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Electronic properties of p-GaAs deposited on n-Si with pulsed-laser deposition

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Abstract
By means of nanosecond laser pulses at 355, 532, and 1064 nm, p(Zn)-type GaAs was ablated and deposited on n-type Si. The samples showed rectification and Hall measurements established that the deposited material was p-type, but the active-doping concentration was six orders of magnitude below the target value. Because secondary-ion mass spectroscopy results indicated stoichiometric material transfer, we concluded that most of the Zn atoms do not act as acceptors because of the amorphous film texture. The work further showed indications that pulsed-laser deposition at 355 nm causes enhanced Si diffusion into the deposited film, compared to the ablations done at 532 and 1064 nm.

(Some figures in this article are in colour only in the electronic version)

Looking along the prospective road of electronics, optoelectronics, and, more and more important, of photonics, it is not difficult to predict that hybrid semiconductor devices will be increasingly required in future technologies [1]. Specifically, the merger of today's main players in the field of semiconductors, GaAs and Si, is of considerable interest for optoelectronic devices and their fabrication. However, straightforward epitaxial growth of GaAs on Si is hampered by the differences in lattice constant (4%) and thermal expansion coefficient (factor 2.5) between the two materials. Thus, research groups and the semiconductor industry are vigorously seeking deposition methods for GaAs on Si substrates [2, 3]. Despite the considerable efforts that have been undertaken including the use of buffer layers [4], an established generally recognized method has not yet emerged. At this point, it is necessary to stress the economic aspect of the problem. It is not only the question of whether a certain technique can be employed to form GaAs on Si, but also whether the achieved film quality justifies the expense. In this context, molecular beam epitaxy (MBE) and metal–organic chemical vapor deposition (MOCVD), the most established growth methods for mono-epitaxial GaAs, have been widely abandoned because the achieved film qualities do not justify the film production expense [2, 3]. The question now becomes whether to pursue other methods for crystalline GaAs formation on Si or, as we did, to seek alternative deposition procedures for producing non-crystalline film textures by straightforward economic means, which, nonetheless, result in operative device structures. The main purpose of this work is to outline the capabilities of pulsed-laser deposition (PLD) for active GaAs-on-Si device formation by using doped GaAs targets. We stress at this point that PLD of thin-film semiconductors has been much less investigated in comparison with other growth methods. In particular, PLD of semiconducting films from doped targets on counter-doped substrates has not been exhaustingly investigated. We are aware of only one paper [5] containing data on GaAs-on-Si PLD before we started to work on the subject four years ago. Meanwhile, we demonstrated that PLD of p-type GaAs onto counter-doped Si produces a technologically appealing photo-responsive hetero-pair with sensitive bias dependence [6–9]. In the current work, we emphasize the dynamic rectification properties and the doping features of p-GaAs/n-Si structures formed with PLD at 355, 532, and 1064 nm.

The ablation has been carried out with a Nd:YAG laser, which is of specific particular interest because several industrial activities rely on this laser type [10]. We formed three samples at an ambient pressure of 10^{-3} Pa, which is the typical operational pressure of our vacuum system used, employing the lowest order transverse electromagnetic mode (TEM_{00}) of a pulsed (6 ns, 10 Hz) Nd:YAG laser at 1064, 532, and 355 nm. The target and the substrate were 50.4 mm/2-inch (100) p(Zn)-GaAs and n(Ph)-Si wafers with doping concentrations of 10^{19} cm^{-3} and about 10^{14} cm^{-3},

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Table 1. Summary of the Hall measurements for p-GaAs/glass formed at 532 nm.

Temperature (K)	Resistivity ($\times 10^5$ Ω cm)	Concentration ($\times 10^{14}$ cm^{-3})	Mobility ($\times 10^1$ cm^2 V^{-1} s^{-1})	Type
300	0.3889	0.2882	0.5570	P

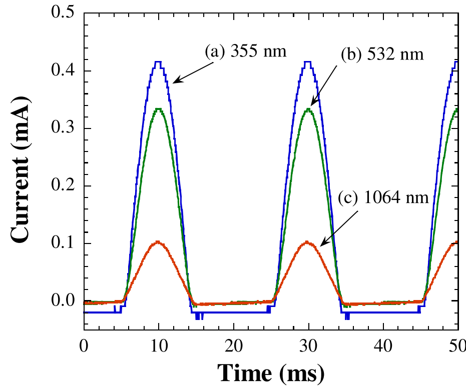

Figure 1. Alternating current rectification of PLD p-GaAs/n-Si diodes formed at (a) 355 nm, (b) 532 nm, and (c) 1064 nm.

