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High Brightness Si-based Quantum Dot Light Emitting Diode

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1. Introduction

Self-assembled column-III-V semiconductor quantum dots (QDs) embedded in Si, hereafter referred to as super QDs (SQDs), are a new class of Si-based QDs which promise an enhancement of the otherwise meager light emission efficiency of Si [1, 2]. Our recent study shows that column III-V/Si SQDs only provide a type-II potential line-up where the conduction band minimum is located in Si [3]. Accordingly, the optical properties of SQDs are expected to be of indirect nature. Fortuitously, however, the built-in dipole arising from the polarity mismatch between III-V compounds and Si induces a short-ranged potential well at the heterointerface. As a result, the electrons in Si are trapped at the III-V/Si boundary and strongly-localized electron-hole pairs are created therein, which are effective in preventing carrier loss via dissipative pathways. Hence, as opposed to Si-based microstructures such as strained $Si_{1-x}Ge_x$/Si quantum wells which are largely lossy, more electron-hole pairs are to eventually recombine radiatively..

In this study, we report the fabrication of a Si-based light emitting diode (LED) of high brightness which contains strained GaSb SQDs in the active layer.

2. Experimental

Strained GaSb/Si SQDs of a few monolayers equivalent were grown by solid-source Si molecular beam epitaxy (MBE) on Si(001). The Si capping layer of SQDs is automatically n-typed doped due to the surface segregation of Sb operating during MBE. A p-n junction is thus obtained simply by using a p-type substrate. Figure 1 shows typical current-voltage characteristics of an SQD-LED.

3. Results and discussion

Shown in Fig.2 is 10-K electroluminescence (EL) spectrum of GaSb/Si SQDs. The inhomogeneously-broadened band over the 1.1– 1.7 μm region below the Si band-gap is clearly visible. The arrow indicates the energy position of the transverse optic phonon replica (SiTO) which was missing in EL as opposed to photoluminescence.

Long decay lifetimes of the order of submiliseconds observed in a separate time-resolved measurement are in support of indirect transition, which is consistent with the band line-up predicted from the model solid theory where GaSb/Si SQDs confine holes alone [3]. It is worth noting that the luminescence intensity was orders of magnitude larger than those of such Si-based quantum structures as strained $Si_{1-x}Ge_x$/Si quantum wells.

The intense luminescence, in view of the long decay lifetime, implies strong localization of carriers. As described earlier, an electric dipole layer developing at the polar/non-polar interface gives rise to a deep potential well which traps electrons in Si. The trapped electron finds a hole confined in the SQDs to form a localized electron-hole pair. Since such electron-hole pairs essentially do not sense dissipative pathways, they eventually recombine radiatively to produce luminescence of high brightness. A record high quantum efficiency of the order of 0.1% was obtained for a Si-based LED, which is comparable with commercially available LEDs made of III-V compound semiconductors.

Low-temperature EL from such an SQD-LED was so intense that we succeeded in direct imaging with a standard near-infrared camera as shown in Fig. 3.

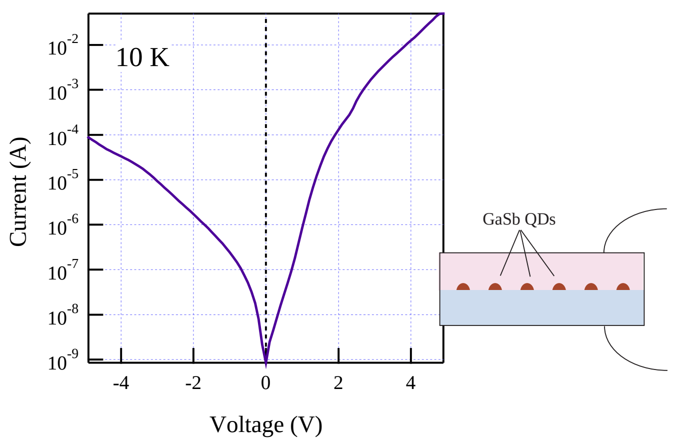

FIG.1 I-V characteristics of GaSb/Si SQD-LED.

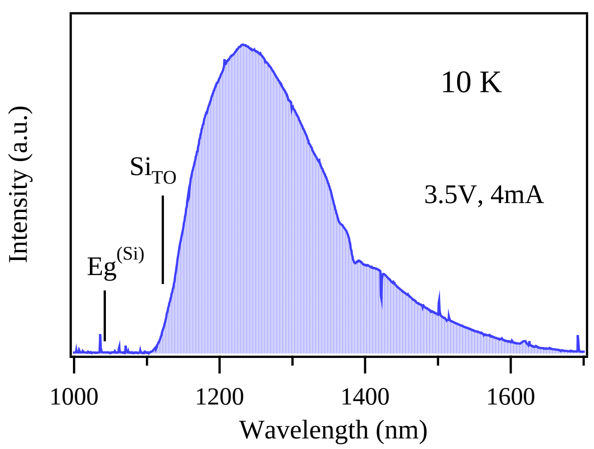

FIG.2 EL spectrum of GaSb/Si SQDs.

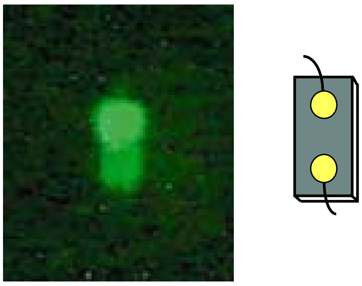

FIG.3 Near-infrared image of an SQD-LED captured by a standard infrared camera. Note that the upper electrode is in operation.

3. Conclusions

Intense electroluminescence was observed from GaSb/Si SQDs grown by Si molecular beam epitaxy. The quantum efficiency under electrical pump at low temperature was found to be of the order of 0.1%, which sets a record for Si-based LEDs.

References

[1] M. Jo, K. Ishida, K. Kawamoto and S. Fukatsu, Phys.Stat.Sol.(to be published)

[2] N. D. Zakharov *et al*., Appl. Phys. Lett. **76**, 2677 (2000)

[3] C. G. Van de Walle, Phys. Rev. B 39, 1871 (1989)