Characterization of low-loss hydrogenated amorphous silicon films for superconducting resonators

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Problem and research questions

Two-level systems (TLSs) in deposited dielectrics cause dielectric loss[1] and frequency noise[2] in superconducting resonators used in spectrometers[3,4,5].

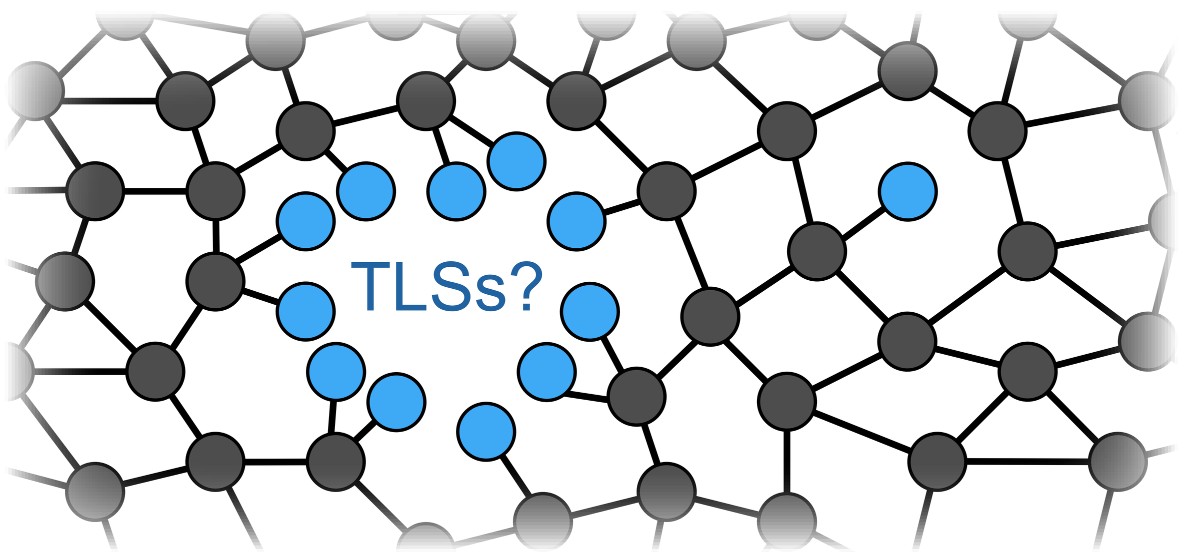

Fig. I Schematic of a-Si:H. Grey: Si atoms. Blue: H atoms. The SiH_2 bonds exist on the surface of voids.

What is the microscopic origin of the TLSs in hydrogenated amorphous silicon (a-Si:H)?

What is the effect of depositing by PECVD at elevated substrate temperatures[6] (T_{sub})?

Hydrogen content, microstructure parameter, infrared refractive index

The microstructure of a-Si:H is goverend by the occcurence of hydrogen bonds[7].

