OPTIMIZATION OF THE PROCESS TEMPERATURE FOR THE FABRICATION OF SELF-ASSEMBLED COLLOIDAL CRYSTALS

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The catalytic, magnetic, mechanic, thermal and optical properties of some materials can be tailored by nanostructuring them. State-of-the-art nanostructuring techniques include micromachining [1] and nanolithography [2], which are either slow or expensive. For this reason, a lot of effort is being devoted to the research in low cost and long scale fabrication methods as self-assembly [3] and laser interference lithography [4].

In this work, the self-assembly of polystyrene spheres to be used as templates for the nanostructuring of materials is studied. In particular, a study of the influence of the process temperature on the final structure of the colloidal crystal is carried out. Optical reflectance measurements in addition to SEM and FEG-SEM micrographs are used in order to characterize the quality of the fabricated structures.

EXPERIMENTAL

Polystyrene samples with different process temperatures (between 30 ºC and 60 ºC) have been fabricated. A monodisperse solution of 419 nm colloidal polystyrene beads with a concentration of 1% is used for the deposition. The chosen method is the vertical deposition technique [5] with a substrate inclination of 10 º.

RESULTS AND DISCUSSION

An inspection of the surface of the samples shows that the superficial quality of the structure is enhanced by increasing the process temperature up to 50 ºC, being the characteristics of the 50 ºC and 60 ºC fabricated samples very similar. The surface roughness is minimal for the samples fabricated at 50 ºC. The presence of bcc areas and amorphous zones in the samples is also improved with increasing process temperature, up to 50 ºC. Although none of the conditions tested in this work gives rise to defectless surfaces, FEG-SEM micrographs of the cracks in the 50 ºC fabricated samples show that the order is conserved in subsequent layers, as shown in Figure 1. For this reason, reflectance measurements are performed in order to check the three-dimensional order of the samples.

The effective refractive index of the structure, n_{eff}, is defined as $n_{eff}^2 = \varepsilon_a \cdot f + \varepsilon_b \cdot (1 - f)$, where ε_a and ε_b are the dielectric constants of the material (polystyrene) and the voids, respectively, and f is the filling factor of the crystal. This parameter provides information about the quality of the structure, taking into account that if the fabricated crystals were perfectly packaged in an fcc structure, their n_{eff} would be approximately 1.41 ($f = 0.74$). Using the Bragg-Snell law [6], which relates the position of the reflectance peaks to the effective refractive index and the angle of incidence of the light on the sample, θ,:

$$\lambda = 2D\sqrt{n_{eff}^2 - \sin^2\theta} \qquad (1)$$

where $D = d\sqrt{2/3}$, and d is the diameter of the spheres, the n_{eff} of the fabricated samples can be calculated using reflectance measurements.

Calculating the n_{eff} with the theoretical values of the reflectance peaks obtained from simulation of the structure [7], a small dependence on the angle of incidence is observed. The most approximate value to the theoretical is obtained with an angle of incidence of 45º.

In Figure 2, the average values for the n_{eff} are shown, in comparison with the theoretical value calculated from the simulations. As can be seen, this parameter becomes closer to its theoretical value with increasing temperature, which implies the improvement of the fabricated structures, in agreement with the surface analysis previously carried out.

CONCLUSION

In this work, the dependence of the process temperature on the quality of self-assembled colloidal structures has been studied. In addition, it has been shown that the surface roughness of the structures, which is minimal at 50 ºC, has a direct dependence on the effective refractive index. This result provides a way of structurally characterize the quality of the colloidal crystals via reflectance measurements.

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FIGURES

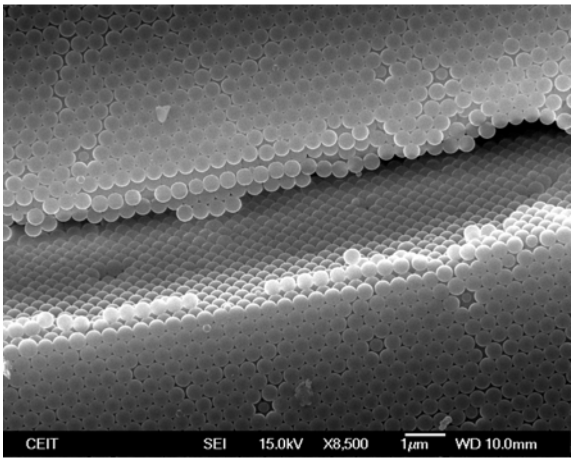

Figure 1. FEG-SEM micrograph of the insight of a crack in a 50 ºC fabricated sample

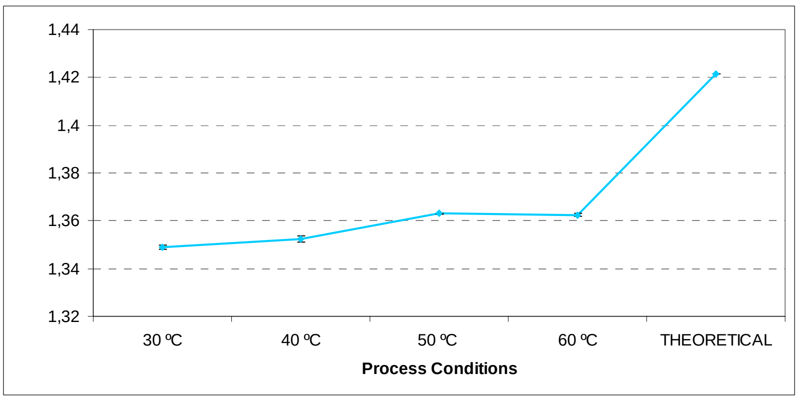

Figure 2. Effective refractive index with respect to the process temperature