Nanophotonic devices based on silicon nanostructures are of wide technological interest for their ability to confine light at visible and infrared frequencies. Nevertheless, strong light-to-heat conversion is expected to occur at resonance. In the first part of the research work we elucidate the design parameters which enable a temperature suppression or enhancement in silicon nanostructures. In fig. 1 it is reported a typical situation. Here is shown the maximum temperature reached by a core-shell nanosphere made by a 100 nm SiO_2 core and a Si shell of variable thickness. Two temperature regimes are present, depending on the conformality of the silicon shell with the substrate. The conformal shell dissipate heat more efficiently than the non-conformal one, and is less affected by temperature rise.

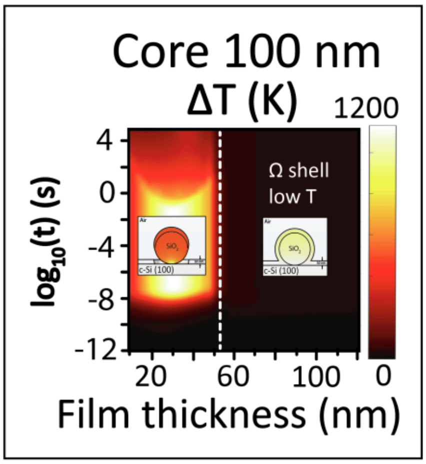

Figure 1. Maximum temperature reached by a SiO_2/Si core-shell system, depicted as a function of time. Shell thickness has been varied continuously from 10 nm to 120 nm. When the shell thickness is lower than the core radius, temperature is very high; when the shell thickness is larger, temperature is much lower.

Thermally stable systems, has been used to demonstrate experimentally and theoretically the possibility to obtain efficient Raman sensing of biomolecules and pollutants. Thermally unstable systems, have been used to locally trigger chemical reactions or phase changes.

The second part of the research activity focus on the light-driven process of crystallization and melting of nanopillars and core-shell resonators with lateral features much lower than the exciting wavelength. The nanostructures are supposed to be initially in amorphous silicon (a-Si). We design a stochastic model for melting and crystallization, and impose heat diffusion and light structure interactions by means of a Finite Element Software.

The low thermal conductivity of a-Si, in concomitance with an appropriate thermal environment sustain large temperature gradients (more than 300K/100nm with a 532 nm exciting wavelength). The hot regions generated by the remote excitation, can overcome the diffraction limit of the exciting radiation itself (they are 4 times smaller than the 532 nm radiation wavelength). Hot regions selectively undergo to crystallization process. This result has never been achieved before, to the best of our knowledge.

Moreover, we are trying to demonstrate that in high aspect ratio nanopillars, it is possible to control the altitude of the crystallized region in a deep sub-wavelength scale, by controlling the wavelength/diameter ratio. In fig. 2 is reported the crystallization of a-Si in three different situations: isothermal treatment (first panel), which is achieved by traditional furnace heating, and laser processing (second and third panels), carried out at two different wavelengths. The result shows that crystallization follow three different evolution pictures. By properly stopping the process, it is possible to obtain an hybrid a-Si/c-Si nanostructure.

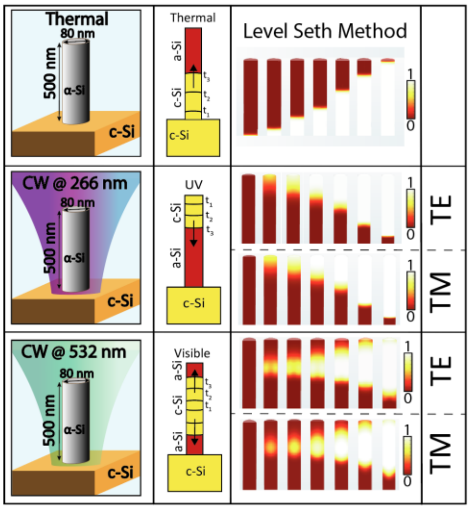

Figure 2. Schematic picture of the crystallization dynamics in high aspect ratio nanostructures. In panel a) is shown the crystallization obtained by a traditional furnace treatment, also called Solid Phase Epitaxial Regrowth. In panel b and c is represented the crystallization dynamic of UV Laser Thermal Annealing and Visible Laser Thermal Annealing. Spatial evolution of the crystallization has been taken at different times.

Monitoring the optical proprieties of those hybrid systems during crystallization, we find optical performances enhanced respect to the ones predicted with the "effective medium approximation", which is traditionally used to describe hybrid deep sub-wavelength a-Si/c-Si nanostructures. The reason for such a non–trivial result has to be fully clarified yet. Those enhanced optical proprieties suggest possible applications in the fields of nanophotonics, a-Si/c-Si heterojunction solar cells, photo-chemical devices and chemical sensors.

Another process which has been investigated is the melting and recrystallization of a-Si in resonant nanostructures. Melting occur in thousands of nanoseconds and is a process much faster than crystallization, which occur in seconds. The complex coupling between light, structure and material proprieties is usually neglected in the analysis of silicon laser processing. We develop a model able to describe the time and space evolution of light-structure, light-material and material-structure coupling during a melting-crystallization process. If we study the laser processing of an a-Si nanostructure, we observe that the system can move from an initial resonance condition, to a non-resonance one, or vice-versa. The main consequence is an increase or depletion of light-to-heat conversion rate. By analyzing SiO_2/Si core-shell systems, we observe that melting can be self-sustaining or self-limiting, according to the modification of light coupling conditions. The main parameter affecting the behavior is the shell-core size aspect ratio. In case of a self-limiting process, the system reaches a metastable equilibrium condition of partial melting, where only a portion of the shell is melted. The remaining a-Si portion undergoes a crystallization process on a longer timescale. During such a crystallization, the system can weaken or reinforce the light-coupling. In the first case a complete recrystallization of the melted region is observed. In the second case, a complete melting take place. Such a wide plethora of possible scenarios has never been investigated before, to the best of our knowledge.

Other research activities and collaborations:

1. Study and development of a self-tuning optical devices based on VO_2. The idea is to design smart optical devices which are able to tune the transmission and/or reflection of an incident radiation as a function of the intensity. To do this, we exploit the change in the refractive index of VO_2 with temperature, induced by the laser heating. VO_2 has been synthetized and characterized, while the device has been designed by means of Finite Element Software. A model for temperature dependence of VO_2 refractive index has been developed, and the opto-thermal behavior has been simulated under different intensities. Both static and time-dependent studies have been performed.

2. Whispering gallery resonators for all-dielectric SERS. Micrometer size core-shell systems are known to show Whispering Gallery Modes (WGM) when the shell/core aspect ratio is properly tuned respect to an incident wavelength. The WGM can enhance light density of 2 orders of magnitude. In this framework it is of fundamental importance the choice of the shell material and thickness. In this research work we use finite element simulation to tune the WGM position in order to obtain the best coupling with the 532 nm, 633 nm and 785 nm wavelength, which are usually used in SERS.