Structural and luminescence properties of silicon-rich oxides and nitrides fabricated by PECVD

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Abstract

During the last two decades, silicon-based light emitters have attracted a lot of attention due to the many benefits envisaged [1]. The implementation of a silicon-based light source using the mainstream CMOS technology is sound and also interesting as it provides an entire new framework for more efficient, sustainable and low-cost devices with full integration capabilities [2]. Thus, several strategies were tackled in order to overcome the poor emitting properties offered by silicon, due to its indirect band gap. In particular, it was in the early nineties when silicon nanocrystals (Si-ncs) came into play, taking advantage of the photoluminescence (PL) enhancement provided by the quantum confinement of trapped excitons within Si-ncs embedded in silicon oxide [3]. From this point on, many research groups focused on the topic, accomplishing major breakthroughs for the scientific community [4]. Noteworthy, there is still a lack for an efficient electrically driven silicon-based light emitter (LED or even a LASER). Among other drawbacks not solved yet, one has to consider the challenge of injecting electrons into a dielectric material without limiting other key factors such as the reliability or device lifetime [2]. Furthermore, there is a strong trade-off between electrical conduction and emission efficiency in silicon-rich oxides (SRO). In terms of PL efficiency, a well passivated material is desired to reduce local defects situated at the nanocrystal-oxide interface and hence diminish the non-radiative paths, although it also makes more difficult the electrical injection. On the contrary, highly defective dielectrics provide good electrical conductivity while displaying low optical efficiency (high non-radiative recombination rates). Consequently, there is only a narrow window of success where both the light efficiency and the electrical injection provide good electrical injection and efficient luminescent emission. Also, other dielectric materials such as silicon nitrides have been investigated as host matrices for Si-ncs [5-7]. Silicon nitride presents several advantages compared to silicon oxide. For instance, it has a larger refractive index and a lower barrier height that makes it suitable for high quality resonant cavities [8] and electrical injection [6]. Moreover, the low two-photon absorption provided in the infrared range stimulates its application in infrared light emitting devices [9].

In this work, we present our roadmap towards the development of efficient silicon nanocrystal-based light emitting devices. In particular, we have centered our efforts in the structural and luminescence properties of silicon-rich oxides and silicon-rich nitrides (SRN) fabricated by plasma-enhanced chemical-vapor deposition (PECVD). The stoichiometry of luminescent layers was sequentially modified in order to introduce a different silicon excess in each sample. Si-nc formation was accomplished after high-temperature annealing samples for 1 h under N_2 atmosphere. Different temperature annealing treatments were performed in samples, ranging from 800°C to 1100°C. X-ray photoelectron spectroscopy (XPS) denoted a variable silicon excess in the matrix and the existence of Si-Si bonds in samples annealed at 1000°C or above. Variable angle spectroscopic ellipsometry (VASE) was used to identify important parameters such as the deposited thickness, the roughness, the refractive index or the extinction coefficient of samples. Layer thickness and roughness were found to be almost independent from the silicon excess, whereas an evident shift of the refractive index and extinction coefficient was displayed in SRO [see figure 1(a)]. On the contrary, only slight differences were observed for SRN, denoting its low sensitivity to silicon excess variations.

The PL of samples excited under 325 nm displayed two different trends. Whereas SRN showed a broad white emission centered at 550 nm, bright red-near infrared emission located around 750 nm was observed in SRO [see figure 1(b)]. Similarly, a different PL lifetime was measured in SRN with respect

to SRO. Whereas very fast decay times were identified for all SRN (in the picosecond range), longer values were determined for annealed SRO (few microseconds). Moreover, an evident increase of the decay time was observed for higher annealing temperatures [see figure 1(c)].

The good optical properties of the studied SRO and SRN layers strongly encourage their implementation as luminescent layers in metal-oxide-semiconductor structures to procure the electrical injection and consequently electroluminescence emission. The light emitting device consists of a semitransparent electrode from which electrons are injected (anode), a luminescent layer (SRO or SRN) and finally a cathode to collect injected electrons. Ongoing work is being done in that direction, thus providing an exciting scenario for the progress on the complete integration of the electronic drivers and the optical performance in a silicon CMOS line.

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Figures

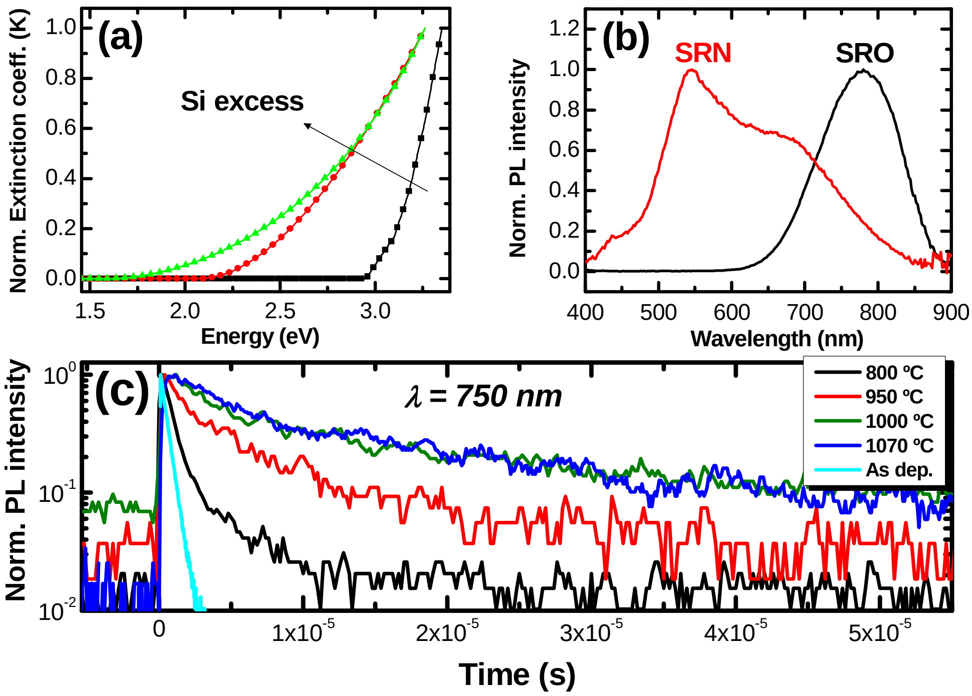

Figure 1 (a) Variation of the extinction coefficient as a function of silicon excess, (b) typical photoluminescence spectra for SRO and SRN, and (c) evolution of PL decay times as a function of the annealing temperature for different SRO samples.