Optimizing Er-doped layer stacks for integrated light emitting devices

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Abstract

We will review the recent advances of our group in the field of Er doped integrated light emitting devices. The emphasis will be in optimizing internal quantum efficiency and in multilayer-stack engineering.

Introduction

Following the paradigm of miniaturization in CMOS microelectronics, integrated photonics is expected to impact in the coming decades in most areas of our lives. Silicon CMOS photonics is currently accepted as the key technology platform for this purpose because: i) It enables convergence of electronic and photonic functions in the same chip (e.g. telecom signal processing and optical interconnects); ii) It allows the mass manufacturing of large scale of integration photonic chips with such mature technology that has well developed design and simulation tools and iii) It is a versatile photonic technology that is contributing to the 'green photonics' revolution in all its dimensions through the vast deployment of smart lighting products, photovoltaic components and photonic sensors. Development of silicon based integrated light emitters will impact then telecom applications if they emit at telecom wavelengths (Er-doped for example) and lighting and signaling applications and displays if they emit in the visible.

Silicon oxide and silicon nitride as single layers or as nanostructured materials (off-stoichiometric) have been widely employed in mainstream CMOS technology as dielectric materials. They have been used by our group as matrix materials for integrated light emitters. Er doping allows shifting the emission to the important telecom wavelength at 1.54 μm. For optical excitation Si nanoclusters and Er-codoping benefits are still not clear due to the low number of coupled ions. Nevertheless, for the electrical excitation, the presence of a nanostructured layer brings some benefits: i) reduction of the effective barrier height for the electrical injection; ii) increase of the conductivity of the matrix and iii) a clear improvement of the reliability of the devices.

We report on the electrical and electroluminescence properties of four different matrices based on silicon oxide and nitride co-doped with Er ions and Si-ncs. The different conduction mechanisms and their correlation with the luminescent ones are investigated. Different geometry of the multilayered stack is investigated for electron acceleration and impact ionization. In addition, an assessment of the electroluminescence at 1.54um in terms of efficiency, reliability and lifetime operations of the devices will be presented. Finally, electrically driven Er^{3+} doped Si slot waveguides emitting at 1540 nm will be demonstrated

Experimental Details

Most of the results that will be presented are on samples obtained by PECVD and LPCVD. Silicon rich oxides and nitrides are deposited and then annealed for phase separation and Si clusterization. Other series of samples were grown by reactive sputtering. Er is introduced by ion implantation in the CVD samples and in situ by sputtering co-doping. Electrical measurements were accomplished in MOS capacitor devices with area of 300 x 300 μm^2. Also, all devices were polarized under DC regime by means of Agilent Semiconductor Analyzer B1500A.

Results and Discussion

Layers with silicon nanoclusters are much more conductive than layers without ones in a degree that depends on the silicon excess. The optimization of the electrical characteristics and the optical response has allowed determining that a silicon excess of 10-15% is the best one in terms of efficiency and reliability.

An injection layer with relatively high silicon excess (20%) is useful to reduce the Fowler-Nordheim barrier for injection and allows the device to work at lower voltages. The presence of a stoichiometric oxide accelerator layer has a strong impact on the efficiency and power emitted in consequence with the fact that it is impact ionization and not energy transfer or bipolar injection the main mechanism for Er excitation. Figure 1 also shows that not only the fundamental level but also many upper levels of Er are excited upon impact of the hot electrons.

Silicon rich oxides are the most efficient matrices to host the Er ions although stoichiometric silicon nitride works quite well and at a lower voltage. We believe that silicon rich nitrides present a lot of leakage paths and are not so well suited to host optically active Er ions. This last issue demonstrates also that silicon nanoclusters provide conduction but are not a means to transfer excitation energy to the Er ions, i.e. they are not good sensitizers for the electrical excitation.

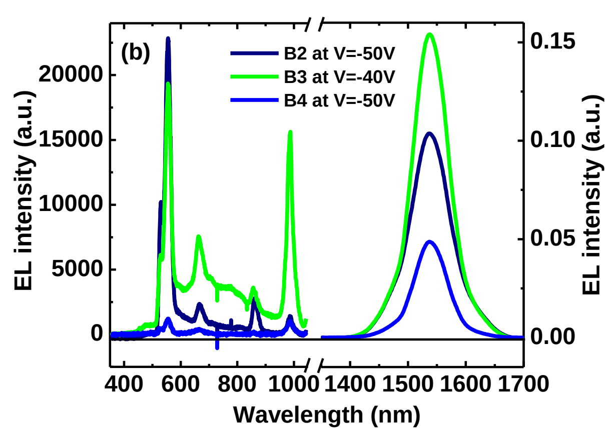

Figure 1. Visible and infrared emission spectra of Er-doped silicon oxide and nitride layers.

As for the electrically driven Er^{3+} doped Si slot waveguides we have accomplished the horizontal coupling of an integrated LED to a silicon wire and a grating. Pulsed polarization plus pump and probe experiments provided information about carrier losses and lifetime as a function of voltage. More results will be presented at the conference.

References

[1] S. M. Sze, and Kwok K. NG, Physics of Semiconductor Devices, 3rd ed. Wiley, New York, 2007.
[2] D. J. Lockwood, and L. Pavesi "Silicon Photonics II, components and integration", Springer, 2011.
[3] O. Jambois, et. al., J. App. Phys. **106**, 63526 (2009).