

Infrared study of light-induced reactivation of neutralized dopants in hydrogenated n-type GaAs doped with silicon

D. Loridant-Bernard, S. Mezière, M. Constant, N. Dupuy, B. Sombret, and J. Chevallier

Citation: [Applied Physics Letters](#) **73**, 644 (1998); doi: 10.1063/1.121934

View online: <http://dx.doi.org/10.1063/1.121934>

View Table of Contents: <http://scitation.aip.org/content/aip/journal/apl/73/5?ver=pdfcov>

Published by the [AIP Publishing](#)

Articles you may be interested in

[Carbon reactivation kinetics in GaAs: Its dependence on dopant precursor, doping level, and layer thickness](#)
J. Appl. Phys. **91**, 5923 (2002); 10.1063/1.1467953

[Influence of the hole population on the transient reflectivity signal of annealed low-temperature-grown GaAs](#)
Appl. Phys. Lett. **80**, 2505 (2002); 10.1063/1.1463209

[Intervalenceband and plasmon optical absorption in heavily doped GaAs:C](#)
J. Appl. Phys. **91**, 171 (2002); 10.1063/1.1424050

[Infrared absorption study of nitrogen in N-implanted GaAs and epitaxially grown GaAs 1-x N x layers](#)
Appl. Phys. Lett. **77**, 3331 (2000); 10.1063/1.1328096

[Electron-beam-induced reactivation of Si dopants in hydrogenated GaAs: A minority carrier generation effect or an energetic electron excitation effect?](#)
Appl. Phys. Lett. **77**, 3206 (2000); 10.1063/1.1324988

The image shows the cover of the journal Applied Physics Reviews. It features a white background with a blue and orange design. The AIP logo is at the top left, and the title 'Applied Physics Reviews' is at the top right. Below the title is a diagram of a layered structure. The bottom of the cover has a blue and orange border.

NEW Special Topic Sections

NOW ONLINE
Lithium Niobate Properties and Applications:
Reviews of Emerging Trends

AIP Applied Physics Reviews

Infrared study of light-induced reactivation of neutralized dopants in hydrogenated *n*-type GaAs doped with silicon

D. Loridant-Bernard and S. Mezière

Institut d'Electronique et de Microélectronique du Nord—U.M.R. C.N.R.S. 9929, B.P. 69 Avenue Poincaré, 59652 Villeneuve d'Ascq cedex, France

M. Constant,^{a)} N. Dupuy, and B. Sombret

Laboratoire de Spectrochimie Infrarouge et Raman—U.P.R. 2631L C.N.R.S., Université des Sciences et Technologies de Lille, 59655 Villeneuve d'Ascq Cedex, France

J. Chevallier

C.N.R.S. Laboratoire de Physique des Solides, 1, place A. Briand, 92195 Meudon Cedex, France

(Received 23 March 1998; accepted for publication 30 May 1998)

Effects of light-induced reactivation of neutralized dopants in hydrogenated *n*-type silicon-doped GaAs epilayers have been investigated using infrared spectroscopy and electrical measurements as well. Photoexcitation of the passivated material has been performed over a wide wavelength domain (250 nm–1.06 μm), and the samples have been analyzed by using extensively both specular reflection and transmission infrared techniques. In all cases, the observed structural modifications have been correlated to the electrical properties evaluated by measuring sheet resistance of the material. The obtained experimental data permit a simplified analysis of the dissociation of dopant-hydrogen complexes versus the photon energy of the incident light. © 1998 American Institute of Physics. [S0003-6951(98)01531-9]

The exposure of *n*-type silicon-doped GaAs to a hydrogen plasma induces the neutralization of the active donors and the formation of electrically neutral silicon hydrogen complexes. This model is supported by several experimental results: (1) the decrease of the free-carrier concentration as well as an increase of the electron mobility after hydrogenation,¹ and (2) the observation of the infrared bending and stretching vibrational modes of hydrogen attached to the silicon dopant, respectively, at 897 and 1717 cm^{-1} (at 7 K) in hydrogenated *n*-GaAs doped with silicon.^{2,3}

The use of hydrogen diffusion in the fabrication of microelectronic devices offers the possibility to adjust the doping level and to produce, using appropriate masks and controlled reactivation under UV illumination, patterns of conductive and resistive regions.^{4–6} Moreover, many investigations have been made to study the stability of the complexes and the kinetics governing their dissociation.^{7,8} Major recent studies in this regard have reported that near-above-band-gap illumination or minority-carrier injection may greatly enhance the thermal dissociation of the complexes.^{9–11} As a result, before the possible benefits of hydrogenation can be applied to processing techniques and technological applications, the important question regarding the stability to light of the dopant-hydrogen complex needs to be addressed.

