallium arsenide during surface gettering

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Abstract

Spatial redistribution of anti-site defects after surface gettering of GaAs wafers coated by an yttrium film has been found. It has been established that both one- and two-side coating of the GaAs wafer with an yttrium film followed by a heat treatment allows a high-resistivity ($n = 10^{12}$ cm^{-3}) material to be obtained with uniform distributions of both electrons and the effective hole lifetime in a depth of 1.6 mm. The material obtained is suitable for creating Schottky barriers and structures for use in both high-power devices and x-ray detectors.

1. Introduction

To improve the characteristics of power devices and x-ray, γ-ray, and neutrino detectors, GaAs wafers are required to be of low carrier concentration (below 10^{10} cm^{-3}), with adequate depletion depth (more than 100 μm), and high charge carrier mobility.

One way to improve the characteristics of high-resistivity GaAs is to anneal wafers coated with 1000 Å thick films of SiO$_2$, Si–W, Cr, or Si–Cr [1]. This is called 'surface gettering'. Our preliminary investigations of 1.6 mm thick undoped (111) GaAs wafers coated with yttrium film and annealed showed that material properties were improved: $N_d - N_a$ from (1–3) $\times$ 10^{15} cm^{-3} to 10^8–10^{13} cm^{-3}, and mobility from 1500–2000 to 7000 cm^2 V^{-1} s^{-1} at 300 K [2–4]. It should be noted that the carrier concentration in the initial material was determined by native point defects (V$_{\mathrm{Ga}}$, V$_{\mathrm{As}}$, I$_{\mathrm{Ga}}$, I$_{\mathrm{As}}$, As$_{\mathrm{Ga}}$, Ga$_{\mathrm{As}}$) and their complexes rather than by background impurities.

In the present paper, the distributions of electrons and the effective hole lifetime have been investigated by photoelectrochemical C–V profiling in GaAs wafers coated with Y films on one or two sides after a heat treatment (HT). Moreover, the low-temperature photoluminescence has been studied.

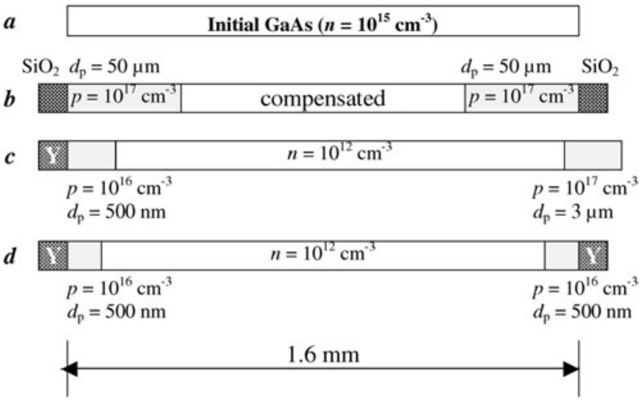

Figure 1. A schematic view of the GaAs wafers treated: (*a*) initial GaAs; (*b*) GaAs with the TSC SiO_2 film; (*c*) GaAs with the OSC Y film; (*d*) GaAs with the TSC Y film.

2. Experiment

Undoped (111) GaAs crystals grown by the LEC (liquid-encapsulated Czochralski) method from 99.999 99% purity gallium and arsenic [5] were used as the initial material. The electron concentration was (2–3) × 10^{15} cm^{-3} and the electron mobility was 1500–2000 cm^2 V^{-1} s^{-1} at 300 K. It was shown [2] that the conductivity was determined by a shallow donor level with an activation energy (E_a) of 10–12 meV and by a deep donor level with $E_a \sim 150$ meV. The degree of compensation (N_a/N_d) was 40% and was probably dependent on the concentration of native defects and their complexes.

1.6 mm thick (111) GaAs wafers were used for the gettering experiments. The wafers were coated with a 1000 Å thick yttrium film either on one side (one-side coating—OSC) or on both sides (two-side coating—TSC) using the vacuum deposition technique. Subsequently, the wafers were heat treated in pure hydrogen ambient at either 700 °C for 0.25 h or 800 °C for 0.5–28 h. The Y films were removed by etching in plasma after the HT. For comparison, the wafers coated with SiO_2 films were investigated.