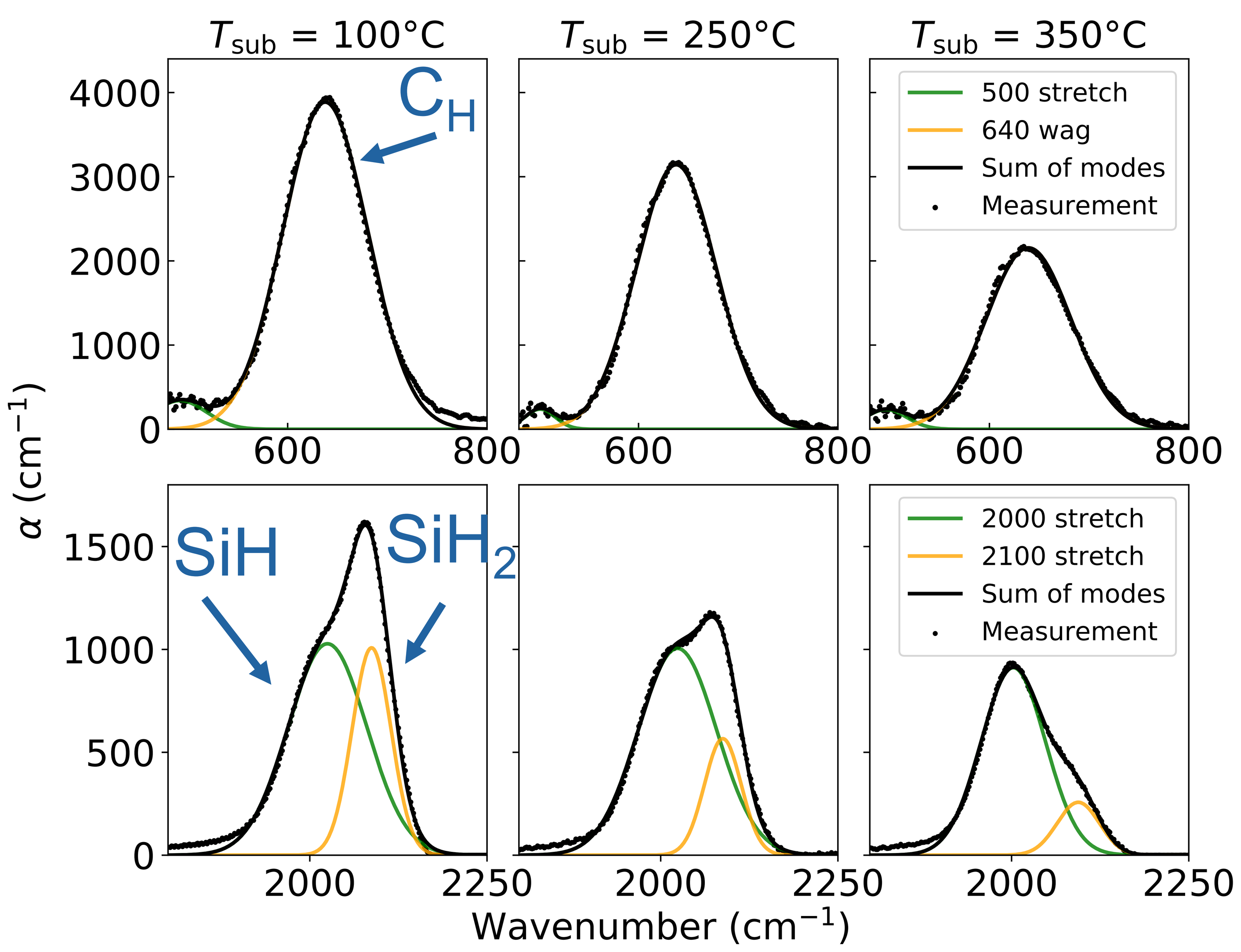

Fig. II Fourier-transform infrared (FTIR) absorption coefficient (α) measurements, showing the stretching and wagging modes from which we determined the hydrogen content (C_H) and the microstructure parameter (R^*)[7].

