A new paradigm for infrared light emission from Er-doped porous silicon

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The possibility to obtain light emission from silicon would open the way to cheaper and more efficient all-Si light emitting devices (1-5). Er clustering is one of the major drawbacks in the aim of obtaining sufficient optical gain in Er-doped Si materials. Till now, the aggregation of Er atoms in the doped structures seems an unavoidable obstacle in both Silicon rich oxide structures and porous silicon (PSi) structures. Significant efforts have been spent in the search of an equilibrium between the amount of Er present in the structure, the Er clustering and the overall light emission intensity. Unfortunately, whatever the effort, no successful result has been reported in the literature.

For PSi, the long-standing failure to govern the clustering has been attributed to insufficient knowledge of the several, concomitant and complex processes occurring during the electrochemical Er-doping as, for instance, the effect of the doping current density or the current intensity-dependent formation of an Er ethanolate gel (6-8). The only common result of the research efforts in this field is that the explored solutions are unable to lead to a solution to the problem of light emission from Er-doped silicon. To overcome these difficulties, a different approach to the problem is needed. For this reason, we propose here an alternative road to solve the issue: instead of looking for an equilibrium between Er content and light emission using 1-2% Er, we propose to significantly increase the electrochemical doping level to reach the filling the porous silicon pores with luminescent Er-rich material. With this approach, the Er clustering will not be an issue anymore, since the fabrication of a luminescent Er composite within the pores completely changes the point of view on this theme and gives a fresh new research direction to explore.

To better understand the intricate and superposing phenomena of this electrochemical doping process, we exploit an original approach based mainly on needle electron tomography, EXAFS and photoluminescence (9). The first important result is obtained from needle electron tomography, that surprisingly shows a heterogeneous distribution of Er content in the silicon thin pores that until now couldn't be revealed by the sole use of scanning electron microscopy compositional mapping. This analysis shows that whatever the Er concentration, the clustering is always present and then demonstrate that the effort to obtain an equilibrium between Er concentration and clustering is a hopeless approach.

By the combined use of standard, time- and spatially- resolved photoluminescence, Scanning Electron Microscopy with secondary and backscattered electrons, Energy Dispersive X-ray Analysis and EXAFS we were able to show that pore filling leads to enhanced photoluminescence emission, and that this emission is originated from both erbium oxide and silicate. In Figure 1 we show a slice of an Er-filled porous silicon needle and a schematic of the results on the composition of the Er-rich filling material.

Our analysis also shows that the most intense photoluminescence emission is obtained when the pores are filled with the luminescent materials, with an optimum just before the surface accumulation of the excess deposition begins.

These results give a much deeper understanding of the photoluminescence origin down to nanoscale and could lead to novel approaches focused on noteworthy enhancement of Er-related photoluminescence in porous silicon.

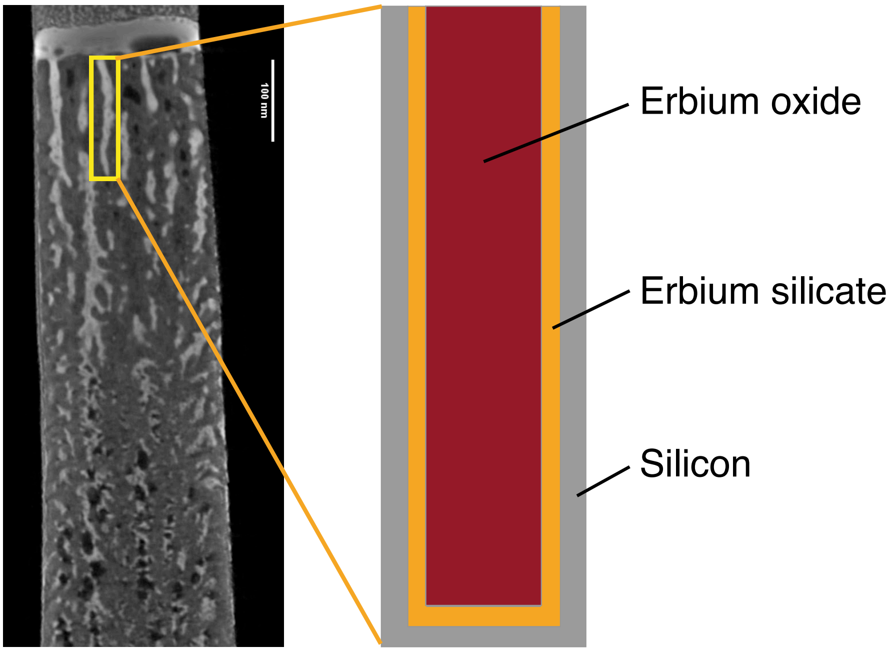

Figure 1: Electron tomography of Er-filled porous silicon (left) and a schematic of the composition of the Er-rich luminescent materials as obtained in this study.

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