Extended Abstracts of the 2006 International Conference on Solid State Devices and Materials, Yokohama, 2006, pp. 50-51

B-2-5

Light emission from two junction Si CMOS LED's (450nm – 750nm) with two order increase in emission intensity - Applications for next generation silicon-based optoelectronics

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1. Introduction

Light emission has been observed from silicon devices operating in the reverse biased avalanche mode [1]. However, this technology seemed not very viable because of the low external power and quantum conversion efficiencies which were measured for the early devices. We have also recently realized a series of practical light emitting devices (Si LED's) using the avalanche mode of operation and that is *completely*compatible with *standard* 1.2 micron and 0.8 micron silicon CMOS design and processing procedures [2]. We have succeeded in increasing the quantum conversion efficiency as associated with these devices by about three orders of magnitude [3]. Currently, light emitting devices that can be incorporated in the mainstream silicon CMOS integrated circuit technology show enormous potential, which is a current multi-billion mainstream technology [4].

In this paper, we specifically report on a recently observed dependency of the light emission intensity as a function of current when electrons are injected (as originating from an adjacently located forward biased junction) into the main avalanching Si LED junction.

2. Approach

A series of innovative designs were realized using the European ASIC ESPIRIT programme, utilizing a number of innovative design structures using bi polar like transistor structures incorporated into CMOS technology and using standard 0,8 micron BiCMOS design and processing procedures (See Fig. 1 and 2) Each structure comprised of main junction that could be operated in deep avalanche mode with an adjacently lying pn junction near to it (Fig. 2).

Our earlier investigations wrt origin of light emission processes [2] suggest that the main light production processes may be related to host silicon atom ionization processes in the high field avalanching conditions followed by subsequent intraband relaxation processes. In the two junction mode of operation, a possibility exists for recombination of high energy (hot) holes (as exited in the avalanching junction) with low energy (cool) energy electrons as being

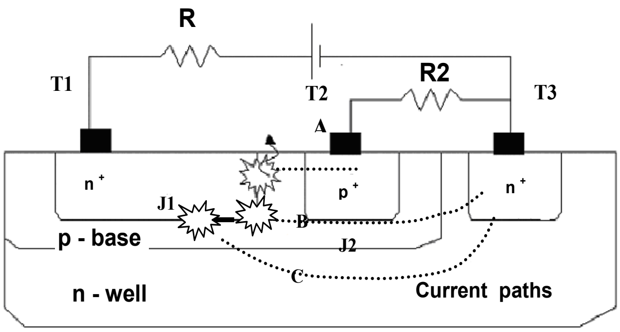

Fig. 1. Circuit and bias configuration for various modes of operation of a two junction BJT Si Light Emitting Device (LED) fabricated with Si CMOS technology. The origin of the light emission processes is schematically illustrated for current paths A, B and C, respectively.

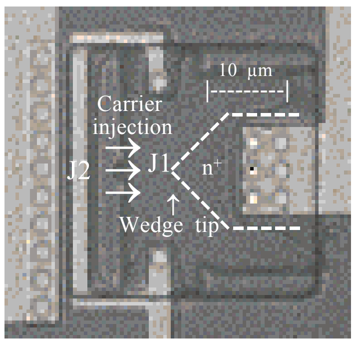

Fig. 2 Bright field optical micrograph showing the top surface of the device as well as the current configuration for current path C of operation with J2 injecting electrons into the avalanhing junction J1.

injected from the second junction. Taking the product of the carrier densities into consideration as well as the band to band transition probabilities at various eV's and momentum states, the total electron-hole recombination is estimated to be several orders of magnitude higher than for single junction operation.

