Spectral Analysis of High-Power Infrared Silicon Light Emitting Diodes by Dressed Photons : Contribution of Phonons

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We studied the phonon-assisted radiative recombination process in the high-power infrared Si light-emitting diodes fabricated using the dressed-photon-phonon-assisted annealing. A photoluminescence study conducted by using an exciting wavelength of 532 nm indicated that one and three optical phonons were responsible for the efficient light emission of the device. The device exhibited a high external quantum efficiency of 14 % and a total output optical power of 200 mW.

1. Introduction

Recent dressed photon research has spurred new developments of efficient high-power Si light-emitting diodes (LEDs) [1]. The key to achieve the Si LED is the dressed-photon-phonon (DPP)-assisted annealing technique at the p-n junction that causes the implanted B atoms redistribution. At the DPP-rich site at the diffused B atoms, momentum exchanges between conduction-band electrons and DPPs occur, leading to radiative electron relaxations [2]. We have previously reported that the Si LED after the annealing showed the photon breeding effect where emitted photon energy is equal to that constituting the DPP [2]. Here, we present the emission mechanism of the infrared Si LED obtained from a photoluminescence (PL) study using a fabricated Si LED.

2. The emission mechanism of the Si LED

The Si LED consists of a p-n junction, formed by B implantation into an As-doped Si substrate, and a Cr/Al mesh electrodes (Fig. 1(a)). After the fabrication, a DPP-assisted annealing was performed by irradiating the implanted area with a 1 W laser of a wavelength of 1314 nm for 1 hour. During this time, conduction-band electrons were simultaneously injected into the p-n junction using a time-dependent electrical current of a triangular waveform of an amplitude of 1 A and a frequency of 1 Hz. The fabricated Si LED had a total output optical power characteristics depending upon the injected current as shown in Fig. 1b. When the injected current amplitude is below 1.0 A, the total output optical power (P) versus the injected current amplitude (I) follows a quadratic relationship as shown in Fig. 1b. When $I > 1.0$ A, P varies with I exponentially, leading to the maximum total output optical power of 200 mW, or, an external quantum efficiency of 14%.

To understand the Si LED's emission mechanism, we conducted a PL study using a 120 mW excitation laser of a photon energy of 2.33 eV (532 nm). We measured the PL spectrum of the Si LED shown in Fig. 1(c). We observed two emission peaks at 1.047 eV (1184 nm) and 0.9432 eV (1314 nm), which had lower energies than the Si band gap. This indicates the phonon-assisted radiative processes (Fig. 1(d)). Furthermore, the observed emission peak at 0.9432 eV (1314 nm) confirmed the photon breeding effect in the device. We believe that the radiative recombination process in the Si LED was assisted by optical phonons since the differences in the peak energies were of integer multiples of that of the phonons (63 meV [3]) as illustrated in Fig. 1(d).

3. Conclusions

We studied the electroluminescence mechanism in the Si LED. PL study showed that the photon breeding effect occurred after the DPP-assisted annealing. The emission mechanism could be explained by the radiative recombination processes assisted by either one- or three-phonon coupling.

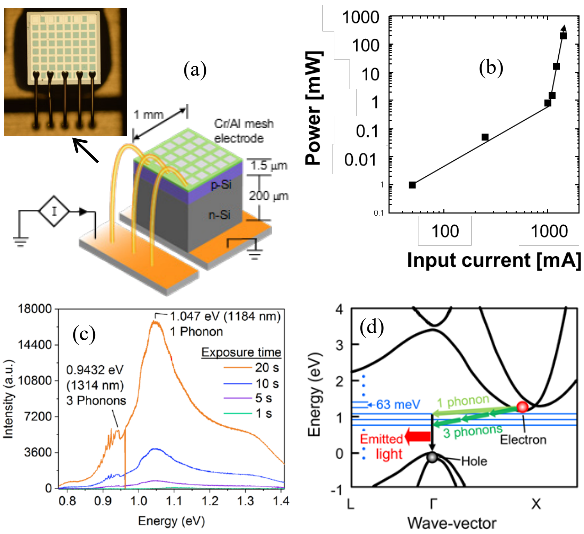

Fig. 1. (a) The Si LED. (b) The total output optical power vs input current. (c) The PL spectrum. (d) The band diagram of the Si LED.

References

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