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Impact of Nitrogen Doping on the Q-Factor of Polycrystalline 3C-SiC MEMS Resonators

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Summary:

This paper reports on the impact of nitrogen doping on the quality factor (*Q*) of polycrystalline 3C-SiC MEMS resonators. The resonance characteristics of mechanical beam resonators fabricated from an unintentionally and an intentionally doped 3C-SiC thin film were measured with laser Doppler vibrometry. We find a reduction of *Q* of 28% and 39% for the first and second out-of-plane modes when comparing the unintentionally with the intentionally doped thin film. The difference in *Q* is attributed to a modification of Young's modulus (*E*), due to a change in microstructure and/or the average bond strength.

Keywords: MEMS resonators, SiC, doping, Q-factor, LPCVD

Background, Motivation, and Objective

For more than 30 years, SiC has been intensively studied for MEMS applications. In contrast to silicon, it has superior mechanical properties, like hardness, Young's modulus, and thermal stability for high-temperature applications [1]. SiC is also a promising candidate for RF applications like filters and timing devices [2]. Capacitive actuation of these devices is very common, due to a straightforward realization of the transducer elements and fast response times. However, a sufficient conductivity of the electrodes is necessary to support high resonance amplitudes. In-situ doping of polycrystalline 3C-SiC thin films is a well-known approach to reach this goal [3].

Our research adopted the LPCVD growth of polycrystalline 3C-SiC on SiO_2/Si substrates and extended the characterization tools on static cantilevered MEMS resonators as stated by Trevino et al. [4] to evaluate the resonance properties of cantilevered MEMS resonators, as well as the thin films microstructure for different thicknesses.

Description of the New Method or System

Alternating supply deposition (ASD) is used in an LPCVD process to grow polycrystalline 3C-SiC on silicon dioxide layers of 4"-silicon wafers [5]. Within 2000 cycles of ASD, a flow of 2.5 sccm ammonia is used simultaneously with silane and propane for the synthetization of an n-type doped thin film. Cantilevered MEMS resonators shown in Figure 1 are fabricated from both unintentionally and intentionally doped thin films. In the same step, multiple trenches are etched into the thin films close to the anchor regions of the resonators to determine with white light interferometry (WLI) the local value of the film thickness (*h*), as shown in Figure 2. The frequency response of photo-thermally actuated resonators is measured with laser Doppler vibrometry under vacuum, and a Lorentzian fit is performed to extract *Q* and the resonance frequency (*f*).

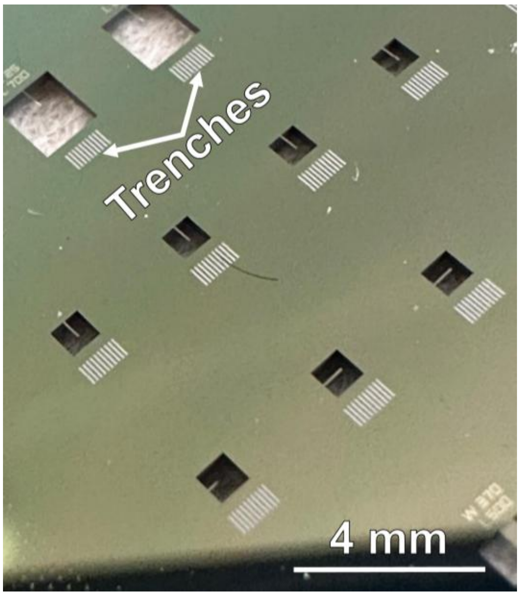

Figure 1: Optical photograph of cantilevered MEMS resonators with a length of 500 µm and a width (w) of 50 µm. Next to each resonator trench-type test structures are etched into the device layer and down to the buried silicon dioxide for a precise local thickness measurement with WLI. A variation in h across the wafer is expected due to the gas flow parallel to the substrate surface in the LPCVD process.

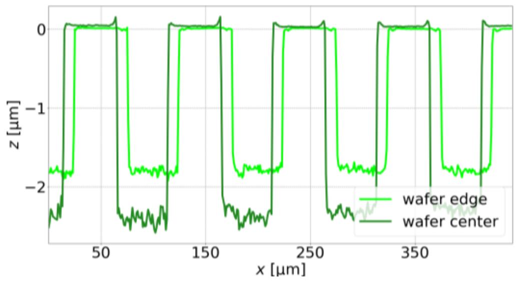

Figure 2: The device layer thickness equals the device height and is measured with WLI via trench-type test structures etched through the device layer. Two typical examples illustrate the local variation in device height from the wafer edge to the wafer center, due to the horizontal arrangement of the wafers during the LPCVD process. Postprocessing is performed on the measured data and the actual height is extracted automatically.