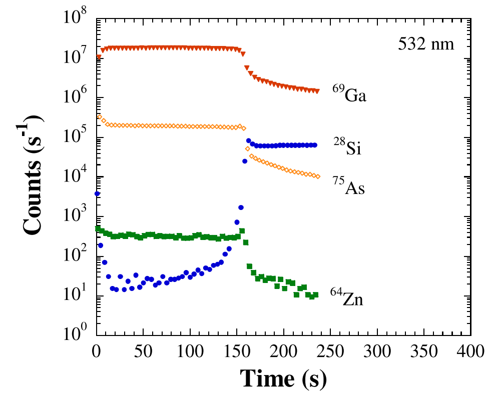

Figure 2. SIMS depth profile obtained from PLD p-GaAs/n-Si formed at 532 nm.

respectively. For the purpose of measuring the Hall properties of the deposited material without interference caused by the n-type Si substrate, we also deposited GaAs on fused silica glass employing the 532 nm line. Besides the variation of the ablation laser line, we maintained all conditions. All samples were deposited with a target-to-substrate distance of 60 mm, while rotating the target to keep the ablation as uniform as possible. At 355 and 532 nm, the samples were deposited for 60 min, while at 1064 nm, the ablation was maintained for 180 min. The PLD was performed in the most straightforward way, i.e., without a substrate heater, while employing a laser fluence of 0.79–0.84 J cm^{-2}. The flux and ablation time combinations resulted in film thicknesses of 300 nm, 600 nm, and 180 nm, for the ablation at 355 nm, 532 nm, and 1064 nm, respectively. The electric contacts have been realized in the same way as in [6–9], i.e., with vacuum evaporated Al on the GaAs layer and with sliver paste to the substrate.

The dynamic rectification capabilities of the samples were checked with alternating current (AC) measurements at room temperature without illumination. For this purpose, a peak-to-peak bias of 20 V at 50 Hz was applied to a series circuit consisting of the sample and a 1.4 kΩ shunt. The current passing through the shunt was displayed with a 500 MHz oscilloscope. Curves (a)–(c) in figure 1 show the measurements for the samples formed at (a) 355 nm, (b) 532 nm, and (c) 1064 nm, respectively. The results exhibit the typical appearance of half-wave rectification—as expected of pn junctions. However, the results show that in the forward direction the junction exhibits a rather high series resistance of about 30 kΩ for the junctions formed at 355 nm and 532 nm, and 100 kΩ for the 1064 nm sample. The results are in agreement with our measured current–voltage (I/V) characteristic shown in [8].

Having established that the samples are functioning as rectifiers, it is clearly of importance to quantify the doping concentrations of the films. Table 1 shows the result of Hall measurements for the GaAs/glass sample formed at 532 nm. The measurement has been carried out at room temperature in Van der Pauw geometry with In contacts employing a magnetic field of 1.5 T. The result reveals that the deposited GaAs film is indeed p-type but with extremely low acceptor concentration and mobility, approximately 10^{13} cm^{-3} and 6 cm^2 V^{-1} s^{-1}, respectively. The low mobility, which is well below the GaAs bulk value of 400 cm^2 V^{-1} s^{-1} for holes, explains the intrinsic serial load of the samples revealed in figure 1 and confirms our conclusions in [11] that PLD GaAs is of multi-phase nature including crystalline but also amorphous parts, which hamper carrier transport.

So far, the experiments have not provided information about the number of incorporated Zn atoms in the GaAs films because Hall measurements count only electronically active dopants. In order to find the total Zn concentration, secondary-ion mass spectroscopy (SIMS) was employed; Cs^+ was used as the primary ion species, at an incident energy and angle of 5.5 keV and 45°, respectively. The measured secondary-ion species were Si as $^{28}SiCs^+$, Zn as $^{64}ZnCs^+$, Ga as $^{69}GaCs^+$, and As as $^{75}AsCs^+$. To quantify the SIMS data, measurements were also made on a GaAs standard with known Zn concentration. The raw data for the film formed at 532 nm are shown in figure 2. The quantified Zn-doping profiles for all films are overlaid and revealed in figure 3. The results demonstrate that the Zn concentration was perfectly maintained at 1064 nm and transferred to a somewhat lower extent (but still clearly above 10^{18} cm^{-3}) at 532 and 355 nm. Thus, the doping concentration of the target is transferred but as a consequence of the complex film texture most of the impurities are electronically inactive. In this context, we stress that GaAs formed with PLD possesses a satisfactory, balanced stoichiometry [12].

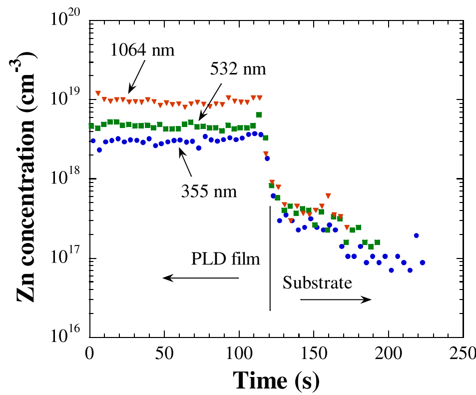

Figure 3. SIMS Zn concentrations in the PLD GaAs films formed at 355 nm, 532 nm, and 1064 nm.

