Extended Abstracts of the 2009 International Conference on Solid State Devices and Materials, Sendai, 2009, pp739-740

Cathodoluminescence Microcharacterization of Recombination Centers in Lifetime-Controlled IGBTs

Ryuichi Sugie[1], Takeshi Mitani[1], Masanobu Yoshikawa[1], Yoshiharu Iwata[2], and Ryohei Satoh[2]

[1]Toray Research Center Inc., 3-3-7, Sonoyama, Otsu, Shiga 520-8567, Japan
Phone: +81-77-533-8609 E-mail: Ryuichi_Sugie@trc.toray.co.jp
[2]Center for Advanced Science and Innovation, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan

1. Introduction

An insulated gate bipolar transistor (IGBT) is widely used as switching devices for high power and high voltage control applications. The device is a minority-carrier device and uses the conductivity modulation by the injection of minority carriers into the resistive drift layer needed for sustaining high voltage, which lead to the reduction of the on-state voltage drop. However, switching losses are largely influenced by the minority carrier lifetime. Lifetime control techniques such as gold or platinum diffusion and irradiation with electrons, protons or helium ions have been used to optimize the characteristics of bipolar power devices [1-7]. The electron having energy of 1-10 MeV penetrates entire the device and forms non-localized defect distribution, while the proton or helium irradiation produces localized distribution.

The lifetime killer defects generated by these irradiation techniques have been mainly characterized by deep level transient spectroscopy (DLTS). Although DLTS can clarify the energy level and the capture cross section of the defects, it is difficult to derive the spatial distribution. Cathodoluminescence (CL) is suitable for device characterization such as optoelectronic devices [8] and LSI devices [9]. In this paper, we applied cross-sectional CL measurements to the electron-irradiated IGBTs after annealing at 200-400 °C and discuss the relation between the static and dynamic electrical characteristics and the radiative recombination centers in the n-drift region.

2. Experiment

The devices used in this study are commercially available 600 V punch-through planar IGBTs in surface-mount DPAK (TO-252) packages with lifetime controls by electron irradiation. We additionally annealed these devices at 200 °C, 300 °C, and 400 °C for 1 hour in vacuum. After annealing, electrical measurements were performed at 25 °C. Collector-emitter saturation voltage (V_{CES}) was recorded under the condition of gate-emitter voltage V_{GE} = 15 V and collector current I_C = 5 A. Current fall time (t_f) was defined as the time between the collector current dropping from 90 % to 10 %. Although a melting temperature of solder in the package and a glass transition temperature of the encapsulating plastic resin were less than 300 °C, we considered no serious damage was introduced in the silicon chips themselves based on the electrical measurements and the observation of silicon chips after dissolving the encapsulating plastic resin with solvents.

After electrical measurements, CL spectroscopy and microscopy were applied to the cross-section of IGBTs. The emitted luminescence was analyzed using a Jobin Yvon HR-320 single monochromator equipped with an InGaAs multichannel detector. All CL measurements were performed at 30 K. The acceleration voltage of the electron beam was 30 kV, whose penetration depth was about 9.3 μm according to the Kanaya-Okayama model [10].

3. Results and Discussion

Figure 1 shows the annealing temperature dependence of V_{CES} and t_f. V_{CES} decreases monotonously as an annealing temperature rises and t_f increases rapidly at a temperature above 300 °C. These results show that the on-state losses degrease and switching losses increase as the temperature rises, indicating the decrease of recombination centers in the IGBTs.

Figure 2 shows cross-sectional CL spectra at the mid-point (about 30 μm from the surface) in the n-drift region of IGBTs. Several sharp peaks and a broad band at around 1200-1400 nm are observed in all spectra. TO denotes the transverse-optical phonon replica of the band-to-band transition. *X*, *W*, and *C* lines are known to originate from defects produced by electron irradiation [11]. *W* and *X* centers are considered to related to silicon self-interstitials and *X* center is involved larger interstitial cluster than *W* center [12, 13]. The origin of broad band observed between 1200 and 1400 nm is not clear but probably due to the self-interstitials or their complexes shifted and broadened by inhomogeneous disorder in the lattice. *C* center is well recognized as interstitial oxygen and carbon complexes in the form C_iO_i [11].

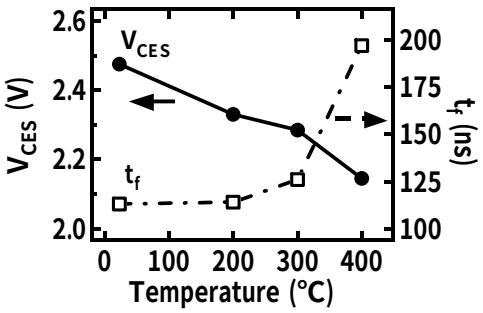

Fig. 1 Annealing temperature dependence of collector-emitter saturation voltage (V_{CES}) and current fall time (t_f).

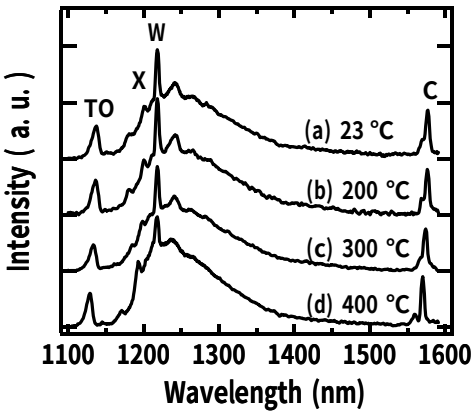

Fig. 2 Cross-sectional CL spectra in the n-drift region of IGBTs annealed at various temperatures.