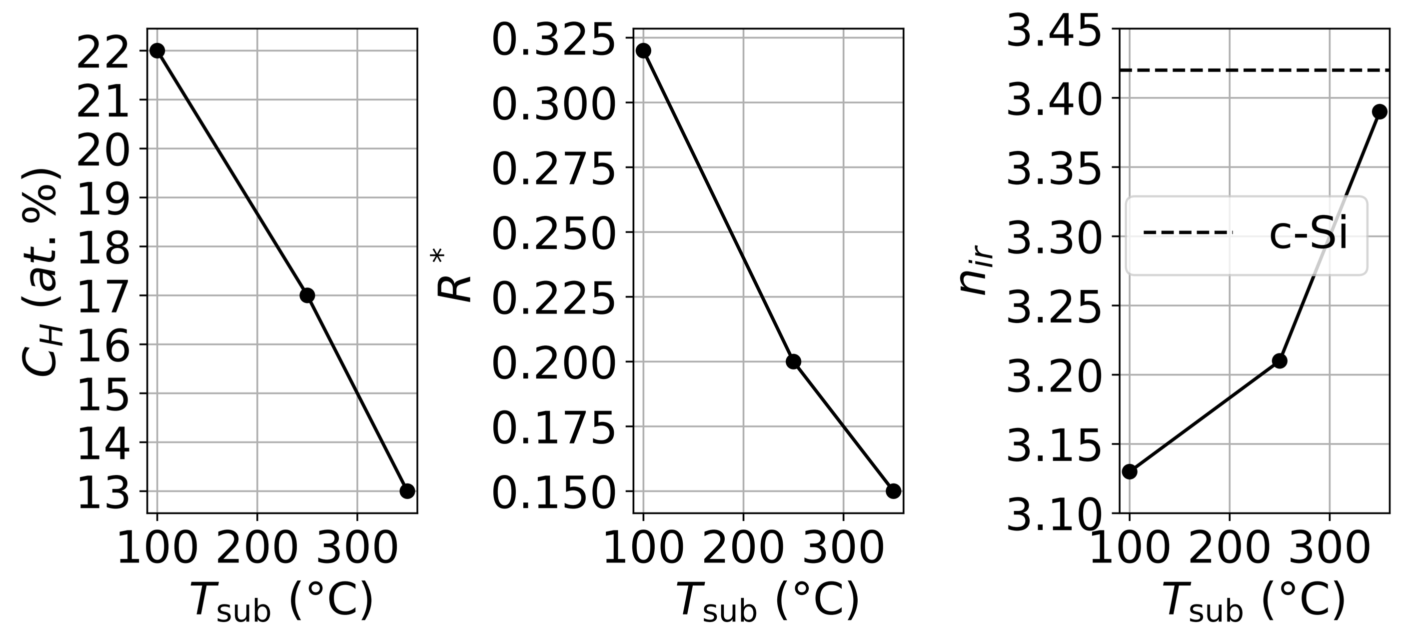

Fig. III Hydrogen content (C_H), microstructure parameter (R^*), and infrared refractive index (n_{ir}) determined by FTIR spectroscopy. A larger R^* indicates more voids.

The hydrogen content (C_H), microstructure parameter (R^*), and infrared refractive index (n_{ir}) show a monotonic dependence on T_{sub}.

Bond-angle disorder

The bond-angle disorder ($\Delta\theta$) decreases monotonically with increasing T_{sub}.