So far, there is only minor reported evidence on the influence of the incident wavelength on reactivation of neutralized dopants in hydrogenated *n*-Si-doped GaAs and the exact location of this effect in the semiconductor layer.¹² The aim of this letter is to present an experimental study of the effects of light over a wide wavelength domain (250 nm–

1.06 μm). Detailed information has been pointed out by cross comparison of related data obtained using electrical measurements and both specular reflection and transmission infrared techniques.

Experiments were performed on epilayers used in the fabrication of hydrogenated field-effect transistors. The structure was grown on a semi-insulating $\langle 100 \rangle$ GaAs substrate by molecular beam epitaxy. The layers in the sequence of growth were 800 nm of undoped GaAs and 300 nm of n^+ -Si-doped GaAs (n^+ : $3\text{--}5.10^{18} \text{ cm}^{-3}$). The above structure has been immersed into a 13.56 MHz capacitively coupled hydrogen plasma under the following conditions: temperature: 190 °C, RF power: 3 W, hydrogen pressure: 1 mbar, exposure duration: 6 h. These plasma conditions have been selected because they are used in the fabrication of hydrogenated field-effect transistors.⁶ GaAs samples of a quarter of 2 in. diam size were used in these experiments.

To study extensively the reactivation of the neutralized donors as a function of the incident wavelength, illumination of the hydrogenated samples has been made with monochromatic light provided by the fundamental, second, and third harmonic lines of YAG and Ti-sapphire lasers at five wavelength values corresponding to photon energies of 1.17, 1.67, 2.25, 3.49, and 4.66 eV, respectively. All the exposures were performed under a light power density of 1 mW/cm². To achieve uniform illumination and to minimize edge effects the laser light was defocused using a diffuser.

One parameter which may affect the light-induced reactivation of neutralized dopants is the penetration depth of the light for which values are between 6 nm (at $\lambda = 266 \text{ nm}$) and $\approx 1 \mu\text{m}$ under visible light. In order to obtain a correct understanding of the structural modifications related to the light-induced effects, it is necessary to separate information obtained from the near-surface region from that arising from

^{a)}Electronic mail: monique.constant@eudil.fr

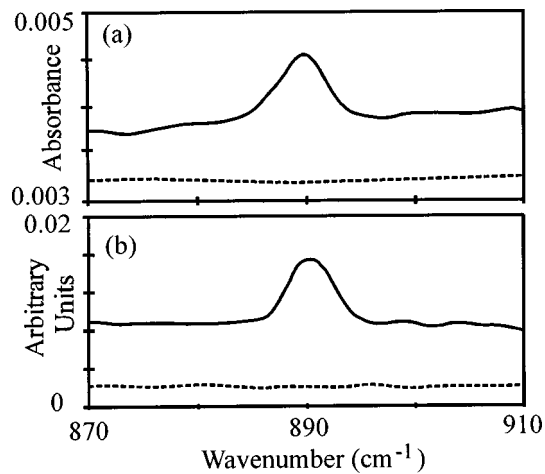


FIG. 1. Transmission (a) and specular reflection (b) IR spectra of GaAs: (— —) before plasma, and (—) after plasma exposure.

deeper within the epilayer. With this aim in view, we have taken advantage of the complementary properties of both transmission and specular reflection infrared techniques. The first technique allows us to investigate the complex formation all over the epitaxial layer thickness. The second method is based on analysis of the infrared beam reflected by the epitaxial layer. In this configuration, the spectrum results from a Kramers–Kronig transformation of the reflectance signal. As a result, the collected information is then representative of a very small thickness below the layer surface.

All infrared spectra were recorded at room temperature with a Perkin Elmer IRTF System 2000 spectrometer (transmission configuration) and a Bruker IFS 88 spectrometer (specular configuration). In the present experiments, a doped GaAs sample before plasma exposure was used as the reference. In Fig. 1 are reported infrared data of GaAs samples before and after plasma exposure. As expected, the bending vibrational mode at 890 cm^{-1} related to the SiH complexes appears in hydrogenated GaAs. It can be observed that the IR spectra obtained either in transmission or in specular reflection have quite the same characteristics, indicating that no surface-related defects have been originated by the plasma exposure. Data relevant to the structural modifications induced by the light into hydrogenated GaAs samples have been analyzed in terms of the intensity variation of the SiH vibrational mode. Figure 2 shows transmission and specular reflection IR spectra of the hydrogenated GaAs after 3 h of illumination at the light power density and the various wavelengths mentioned before.