Peak intensity distributions of *W* and *X* lines are shown in Fig.3 and 4, respectively. Although it seems that the electron irradiation produces uniform defect distribution, *X* and *W* centers are not observed in the p^+ region, suggesting that impurities play important roles to form the recombination centers. Moreover, the intensities of *X* and *W* lines are not uniform even in the n-drift region. *X* line shows more uniform distribution, though the intensities of both lines decrease near the surface.

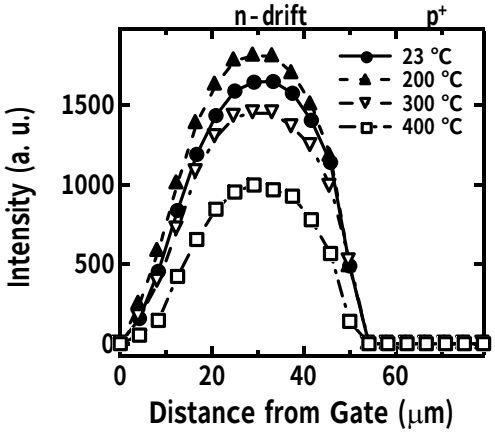

Fig. 3 Peak intensity distribution of W line.

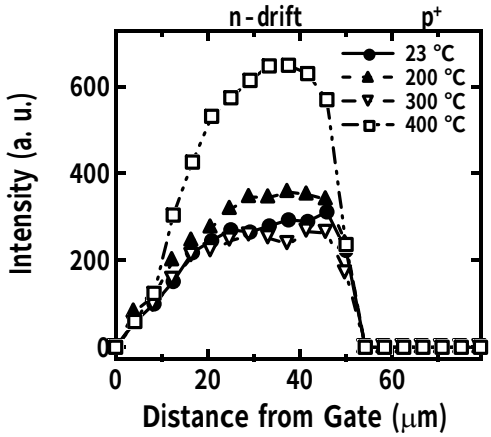

Fig. 4 Peak intensity distribution of X line.

The intensities of these lines vary as annealing temperature. *W* line decreases and *X* line increases at 400 °C while no significant change is observed at a temperature below 300 °C. It is considered that the fewer interstitials, which is the origin of *W* center, cluster and form stable bigger interstitials, which is the origin of *X* center, at 400 °C reducing the number of interstitials. The vacancy type defects such as divacancy and vacancy-impurity complexes, which are usually characterized by DLTS, are known to major recombination centers and form deeper energy levels in the band gap than those of *X* and *W* centers. We consider that the interstitials decrease the lifetime mainly through the interaction between vacancies, since the energy levels of these interstitials are shallower than vacancies.

4. Conclusion

In conclusion, we applied electrical measurements and cross-sectional CL measurements to the electron-irradiated IGBTs and investigated the relation between radiative recombination centers and electrical characteristics. The V_{CES} degreases as an annealing temperature rises and the t_f increases rapidly at a temperature above 300 °C. As a temperature rises, *W* line decreases and *X* line increases, suggesting the number of interstitials decrease and form stable bigger interstitials at elevated temperature. These changes show the good correlation with electrical characteristics. Although CL spectra contain only the information about radiative recombination centers, the application of cross-sectional CL methods to the lifetime-controlled IGBTs is useful because of its spatial and energy resolution.

References

[1] S. D. Brotherton and P. Bradley, J. Appl. Phys. **53** (1982) 5720.
[2] B. J. Baliga, IEEE Electron Device Letters, **4** (1983) 452.
[3] A. Mogro-Campero, R. P. Love, M. F. Chang, and R. Dyer, IEEE Trans. Electron Devices, **33** (1986) 1667.
[4] M. F. Catania,F. Frisina, N. Tavolo, G. Ferla,S. Coffia, and S. U. Campisano, IEEE Trans. Electron Devices, **39** (1992) 2745.
[5] J. Vobecky , P. Hazdra, J. Homola, IEEE Trans. Electron Devices, **43** (1996) 2283.
[6] P. Hazdra, V. Komarnitskyy, Microelectron. J. **37** (2006) 197.
[7] R. Siemieniec, H.-J. Schulze, F.-J. Niedernostheide, and W. Südkamp, J. Lutz, Microelectron. J. **37** (2006) 204.
[8] B. G. Yacobi and D. B. Holt, "*Cathodoluminescence Microscopy of Inorganic Solids*", Plenim Press, New York (1990).
[9] R. Sugie, K. Matsuda, T. Ajioka, M. Yoshikawa, T. Mizukoshi, K. Shibusawa, and S. Yo, J. Appl. Phys. **100** (2006) 064504.
[10] K. Kanaya and S. Okayama, J. Phys. D: Appl. Phys. **5** (1972) 43.
[11] G. Davies, Phys. Rep. **176** (1989) 83.
[12] P. K. Giri, S. Coffa, and E. Rimini, Appl. Phys. Lett. **78** (2001) 291.
[13] R. Jones, B. J. Coomer, J. P. Goss, S. Öberg, and P. R. Briddon, Phys. Stat. Sol. (b), **222** (2000) 133.