Potential of Si-nc MOS devices as Transceivers for interchip optical links

A. Marconi, A. Anopchenko, L. Pavesi
Nanoscience Laboratory, Department of Physics
University of Trento
Via Sommarive 14, 38121 Povo (Trento) Italy
marconi@science.unitn.it

G. Pucker
Microtechnologies Laboratory
Bruno Kessler Foundation
Via Sommarive 18, 38121 Povo (Trento) Italy

Abstract—**New silicon nanocrystal (Si-nc) transceiver is present in this work. Both light emitter and receiver share the same circuit that is fabricated in a standard cMOS line and linked together in free-space with an optical fiber. A high efficiency is achieved which makes good promises for optical links in integrated silicon photonics and numerous applications.**

Si-nc devices; Transceiver; interchip optical link

I. Introduction

Integration of a transceiver in a single chip requires the integration of a light source and a photodetector. These transceivers when realized in silicon have enormous potential market for high speed optical interconnections, for optical signaling in harsh environments with high magnetic and electric field, for (bio)chemical sensing, etc. Many approaches have been tried in order to demonstrate the feasibility of a monolithically integrated transceiver, i.e. all in silicon. In [1] a silicon solar cell was bonded on top of another one; a good optical coupling and system efficiency was shown but the devices were very large, the wavelength mismatch between the light emitted and absorbed yields only 33% of coupling efficiency and the complexity of the cells makes integration difficult. In [2] on-chip integration is shown using a III-V substrate while only 10^{-4} % of power conversion (power from emitter revealed by the receiver) was achieved.

Our approach considers two cMOS capacitors, the simplest structure achievable, where the gate oxide is replaced by a Si-nc multilayer used as active material. Under forward bias Si-nc structure emits light efficiently in visible and under reverse bias the same Si-nc device work as photoreceiver. Each cMOS capacitor could play the role of the emitter as well as of the receiver. The optical link was done by a fiber optic in order to prove the feasibility of a monolithically integrated transceiver useful in telecommunication or sensing application. The silicon based technology needed to grow such system allows potentially low fabrication cost.

II. Experimental

A. Devices and Setup Description

The devices structure is a metal-oxide-semiconductor (MOS) capacitor. Alternating layers of stoichiometric SiO_2 and silicon rich silicon oxide (SRO) were grown on p-type Si wafer by PECVD. This active layer is composed of 5 layer of SRO and has a nominal thickness of about 25 nm.

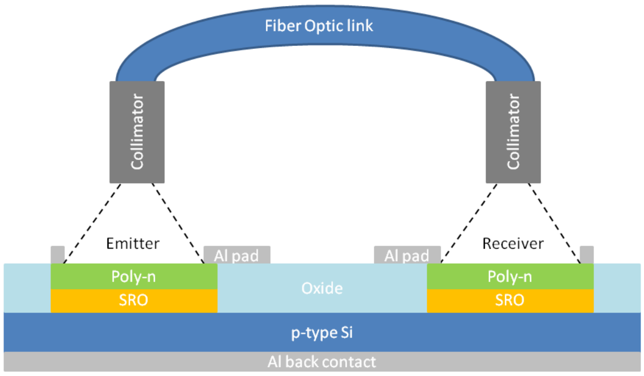

Figure 1. Scheme of the transceiver. Two identical devices are used as emitter and as receiver. The optical link if formed with an optical fiber.

During an high thermal annealing silicon nanocrystals are formed in the SRO layer. This is used as the gate oxide in our capacitors. The top contact is formed by 100 nm n-type polycrystalline-silicon, while 500 nm thick Al grid is used to connect the active area of 10^{-3} cm^2 with the bonding pad.

Recently Si-nc LED emitting in the visible range with the best efficiency reported so far was demonstrated by us [3]. The devices are also able to work efficiently as a detector at low light intensity [4]. More details on the devices and its characteristics are reported elsewhere [5]. Fig. 1 shows the scheme of the setup used to make the optical link. The devices have a diameter of 300 μm and are chosen at a distance of 5 cm in order to prevent interferences through the substrate. A visible multimode fiber optic is used to couple the two devices together. The coupling is optimized with a micromanipulator using each LED as emitter and maximizing the signal at a Si APD detector.

B. Electrical and Opto-Electrical Characterizations

In order to understand the electrical behavior of the devices under test Fig. 2 shows the Current-Voltage characteristics under dark and under illumination. Notice that two different scales are used to emphasize the electroluminescent region in forward bias (at the right) and the detection region in reverse bias (at the left). The dots reported on the I-V curve, in forward bias, represent the current values where electroluminescence is observed.

