Residual Stress Effects in Tunable Microwave Dielectric Thin Films

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There has been a recent shift towards a tunable phase shifter for microwave antenna design. By tuning the phase velocity of the device, the dielectric constant of the material can be tuned in real time, enabling direction control of the signal.[1] Barium strontium titanate ($Ba_xSr_{(1-x)}TiO_3$) thin films are the principal materials of interest in these applications, primarily because of their low loss, high dielectric constant and large tunability.[1] Residual stress within materials is known to have a drastic effect on the material, electrical, and dielectric properties. This becomes of particular importance in thin film materials, where the residual stress can be several orders of magnitude higher than in bulk materials.[2,3,4]

Metal-organic solution deposition (MOSD) is a room temperature deposition technique that allows very precise control of film stoichiometry and surface properties. Pulsed laser deposition (PLD) is a physical vapor phase technique that does not require post deposition annealing. Both doped and undoped films were made using magnesium oxide as the dopant, and they were deposited on magnesium oxide or platinized silicon substrates. The residual stress in the films was measured in three ways. A Tencor stress analysis system was employed to measure the change in the substrate curvature due to the film stress, and a nano-indentation method was used to calculate the residual stress in a system by measuring the maximum penetration, the force at maximum penetration, and the slope of the initial unloading curve.[2,3] These methods were validated using XRD lattice calculations.[5]

The results indicate that an 80% drop in dielectric constant is observed in undoped films with a residual stress as low as 200 MPa. Stresses as high as 2 GPa were observed for certain conditions. The tunability also decreased by a factor of 80% for the same residual stress. The amount of dopant in the system also significantly altered the nucleation behavior. The nano-indentation results corroborate the nucleation behavior observed in AFM. For films that exhibit a nucleation and growth behavior, the stress increases through the thickness approaching the interface, and that at the interface the two materials possess a similar hardness and modulus. This corroborates the bulk material mathematical models. The results also show that the surface region of the films is not “stress” free at these thicknesses (~500 nm) as was mathematically suggested.

Sources:

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