The carrier concentration of the gettered wafers was determined both by the C–V method using a Hg–GaAs Schottky barrier and by Hall effect measurements [6]. The carrier profile was obtained by C–V electrochemical [7] or photoelectrochemical [8] profiling. A solution of H_2SO_4:H_2O_2:H_2O (1:8:1) with a constant etching rate of 4 μm min^{-1} was applied as the electrolyte–etchant. Under illumination of the GaAs–electrolyte interface with light at $h\nu > E_g$, an onset of photocurrent proportional to the hole effective lifetime [9] was observed. This fact allowed a relative distribution of the hole effective lifetime to be obtained throughout the wafer thickness. Photoluminescence investigations at 2 K were carried out using a conventional technique.

3. Results and discussion

Investigation of the carrier concentration distribution in the GaAs wafers coated with both Y (OSC and TSC) and SiO_2 (TSC) films after HT at 700–800 °C has shown that a p-type near-surface region was always formed (figure 1). It should be noted that, in the case of OSC, the region was observed not only on the surface coated with the film, but on the free one as well. The deepest p-type region (50 μm) was obtained for the SiO_2 coating.

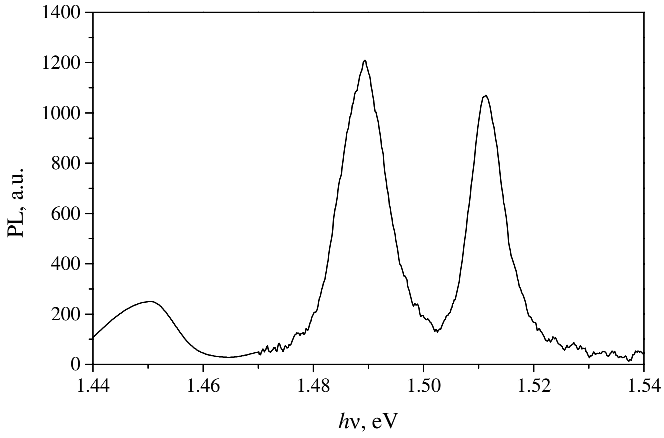

Figure 2. Photoluminescence spectra of GaAs at 2 K: the p-type region after HT at 800 °C for 1 h.

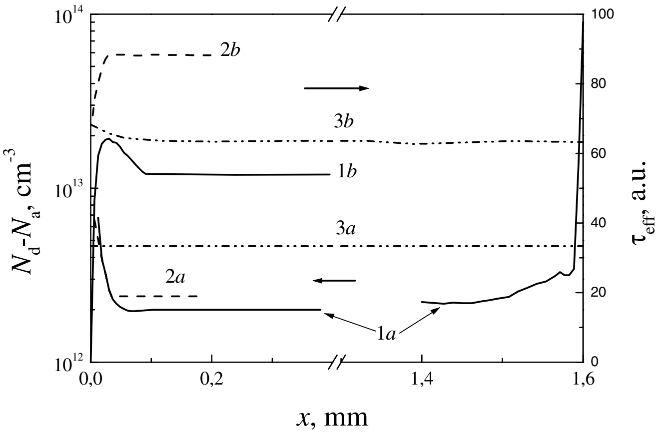

Figure 3. Distribution profiles of carrier concentrations (1*a*–3*a*) and of the effective hole lifetimes (1 *b*–3*b*) obtained after the OSC gettering at 800 °C for 0.5 h (1*a*, 1*b*) and at 700 °C for 0.25 h (2*a*, 2*b*) as well as after the TSC gettering at 800 °C for 0.5 h (3*a*, 3*b*). (The points at 0 mm and 1.6 mm correspond to the coated surface after the Y film removal and the uncoated surface, respectively.)

A 1.445 eV band, which was probably associated with the native defect $\mathrm{Ga}_{\mathrm{As}}^{-}$, was found in the low-temperature (2 K) photoluminescence spectrum of the p-type region (figure 2). The gettering effect—that is, the formation of an n-type high-resistivity region throughout most of the GaAs wafer—was obtained only for the Y film (both TSC and OSC).

Investigations of the carrier concentration and the hole effective lifetime showed that the gettering effect was of bulk character even for OSC with the Y film (figure 3). It should be noted that these profiles were studied for wafers with concentrations down to 10^{12}–10^{13} cm^{-3}, which was the limit for this method.