It is worth noticing that, in all cases, no significant difference is observed in the infrared spectra obtained with the transmission configuration. A better understanding of the light-induced effects involves analysis of the infrared spectra recorded using the specular reflection configuration. As before, within the experimental errors, no change in intensity of the SiH mode is observed after illumination of the hydrogenated samples at $1.06\text{ }\mu\text{m}$ and 740 nm . By contrast, it is important to note the significant decrease of the SiH mode intensity after exposure at 266 nm and 355 nm . At this point, from the trends of the IR data we can suggest that: (i) the rate of reactivation of the passivated Si donors is found to strongly increase with the photon energy of the incident

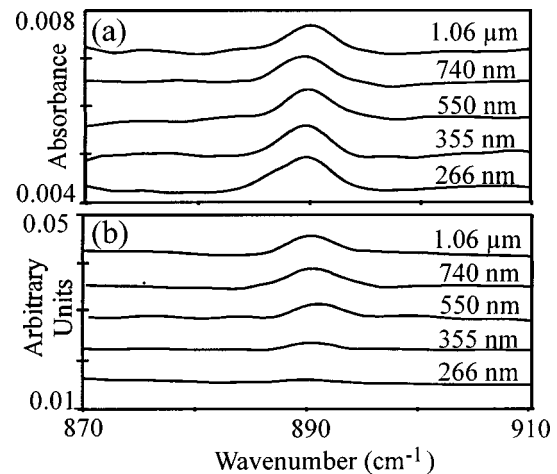


FIG. 2. Transmission (a) and specular reflection (b) IR spectra of hydrogenated GaAs after 3 h light exposure at various wavelengths.

light, and (ii) complex dissociation and dopant reactivation take place in the vicinity of the near-surface region.

Additional quantitative information has been obtained by performing sheet resistance measurements using a harmless contactless method. Figure 3 displays the sheet resistance values measured after various times of light exposure. It can be noted that an important decrease of the sheet resistance appears only after UV illumination in agreement with the evolution of the SiH vibrational mode. Associated with the surface potential and superficial charge in GaAs, a large part of the epilayer is depleted after impurity neutralization resulting from hydrogen plasma exposure and under these conditions, a large variation of the sheet resistance of the studied samples is obtained even if dopant reactivation takes place in a thin region located near the surface.

This recovery of the active impurity concentration observed under UV illumination can also be investigated through the time dependence of the Si–H vibrational mode intensity detected in specular reflection experiments. The obtained IR data illustrated in Fig. 4 show a good correlation between the decrease of both the Si–H mode intensity and the sheet resistance.

Assuming in a very simple model that the carrier mobility and the superficial state charge keep constant values during hydrogen plasma exposure and light illumination, respectively, variation of the sheet active impurity carrier density resulting from complex dissociation under light excitation

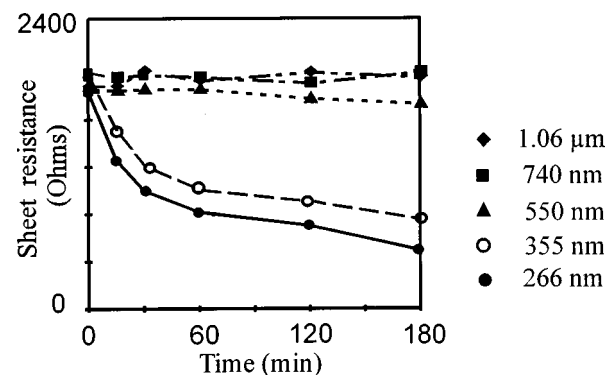


FIG. 3. Evolution of the sheet resistance of hydrogenated GaAs samples vs. light exposure time. Prior to plasma exposure, the sheet resistance is $29\text{ }\Omega$.