3. Experimental results

Recent experiments wrt our two junction mode of operation showed about two orders higher emission intensity (Fig. 3 and 4). The devices emitted visible light at intensities up to 10nWμm^{-2} at operating conditions of 8V and 80 μA – 2mA in the 450 – 750 nm (1.5 -3eV) wavelength region. The power conversion efficiencies are of the order of 10^{-4} and 10^{-3}. Spectrally, the injection condition resulted in the growth of peaks at 2eV and at 2.8eV (Fig. 5). These transitions may be especially possible in the excitation regions near the edge of the depletion region on the p-side, between highly excited (hot) holes and low energy (cool), as injected, electrons.

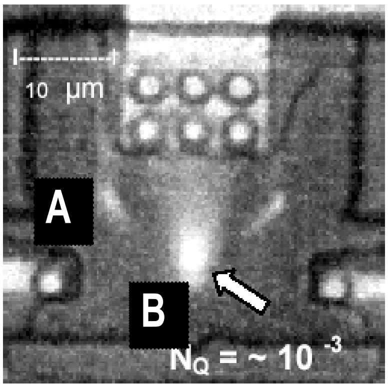

Fig. 3: Intensity versus photon energy profiles as measured for a two junction bipolar like junction Si CMOS LED for various total device current magnitudes (n+ to n region, Fig. 1). Particularly interesting is the growth of the 2.2 e V and 2.8 eV peaks during strong injection conditions of electrons into the main avalanching light emitting junction, J1 (Fig .1).

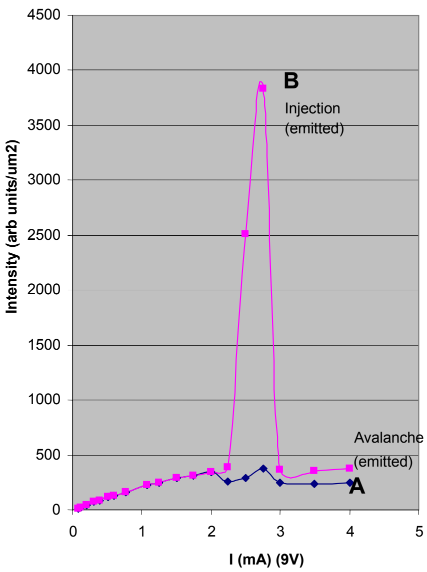

Fig. 4. Optical performance of the n+pn bipolar like Si CMOS light emitting device with the main junction (site B) in avalanching reverse bias light emission mode and about 20 % electron current injected into the junction.

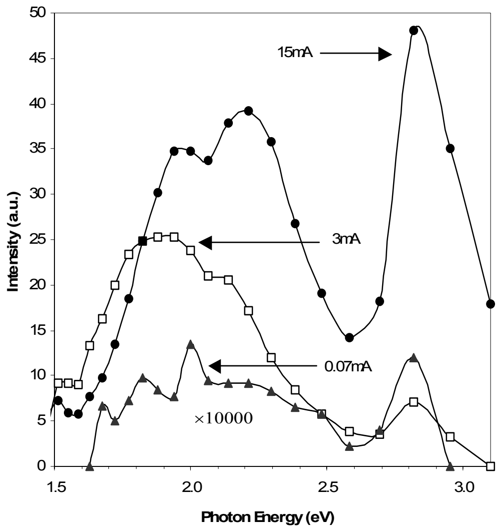

Fig. 5 Light emission intensity profiles for single junction (Site A) and two junction mode (Site B) light emission mode of operation (as were obtained for a second similarly designed device).

4. Conclusions

We have demonstrated an increase in the emission intensity for a novel two junction bipolar like device incorporated in CMOS technology. The emission intensities as observed are about three orders higher than the low frequency detectabilty limit for Si p-i-n detectors of comparable dimension. Diverse optical communication possibilities are, therefore, possible with these devices, either enabling chip to chip optical data communication; or on chip optical data communication and data processing through Si CMOS based optical waveguides. Recently, Wada et al proposed the utilisation of 450nm based LED's for clock pulsing in large diameter, next generation silicon microprocessor circuits [5].

References

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