Results

WLI measurements of the trench-type test structure next to 40 different device positions across the wafer show a comparable mean value of *h* of the unintentionally and intentionally doped thin films of 2.17±0.17 µm and 2.36±0.24 µm, whereas mean *f* values of 11 739±963 Hz and 12 526±1441 Hz were measured. However, there is a significant drop in mean *Q* of the first and second Euler-Bernoulli modes of 28% and 39% from the unintentionally to the intentionally doped thin film, as shown in Figure 3.

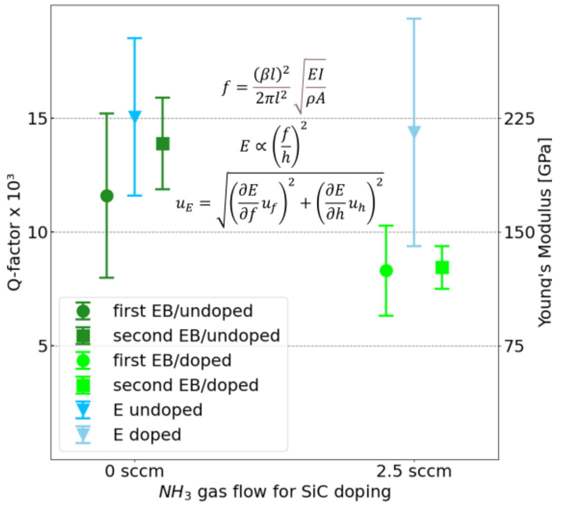

Figure 3: Statistical analysis of the measured Q is performed for 40 resonators, each fabricated from the unintentionally and intentionally doped thin film.

The measured resonance frequencies and device heights were used to calculate *E* from the Euler-Bernoulli beam theory. Here the density ρ = 3210 kg/m^3 is used from literature, while the cross-section $A = w \cdot h$ and area moment of inertia $I = wh^3/12$ are calculated from measured *h* and known width *w*. The error propagation on *E*, (u_E), is calculated according to the formula in Figure 3 with the standard deviations of frequency and thickness, u_f and u_h, respectively. A reduction of *E* from 226±52 GPa to 216±75 GPa is the first indication of the effect of nitrogen doping on the microstructure as well as on the mean bond strength, which decreases due to the presence of nitrogen atoms in the crystal lattice. Similar electronic effects in the elastic constants of doped silicon were described by Hall [6]. Additional SEM images in Figure 4 show a change of the fine-grained microstructure to larger grains with nitrogen doping, while the RMS roughness (S_q) decreases from 16 nm to 10 nm. These results need to be supported and extended by XRD and XPS measurements to get deeper insights, as the microstructure strongly influences the Q-factor of MEMS resonators.

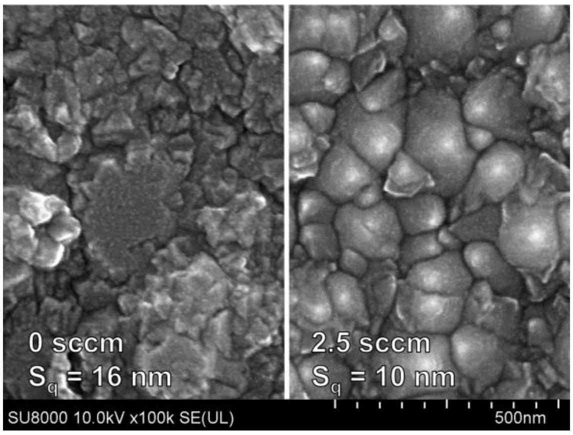

Figure 4: SEM image of polycrystalline 3C-SiC thin films demonstrating that the grainy microstructure of the unintentionally (0 sccm, left) differs from that of the intentionally (2.5 sccm, right) doped thin film. This top view analysis shows that the grains of the intentionally doped thin film are larger, while due to doping AFM measurements show a reduction of S_q from 16 nm to 10 nm.

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