Materials Science & Engineering B 231 (2018) 28–31

Contents lists available at ScienceDirect

Materials Science & Engineering B

journal homepage: www.elsevier.com/locate/mseb

Light emission from a poly-silicon device with carrier injection engineering

Kaikai Xu[a,*], Lei Huang[b], Zhengyuan Zhang[b], Jianming Zhao[a], Zhengping Zhang[b], Lukas W. Snyman[c], Jacobus W. Swart[d]

[a] State Key Laboratory of Electronic Thin Films and Integrated Devices, University of Electronic Science and Technology of China, Chengdu 610054, China
[b] Science and Technology on Analog Integrated Circuits Laboratory, Chongqing 400060, China
[c] Department of Electrical Engineering, University of South Africa, Pretoria 0001, South Africa
[d] Faculty of Electrical and Computer Engineering, State University of Campinas – UNICAMP, Campinas CEP 13083-852, Brazil

ARTICLE INFO

Keywords:
Integrated optoelectronics
Light sources
Silicon

ABSTRACT

Development work was conducted on $N^+PN^+PN^+$ Poly silicon light-emitting devices which are compatible with silicon-based integrated circuit technology. We discuss the emission characteristics of visible light by a monolithically integrated Poly-Si diode under reverse bias. With the structure of modified PN junctions, the carriers injection occurs through silicon slabs of only a few nanometer thick. The dominant role of non-radiative recombination at the N^+ and P^+ contacts is diminished by confining the injected carriers around the PN junction's interface in which avalanche takes place. The current-dependent optical radiation presents a broad spectrum in the 400- to 900-nm range. Although the emission efficiency is low due to silicon's indirect bandgap, it is advantageous to utilize these devices in all-silicon optoelectronic integrated circuits (OIC's).

1. Introduction

Due to the 1.12-eV indirect band gap, silicon emits weak light only by band-to-band transitions [1] or by means of defect states to band transitions in the near infrared [2]. Many attempts are currently made to increase the efficiency of a silicon based light emitters, using quantum confinement [3], nanocrystals [4], or carrier energy and momentum engineering [5]. To realize visible light emission from silicon, an energy of about twice the silicon band gap is required. Such an requirement could be achieved using hot carrier induced radiative recombination [6,7]. These structures emit light in a broad wavelength regime, ranging from 400 to 900 nm [8], particularly in MOS-like structures [9]. Previously mentioned devices emit light with mono-silicon on bulk silicon. Recently, Si-CMOS light-emitting sources appeared with much higher efficiencies by implementing two and three junction Si CMOS injection-avalanche LEDs that emit at 450 to 750 nm [10,11]. However, above-mentioned devices use the mono-silicon as the optical material for light emission.

A poly-silicon diode structure that is reverse-biased for visible light emission in the avalanching region is proposed in the study. To overcome the drawback of high operating voltage and high field in the avalanche mode of operation as normally occur in the avalanche mode, a four-junction ($N^+PN^+PN^+$), diagonal-avalanche control, and carrier injection-based device was designed to investigate the mechanisms involved with light emission from the structure and to determine the dependency of quantum efficiency when current density confinement in the avalanching region with current injection occurs from an adjacent laying forward-biased junction. Also, the proposed device is producible using standard silicon process technology and offers therefore the opportunity to be fully integrated with other silicon devices in order to generate an optical silicon IC's.

A most interesting and most promising result from this study is that the 600 nm peak is seemingly remarkably increased as compared with previous spectrums as observed for lower defect epitaxial layer silicon and avalanche only spectra [12]. Quantum efficiency as observed for the presented $N^+PN^+PN^+$ Poly-Si LED is also about two orders higher as that observed for the low defect single junction Si LEDs [13].

It is organized as follows: after an overview of the device structure, optoelectronic characteristics of the poly-silicon based light-emitting device is presented. Then dependence of emission efficiency on device's driving current is analyzed. Finally, conclusions of this study are given.

2. Device design and physical approaches

The device structure is shown in Fig. 1, $N^+PN^+PN^+$ regions are created in an elongate columnar region on the SiO_2 layer. Appropriate metal (Al) contacting is supplied to the front of N^+ and to the backside of N^+. The fabrication of the silicon device is performed using a simple

---

* Corresponding author.
E-mail address: kaikaix@uestc.edu.cn (K. Xu).

https://doi.org/10.1016/j.mseb.2018.07.002
Received 24 September 2017; Received in revised form 25 June 2018; Accepted 9 July 2018
0921-5107/ © 2018 Elsevier B.V. All rights reserved.

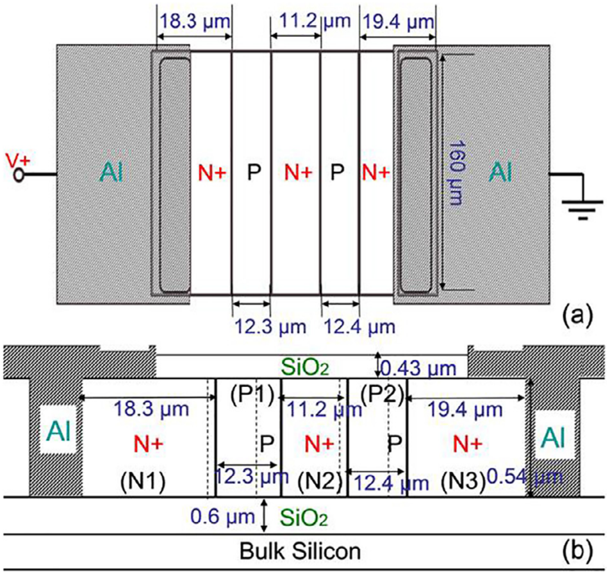

Fig.1. Device design in which $N^+PN^+PN^+$ regions based conduction channel device is created on the SiO_2 layer: (a) top view; (b) cross sectional view.

process that is largely Si-IC compatible with minor modifications.