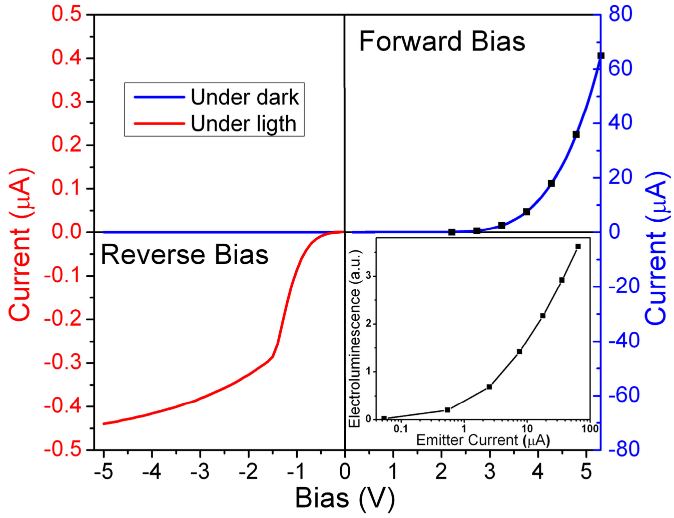

Figure 2. Current-Voltage characteristics under dark (blue) and under illumination (red). Black dots show current values at which EL signal (shown in the inset) was recorded. Left panel shows the photodetector region of the receiver.

In this region I-V characteristic is not affected by the illumination while in reverse bias the characteristics differ due to the contribution of the photogenerated current.

In order to measure the power conversion efficiency of the system the receiver was polarized at -4V and a voltage sweep on the source was done. Fig. 3 shows the photocurrent at the receiver versus the injected current at the source. Under dark a current of 0.5 pA flow through the detector whith a power consumption of 2 pW. Under the illumination the current grow up to 5 pA and the dissipated power is rather low. For the source, as shown in [3], the emission power efficiency reach its maximum at low injecting current because the electroluminescent intensity grow more slowly than the injecting current due to high losses at high biasing.

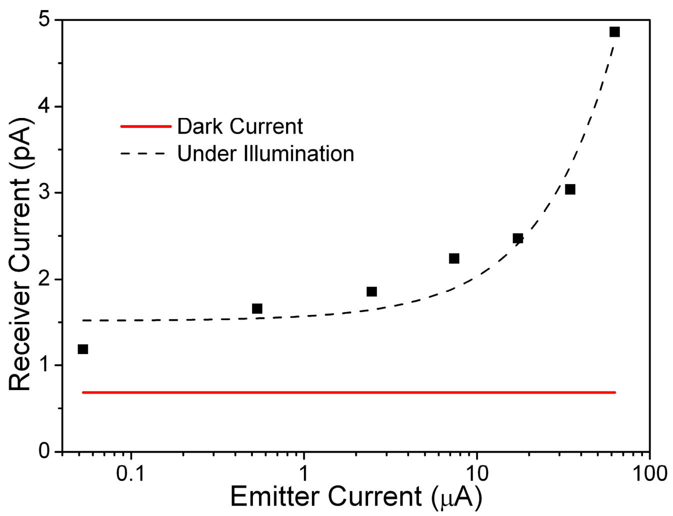

Figure 3. Photocurrent measured at the receiver versus the injected current at the source.

Fig. 4 show the power conversion efficiency of the system:

$$\eta\,\% = \frac{P_{Rl} - P_{Rd}}{P_{Rl} + P_E} \cdot 100.$$

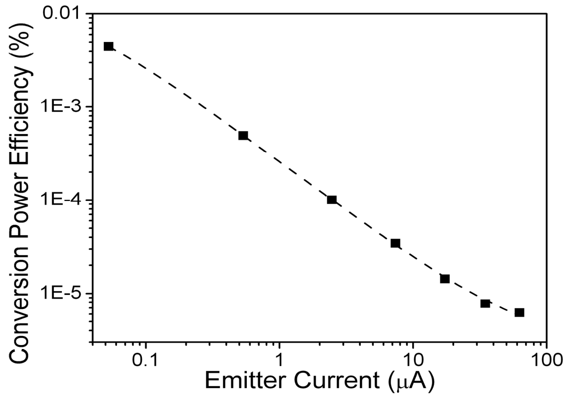

Figure 4. Power conversion efficiency versus source current

P_{Rl} is the power at the receiver under illumination, P_{Rd} the power at the receiver under dark and P_E the power injected at the source. From this figure it is clear that the system is more efficient at low injection current due to the higher efficiency of the emitter at this injection. Even with a not optimized optical coupling due to the crude coupling whit the optical fiber, it was possible to obtain efficiency up to 0.01%. This is attributable to the fact that the visible emission from the emitter can be absorbed by receiver with an efficiency larger than 80%.

III. Conclusion

In this paper we have demonstrated a proof-of-concept for an efficient silicon based transceiver for interchip communication made by standard cMOS technology. It is based on the use of the very same device both as emitter as well as a receiver. Despite the crude optical coupling the results here reported are very encouraging. More characterizations on the behavior of the system, also in pulsed regime, will be presented during the conference.

Acknowledgment

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