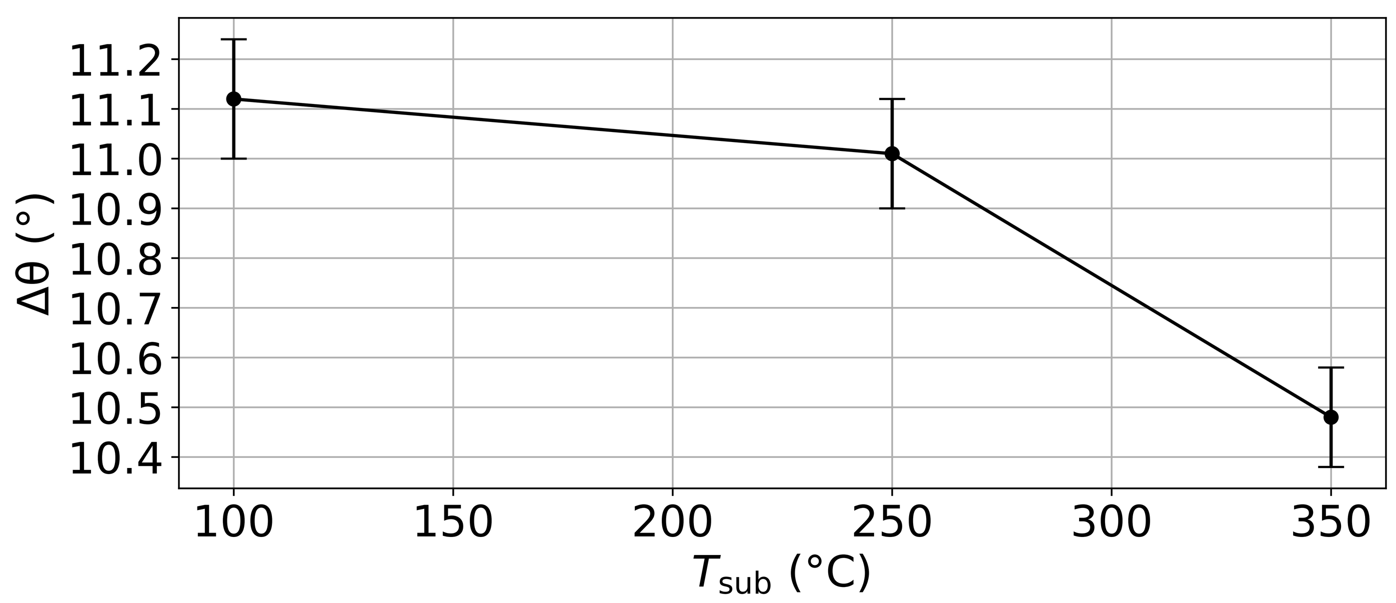

Fig. IV The bond-angle disorder determined by Raman spectroscopy.

Void volume fraction

The void volume fraction (f_v) decreases monotonically with increasing (T_{sub}).

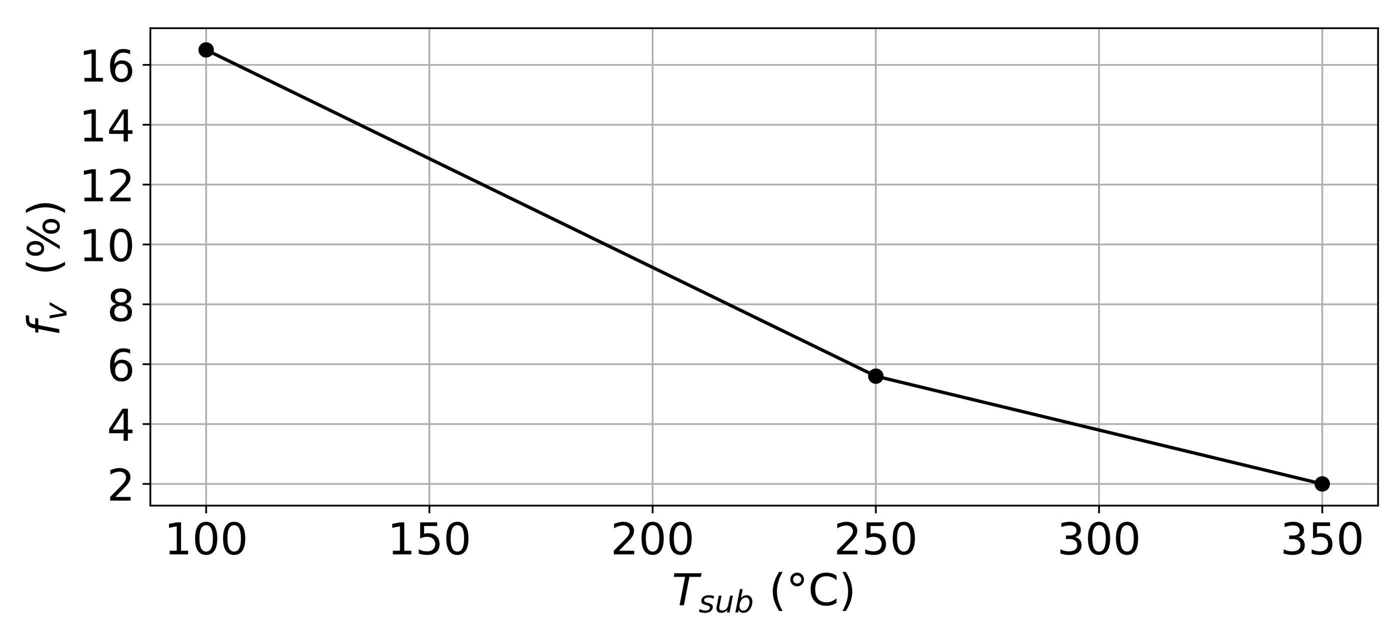

Fig. V The void volume fraction determined by ellipsometry using the Bruggeman effective medium approximation.

