Nanocrystalline Silicon for Optomechanical Applications

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Nanocrystalline materials have attracted great interest thanks to their ability to mimic, tune and even outperform the properties of their single crystal counterparts. Polycrystalline silicon is used, e.g., in solar cells and in thin film transistors. Nanocrystalline silicon (nc-Si), the process developed for MEMS applications already at 80's [1], has recently been considered as a possible material to realize optomechanical devices and circuits. Nanocrystalline silicon films are produced by annealing amorphous silicon layers deposited by low pressure chemical vapour deposition (LPCVD). The thermal annealing process determines the electronic, optical and mechanical properties of nc-Si [2]. In particular, the annealing temperature determines the size distribution of the nanocrystallites and the residual stress in the film. Recently it has been reported that phonon scattering at grain boundaries leads to a reduction of the thermal conductivity [3,4] due to the commensurability of grain boundary size and thermal phonon wavelengths. The grain boundaries in nc-Si host a relatively high number of gap states which impacts the optical absorption, i.e., the efficiency of one- versus two-photon absorption, involved in opto-mechanics [5]. The motivation for this study is to understand the origin of the high mechanical quality factors of optomechanical nc-Si nanobeams as compared to similar devices fabricated using silicon-on-insulator (SOI) substrates [2].

To study the morphology of nc-Si, we use 380-µm-thick double-side polished Si wafers with a 500-nm-thick layer of silicon dioxide as substrate. The 220-nm-thick nc-Si film, deposited by LPCVD at 535°C, is initially amorphous, and annealed for 60 minutes at temperatures ranging from 650 °C to 1050 °C. During annealing, the film transforms from amorphous to nanocrystalline, and the original compressive stress within the amorphous Si film changes to tensile in the nanocrystalline film. The measured tensile stresses were found to be 350 MPa at 650 °C annealing temperature, 120 MPa at 950 °C annealing temperature, and 80 MPa at 1050 °C annealing temperature. These results closely align with previously published measurement data in [2]. Circular windows with a diameter of 340 µm were opened by deep etching from the backside of the wafer to investigate the optical properties of the nc-Si films. These windows are employed for optical absorption measurements and transmission electron microscopy (TEM) characterisation to investigate systematically the dependence of the optical properties on the grain size, the size distribution and the grain boundary thickness.

We will report the structural and optical properties of nc-Si relevant to optomechanical interaction and applications, aiming to elucidate the behaviour of phonons and photons at the grain boundaries and the consequences on dissipation. It is becoming essential to understand the role of the grain boundaries and their impact both on the optical and mechanical properties and quality factors.

References

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