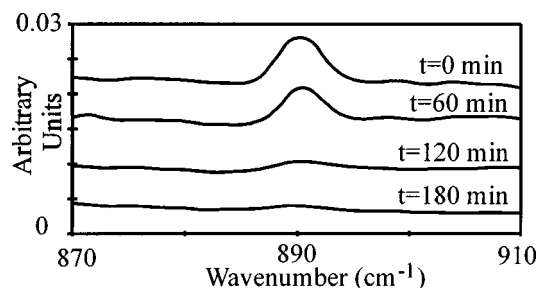


FIG. 4. Evolution of the SiH bending mode intensity of hydrogenated GaAs samples vs light exposure time at 266 nm.

may be obtained from the sheet resistance values measured before and after hydrogen plasma exposure and then after light illumination. The results of interest plotted in Fig. 5 clearly show a threshold photon energy close to 3.5 eV to allow complex dissociation.

It remains to find out the physical mechanism involved in the dissociation of the complexes under UV illumination. SiH complex dissociation enhancement due to minority carriers seems not to be preponderant since no significant variation of the SiH mode intensity as well as the sheet resistance has been observed by illuminating hydrogenated GaAs with

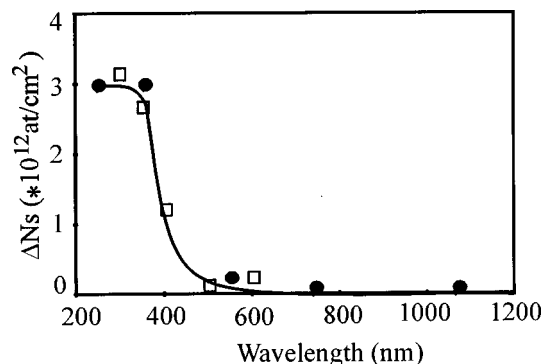


FIG. 5. Variation of the sheet active impurity carrier density resulting from complex dissociation after 3 h exposure under a light power density of 1 mW/cm² vs the light excitation wavelength: ● laser illumination, □ additional data obtained using the monochromatic light provided by an UV spectrometer.

below-band-gap light and just-above-band-gap light. Moreover, direct photodissociation is unlikely because the high absorption coefficient of GaAs in the UV region makes low the probability for a UV photon to be absorbed by SiH complexes. A possible explanation is that dissociation is achieved by high-energy electrons, which have been created under UV illumination. In this model, due to the surface electric field induced by negative surface states, such hot carriers would be pushed away into the epilayer and dissociate SiH complexes present in the neutralized part in the space-charge surface region. On the short distance covered by hot electrons, the relaxation of the electron initial energy (i.e., the difference between the photon and the band-gap energies) has no time to occur before the dissociation of these SiH complexes by hot electrons.

Additional experimental and theoretical studies are needed to check the validity of this analysis of the effects of UV illumination on the active donor concentration in hydrogenated GaAs. This appears quite interesting since such an effect could be very useful to measure in a very simple way UV radiation energies.

The authors are grateful to G. Buntinx for providing laser excitation.

- ¹J. Chevallier, W. C. Dautremont-Smith, C. W. Tu, and S. J. Pearton, *Appl. Phys. Lett.* **47**, 108 (1985).
- ²A. Jalil, J. Chevallier, J. C. Pesant, R. Mostefaoui, B. Pajot, P. Murawala, and R. Azoulay, *Appl. Phys. Lett.* **50**, 439 (1987).
- ³B. Pajot, R. C. Newman, R. Murray, A. Jalil, J. Chevallier, and R. Azoulay, *Phys. Rev. B* **37**, 4188 (1988).
- ⁴J. Chevallier, *Defect Diffus. Forum* **9**, 131 (1996).
- ⁵E. Constant, *Physica B* **170**, 397 (1991).
- ⁶N. Ng Ching Hing, S. Mezière, I. Valin, and E. Constant, *Electron. Lett.* **31**, 1391 (1995).
- ⁷S. J. Pearton, W. C. Dautremont-Smith, J. Chevallier, C. W. Tu, and K. D. Cummings, *J. Appl. Phys.* **59**, 2821 (1986).
- ⁸H. Y. Cho, E. K. Min, S. Min, K. J. Chang, and C. Lee, *J. Appl. Phys.* **68**, 5077 (1990).
- ⁹A. W. R. Leitch, Th. Prescha, and J. Weber, *Phys. Rev. B* **44**, 5912 (1991).
- ¹⁰N. M. Johnson and C. Herring, *Phys. Rev. B* **45**, 11 379 (1992).
- ¹¹I. Szafraneck, M. Szafraneck, and G. E. Stillman, *Phys. Rev. B* **45**, 6497 (1992), and references cited therein.
- ¹²N. M. Johnson, C. Herring, and D. Bour, *Phys. Rev. B* **48**, 18 308 (1993).