Microwave dielecric loss

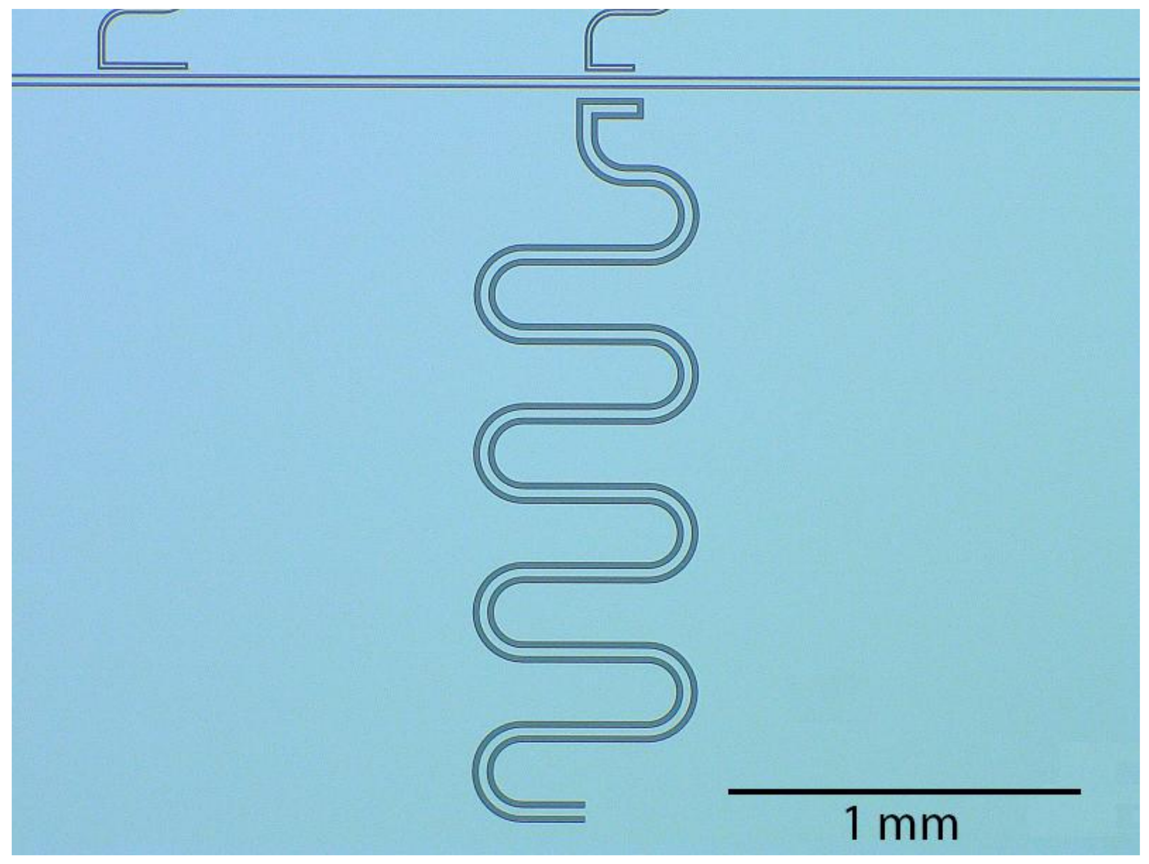

Fig. VI Micrograph of one of the aluminum quarter-wavelength coplanar waveguide (CPW) resonators that we used to measure the loss tangent (tanδ) at 120 mK and at 5-7 GHz. The chip contains multiple CPW geometries.