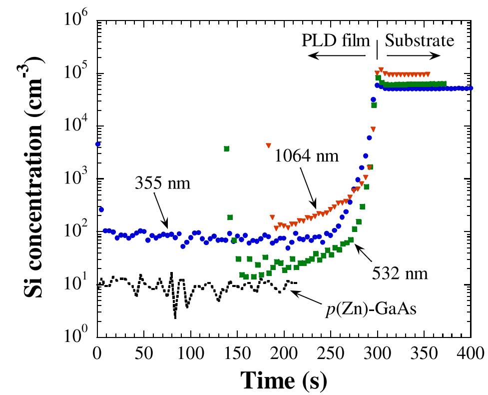

Figure 4. SIMS Si concentrations in the PLD GaAs films formed at 355 nm, 532 nm, and 1064 nm. The results are shown with respect to the Si level of the p(Zn)-GaAs standard.

Of further interest is whether the interaction of the laser induced plume with the deposition substrate might cause diffusion of Si from the substrate into the depositing GaAs film, given its possible effect upon net film dopant. Therefore, in figure 4, SIMS Si profiles from the three PLD samples are compared to the SIMS background signal level of the GaAs:Zn standard. In figure 4, as in figure 3, the depth scales of the profiles are shifted so as to overlay their substrate interfaces. In all the profiles the Si signal seems to display diffusion from the substrate, which instead is likely a profiling artifact caused by the topographic roughness of the PLD films due to clusters [13]. This in turn degrades the depth resolution of the SIMS profile; i.e., the rough surface topography is propagated during the formation of the SIMS sputter crater. For this reason, the characteristic of interest can only be the Si signal at a depth shallower than the broadened Si interface signal. With this point of view, figure 4 shows that the Si concentration in the film formed at 532 nm does not significantly exceed the background signal of the substrate. The shape of the Si profile in the 1064 nm sample shows the promise of the same conclusion although the film thickness is not so great as to allow 'escape' from the broadened interfacial region; i.e., the sample surface is so rough as to expose areas of the substrate interface from the beginning of the profile. In contrast, the deposition at 355 nm clearly shows a higher Si concentration throughout the film. This might explain why the photo-current dependence under reverse bias of this diode differs from the samples formed at 532 and 1064 nm [8]. Apparently, under the current deposition conditions, the plume–substrate interaction at 355 nm favors diffusion of substrate material into the deposited film at concentrations high enough to have a significant effect on diode characteristics. These Si profiles were confirmed by obtaining negative SIMS profiles from the same samples.

In summary, impinging nanosecond ablation pulses of a Nd:YAG laser onto a p-type doped GaAs target has been used to produce p-type GaAs-on-n-type Si films with p-doping concentrations rather independent of the ablation wavelength. Because the deposited films exhibit lower crystallographic quality compared to the single-crystal target material, the overall electronic nature of the doping material will not be completely conferred to the final product, and the dopants may not serve as active acceptors to the same degree. In spite of this observation, operative p-GaAs/n-Si diodes are readily formed with PLD. The work further shows that PLD with ultraviolet laser irradiation favors, with respect to visible and infrared ablation irradiation, Si diffusion from the deposition substrate into the deposited GaAs film.

Acknowledgment

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References

[1] Ullrich B 2002 *Sci. Technol.* **17** L33
[2] Arokiaraj J, Soga T, Jimbo T and Umeno M 1999 *Appl. Phys. Lett.* **75** 382
[3] Chandrasekaran N, Soga T and Jimbo T 2003 *Appl. Phys. Lett.* **82** 3892
[4] Yu Z, Droopad R, Jordan D, Curless J, Liang Y, Overgaard C, Li H, Talin A, Eschrich T, Craigo B, Eisenbeiser K, Emrick R, Finder J, Hu X, Wei Y, Edwards J Jr, Convey D, Moore K, Marshall D, Ramdani J, Tisinger L, Ooms W, O'Steen M, Towner F and Hierl T 2002 *Proc. GaAsMANTECH Conf.*
[5] Budyanu V A, Chechuy S N, Damaskin I A, Fedoseev S A, Nasakin A A, Pyshkin S L, Valkovskaya M I and Zenchenko V P 1984 *Phys. Status Solidi* a **91** 737
[6] Ullrich B, Erlacher A and Jaeger H 2004 *Proc. SPIE* **5339** 365
[7] Ullrich B, Erlacher A, Gerasimov T G, Komarova E Y and Jaeger H 2004 *Proc. SPIE* **5359** 23
[8] Ullrich B and Erlacher A 2005 *J. Phys. D: Appl. Phys.* **38** 4048
[9] Ullrich B and Erlacher A 2005 *Appl. Phys. Lett.* **87** 151115
[10] Dushkina N 2003 *Ind. Laser Solut.* **18** (June) 31
[11] Erlacher A, Ullrich B, Komarova E Y, Jaeger H, Haugan H J and Brown G J 2006 *J. Non-Cryst. Solids* **352** 193
[12] Erlacher A, Ambrico M, Capozzi V, Augelli V, Jaeger H and Ullrich B 2004 *Semicond. Sci. Technol.* **19** 1322
[13] Ullrich B, Erlacher A, Gerasimov T G, Komarova E Y and Jaeger H 2004 *Proc. SPIE* **5359** 23