Journal of Electron Devices, Vol. 6, 2008, pp. 170-173

Journal of Electron Devices
www.jeldev.org

Silicon for optoelectronic

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Review article

Keywords: **Silicon, Optoelectronic, Light, Nano-devices, Junction**.

Silicon, with more than 95% of the international market share, dominates other semiconductors. The high performance of silicon microelectronics devices for electronic systems results from advanced technology in very low size for ultra large-scale integrated circuits with better performance, lower energy consumption and high reliability. New applications for the society of knowledge drive the development of the market. Further increase of speed for transmission, higher qualities of information and imaging restitutions are required for applications in telecommunications, audio-visual, and game devices.

Silicon components, bipolar transistors and field effect transistors, are also required for operations in hostile environments as thermal interactions, radiation exposure and electrical field stress. Scientists have introduced new structures and new processes on nano-meter scales with silicon microelectronic circuits now advanced for "Research and Developments" activities. Performance improvements have seen with single-electron and molecular electronics. Scientists have also the responsibility to inform the public for its understanding and the politics before decisions to be taken, to create debates in order to listen to advice from society. It is the aim of this paper to give an overview of current research work and scientific publications along the past decade (1998 - 2008), concerning optoelectronic silicon devices, together with a description of our results. This paper describes silicon as the material of optoelectronic and concerns light emitting devices, optical gain, photonic crystal and silicon platforms for integrated optical circuits.

Silicon has an indirect band gap structure [1] which limits the light-emitting efficiency of silicon devices. Despite the very fast development of silicon based electronics, optical applications of silicon devices have not been drive. 'How to design an all silicon laser?' is still a topical question. The question 'which silicon device for transformation of electronic signals into optical signals?' is still relevant today. At present, laser diodes made with III-V compound are used to convert signals [2] for the purpose of communications system with optical fibres, but the incorporation of such compounds in silicon layers leads to distortions of the signals, degradation of sensibility, then limitation of reliability. It is well established since 1958 [3] that a reversed biased silicon p-n junction could emit visible light. The evolution of photon emission from the emitter-base junctions of bipolar transistors during electrical aging was published for the first time in 1999 [4]. The junction in [4] was biased in avalanche breakdown. And the study concerns measurements after different durations of the applied electrical constraint. The photon emission was shown to evolve as a function of time. Hot carriers degradations and hydrogen liberation mechanisms have been considered. Figure 1a displays the geometry of the emitter-base junction of a commercial bipolar transistor (2N2222A), and the light emission from the emitter base junction after 6 mn of stress duration (V_{DE} = Volts) is shown in Fig. 1b. The emission is concentrated on a particular part of the junction with high curvature.

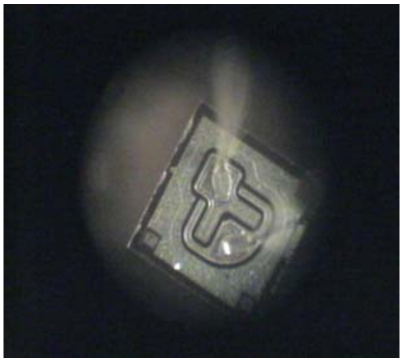

Fig. 1a. Geometry of emitter-base junction, bipolar transistor 2N2222A.

Fig. 1b. Photon emission along emitter-base junction during stress (V_{BE} = -8 Volts)

Silicon is considered as a material option for photonics since the middle of this decade. Many works considered silicon optoelectronic applications [5] with the goal to create an all silicon laser.
El Tahchi (2004) presents in [5] an advance in optoelectronic silicon based applications: a nano-defect structure has been created which boosts the radiative recombination processes which lead to a localised silicon emitting process. The junction is polarised for high injection operations. Fig. 2 shows the linear increase with the injected current, of the emitted light intensity.