The first N^+P junction (N1P1) is reverse-biased such that the depletion region reach through to the second N^+P (N2P2) junction. Since the third layer is N^+ (N2), the electric field in the lower doped P region (P1) is enhanced when the depletion region reaches through to the N^+ region (N2), with the E-field profile being almost flat. This leads to enhanced multiplication and avalanching in the lower doped P region (P2). Energetic carriers under the influence of the high E-field undergo various excitation and recombination processes in this region.

Based on the concept of light emission from avalanche Si p-n junctions, the proposed device is hence nomenclated as a "$N^+PN^+PN^+$ Si avalanche-based" optical source. Fig. 2 shows a photomicrograph of the eventually realized device as it appeared under an optical microscope at high magnification conditions. Particularly notice the very small dimensions of the respective bodies and their proximity with each other.

Indeed, the device can be treated as two forward-biased PN junctions and two reverse-biased PN junctions in series. Accordingly, light emission occurs in the avalanching region where PN junction is reverse-biased for high-field require to generate photons, as shown in Fig. 3.

3. Results and discussion

Current-voltage (I-V) characteristics for such a rectangular diode structure in which the $N^+PN^+PN^+$, four-junction device is biased by a driving voltage V_D is shown in Fig. 4. The original breakdown by avalanche multiplication occurs at a bias of 25 V. At a reverse bias of approximately 20 V, an early breakdown occurs. Using a linearization of this early breakdown, the breakdown voltage is determined to be 21.5 V.

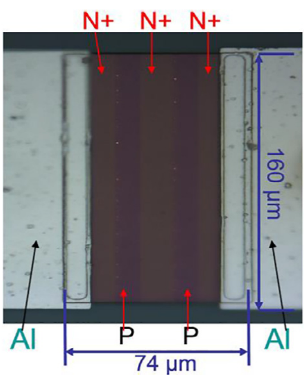

Fig. 2. Micrograph of the fabricated device in which the four junctions are, diagonal avalanche controlled.

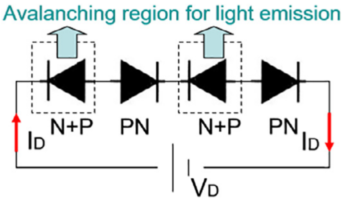

Fig. 3. The device operates as four junctions in which two of them are reverse-biased to realize avalanche-based light emission in silicon.

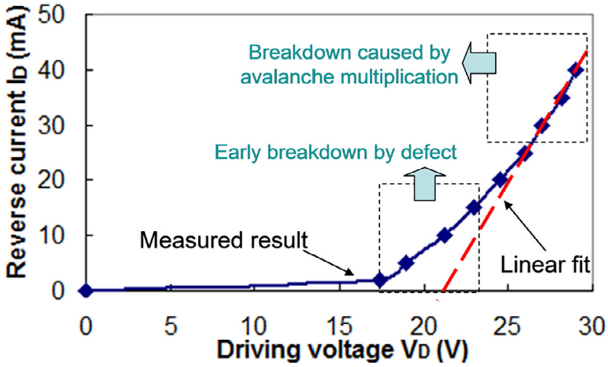

Fig. 4. Reverse current I_D versus applied voltage V_D for the four junction $N^+PN^+PN^+$ Poly Si light-emitting device.

The early breakdown is assumed to be caused by localized defects at the metallurgical p-n junction. The ascending slope of reverse current versus driving voltage at early breakdown is much softer than that of avalanche-multiplication breakdown. Indeed the early breakdown by defect is attributed to soft breakdown, whereas the breakdown caused by avalanche multiplication is defined by hard breakdown.

With diagonal avalanche control junctions, the optical output is measured with a photo-multiplier tube normal to the surface of the structures with minority carriers into the avalanching junctions. Fig. 5 demonstrates the control of light intensity via the driving voltage V_D.

In accordance with correlation between reverse current I_D and light intensity as a function of driving voltage V_D, Fig. 6 further demonstrates that the four-junction based silicon device has a linear "light intensity versus reverse current I_D" characteristic. The total emission intensity is integrated over the entire spectral response of the detector and summed for all pixel values that correspond to the diode-based device region.

At lower reverse current, the relationship of the output optical

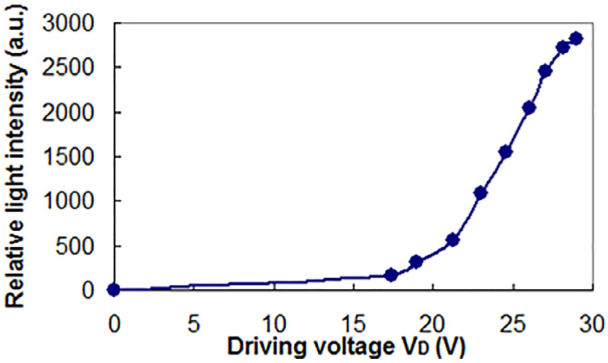

Fig. 5. Relative light intensity emitted from the silicon device as a function of driving voltage V_D applied on the $N^+PN^+PN^+$ regions.

Download English Version:

https://daneshyari.com/en/article/7924046

Download Persian Version:

https://daneshyari.com/article/7924046

Daneshyari.com