Investigations of the low-temperature photoluminescence demonstrated that, upon gettering under optimal conditions, the 1.445 eV band disappeared in the spectra of the GaAs wafers (figure 4). Moreover, the intensity of the 1.487 eV band, which is conditioned by the two-hole transition of the exciton state associated with the neutral Si acceptor [10], decreased by several times. Therefore, spatial redistribution of the defects, which occupied the whole

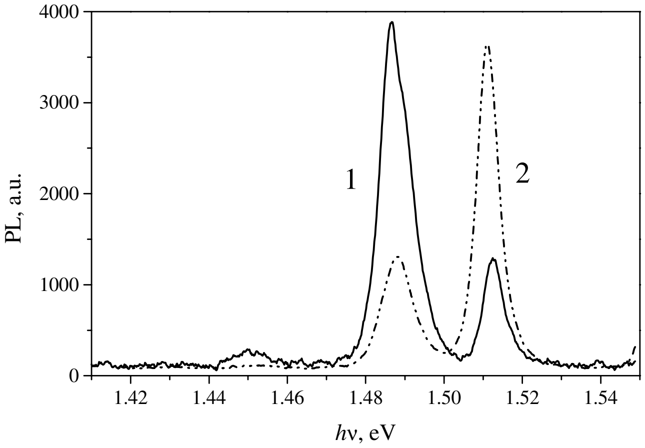

Figure 4. Photoluminescence spectra of GaAs at 2 K before (1) and after (2) surface gettering: the n-type region after HT at 800 °C for 1 h.

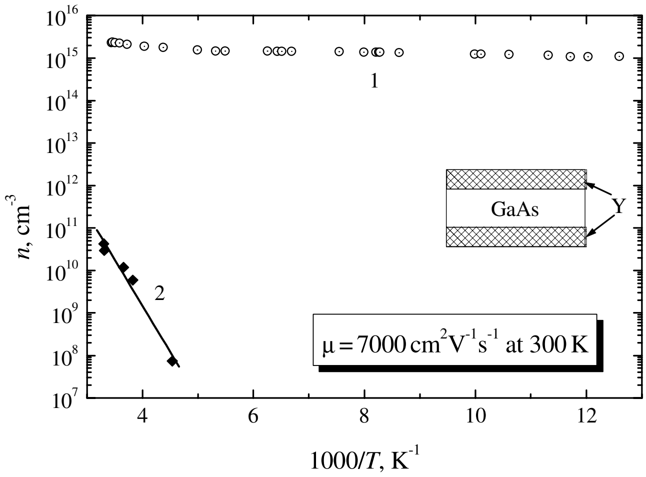

Figure 5. The temperature dependence of the carrier concentration: initial GaAs (1) and the GaAs wafer two-side coated with the Y film after HT for 3 h (2).

volume of the initial material, was observed after the gettering. As the result, the anti-site defects which manifested themselves in the photoluminescence spectra of the initial material (figure 4, curve 1) were observed only in the p-type near-surface region (figure 2).

Under the optimal time–temperature HT regime, the carrier concentration could be reduced down to 10^8–10^{11} cm^{-3}. The temperature dependence of the concentration for that material is presented in figure 5. The dependence of the initial material is given for comparison.

Comparative studies of photoluminescence properties and in-depth carrier concentration distributions in the GaAs wafers obtained after the gettering using both OSC and TSC films of Y and SiO_2 allowed us to conclude that the stress created by coatings during the gettering plays the significant role in the native defect gettering. Moreover, the spatial defect redistribution observed probably plays the most significant role in the gettering rather than their direct annihilation.

A 2 mm diameter Schottky barrier was made by deposition of Ti–Au on the material annealed. The current value of 3×10^{-8} A cm^{-2} at 10 V was close to those for the radiation detectors based on GaAs obtained under super-pure conditions [11].

4. Conclusions

A complicated behaviour of defects and impurities was found in GaAs wafers during surface gettering. The anti-site defects, which occupied the whole volume of the initial material, were observed only in the near-surface region after the gettering. These defects were probably responsible for the formation of the p-type region.

The surface gettering of GaAs wafers, both one-side and two-side coated with Y films, was shown to be of a volume character through the whole thickness of 1.6 mm. This allowed high-resistance GaAs wafers to be obtained with uniform distributions both of electron concentration and of minority carrier lifetime, as well as with mobility up to 7000 cm^2 V^{-1} s^{-1} at 300 K. This material is very promising for use in high-voltage power devices, detectors of x-rays, nuclear radiation, and particles, including neutrinos, as well as in ultralarge-scale and ultrahigh-speed integral and optoelectronic circuits.

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