Introduction into the silicon layer of selected doping material together with realisation of quantum confinement have been considered [6] in order to increase the radiative recombination rate. Liu.et al [7] obtained a high speed silicon modulator. Reed [8] introduced the idea which concerns the development of "optical circuits" as light emitters, modulators, amplifiers, detectors, to realise photonic silicon circuits. Technology for the development of photonic devices [9, 10] led to the emergence of waveguides obtained as a periodic crystalline structure. Photonic crystal structures for integrated optics [11] and applications with silicon-on-insulator technology for waveguide photonic were reviewed in [12]. Krauss [13] discussed applications of photonic crystal slow light waveguides to functional devices like optical delay lines and switches from operating processes related to phase changes. Point defects have been observed [|6] to modify the electromagnetic properties of the waveguide introducing photonic microcavities. Light emitting [14] molecules or ions have been injected in nano-structres in order to modify the emission properties of the photonic crystal. The selective transmission of heterostructures (which consist of multiple photonics waveguides) in photonic crystals [15] is related to properties of the high quality of the nano-cavities. The success of photonics devices has generated the interest/development of silicon based integration platforms [16]. New photonic devices [6] are expected from exploitation of very low dimensional silicon crystals.

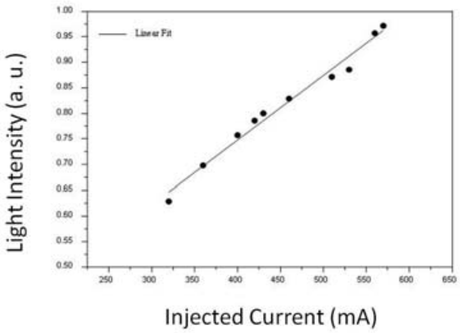

Fig. 2. Intensity of the IR emission from active nano-defect on the surface layer of a forward biased silicon n-p junction, as a function of the injected current (bipolar transistor 2N2222).

Silicon microelectronic devices have been studying when operating in conditions where high electrical fields produce hot carrier degradation processes in the crystal layers. The description [17] of the induced implanted defect layer leads to identify the conditions of high injection effects. An inversion of carrier's populations is observed which leads to emphasize applications for laser effects in silicon devices. Figure 3 shows a stability of the degradation of the junction quality factor during the phase of creation of the substructure. For this work in [17], the degradation processes are correlated with induced high injection effects and the changes in the avalanche generated light emission. Hot carrier injection is considered as a process to implant selected point defects leading to local modifications of the semiconductor band structure. A reliable [18] simulation of the induced effects needs a new description of carrier transport in nano-scale layers together with a quantum approach for the electronic structure. H. Toufik in [19] has introduced a nano-layer degradation to aid in the recombination processes necessary to obtain a silicon light emitting process.

Silicon based platforms have still, at the end of 2008, to be improved before developments of optical silicon devices. The challenge concerns the speed limitations related to low bandwidth and the increase of efficiency for light emitting processes in silicon systems. These systems are dominated by quantum effects and strong interactions either between carriers or with the environment. Collaborations are needed between knowledge workers in solid state matter, statistical physics and quantum field theory. The introduction of new theoretical paradigms to answer the fundamental questions encountered in physics of nano-systems will generate a development of chip-scale technology which promises to drive a world market for a new generation of all-silicon photonic nano-devices.

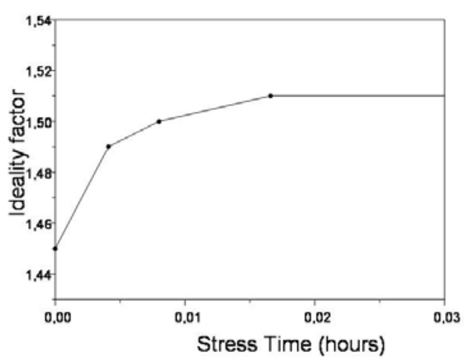

Fig. 3. The junction ideal factor evolution during the stress (V_{BE} = - 8V). The stability of the degradation is correlated with the creation of a substructure in a high injection process (npn bipolar transistor).

Acknowledgments

The authors thanks Doctor Max Blanco for fruitful discussions and the review of this paper;

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