We do not observe a correlation of the microwave dielectric loss with T_{sub}.

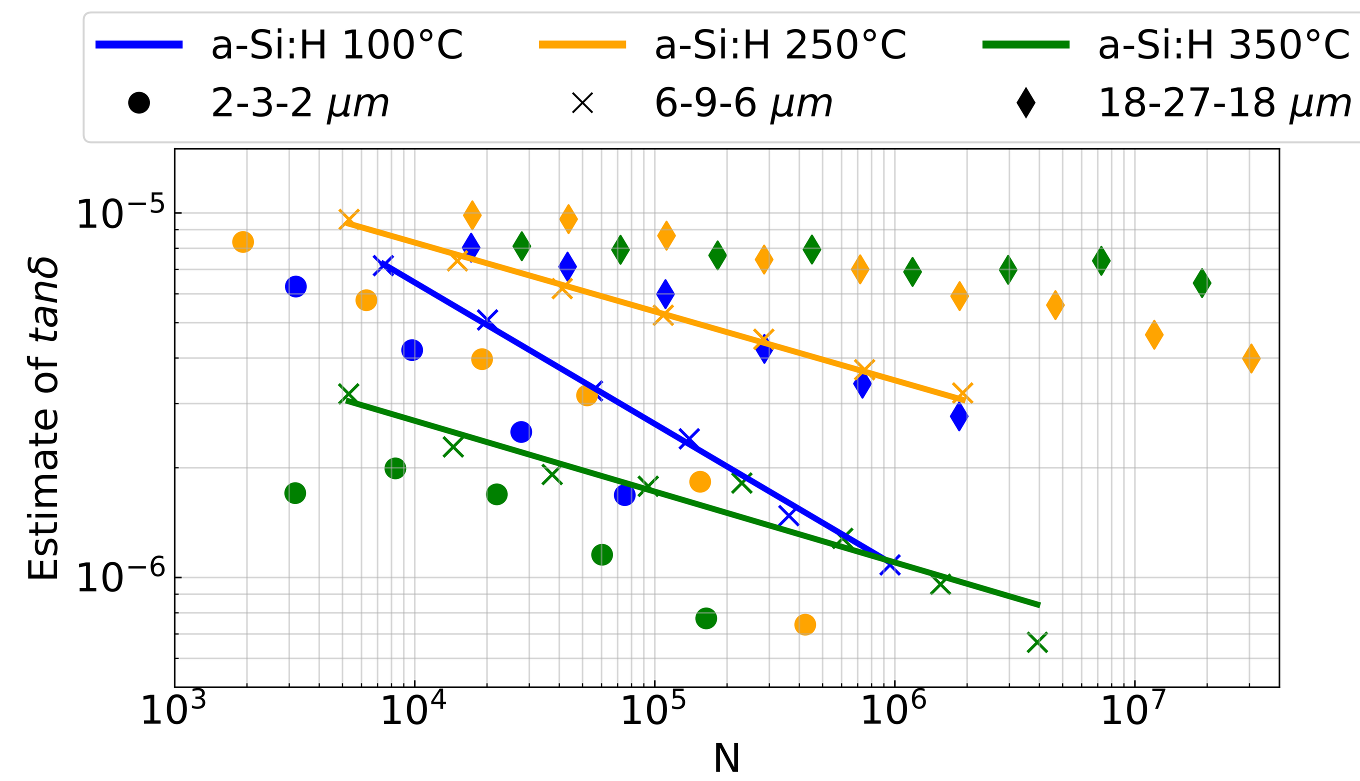

Fig. VII The loss tangents (tanδ) that we estimated by referencing to a chip directly on top of the c-Si substrate. The x-axis shows the number of photons in the resonator. The symbols denote the CPW slot and line widths.

Conclusions

1. The PECVD substrate temperature controls the microstructure and composition of a-Si:H.
2. We do not observe a correlation of the room temperature properties with the 120-mK microwave dielectric loss at a resonator energy of ~ $10^4 – 10^6$ photons.

References

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