Simulation of the Electrical Properties of Conductive Ito Thin Films by Finite Element Analysis

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Introduction: Finite element analysis (FEA) can be used to study the electrical properties of conductive ITO thin films and assist the experimental measurement to have a correct interpretation. In this study, ITO films on insulating substrate with different geometric dimensions and electrode geometry were investigated.

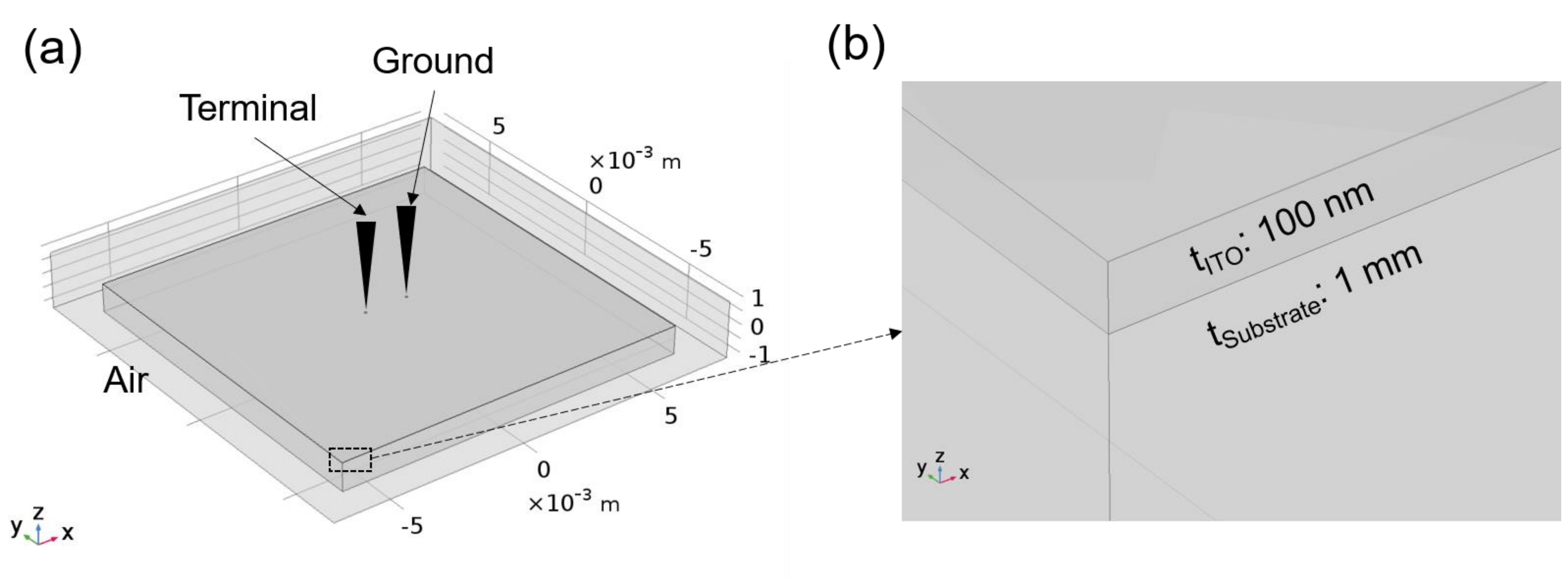

Figure 1. Simulation setup of electrical properties of conductive ITO thin films on insulating substrate. (a, b) 3D model geometry for ITO film.

Model setup: The FEA tool used in this work is COMSOL Multiphysics 5.3. The simulations utilized a Bi-conjugate gradient stabilized iterative solver in the ac/dc module in a frequency domain study, which implements a finite element method to solve partial differential equations. The goal is to solve the Maxwell's Equation in terms of electric potential (V).

$$-\nabla\cdot\left(\left(\sigma+\varepsilon_r\varepsilon_0\frac{\partial}{\partial t}\right)\nabla V\right)=0 \qquad (1)$$

Derivation of Impedance and Capacitance from:

$$Z^*=\frac{1}{Y^*}=Z'+jZ'' \qquad (2)$$

$$C^*=C'+jC''=\frac{Y''}{\omega}+j\frac{Y'}{\omega} \qquad (3)$$

Results: 3D electric potential map and electric field lines were obtained for ITO films. The impedance and capacitance were calculated using above equations.

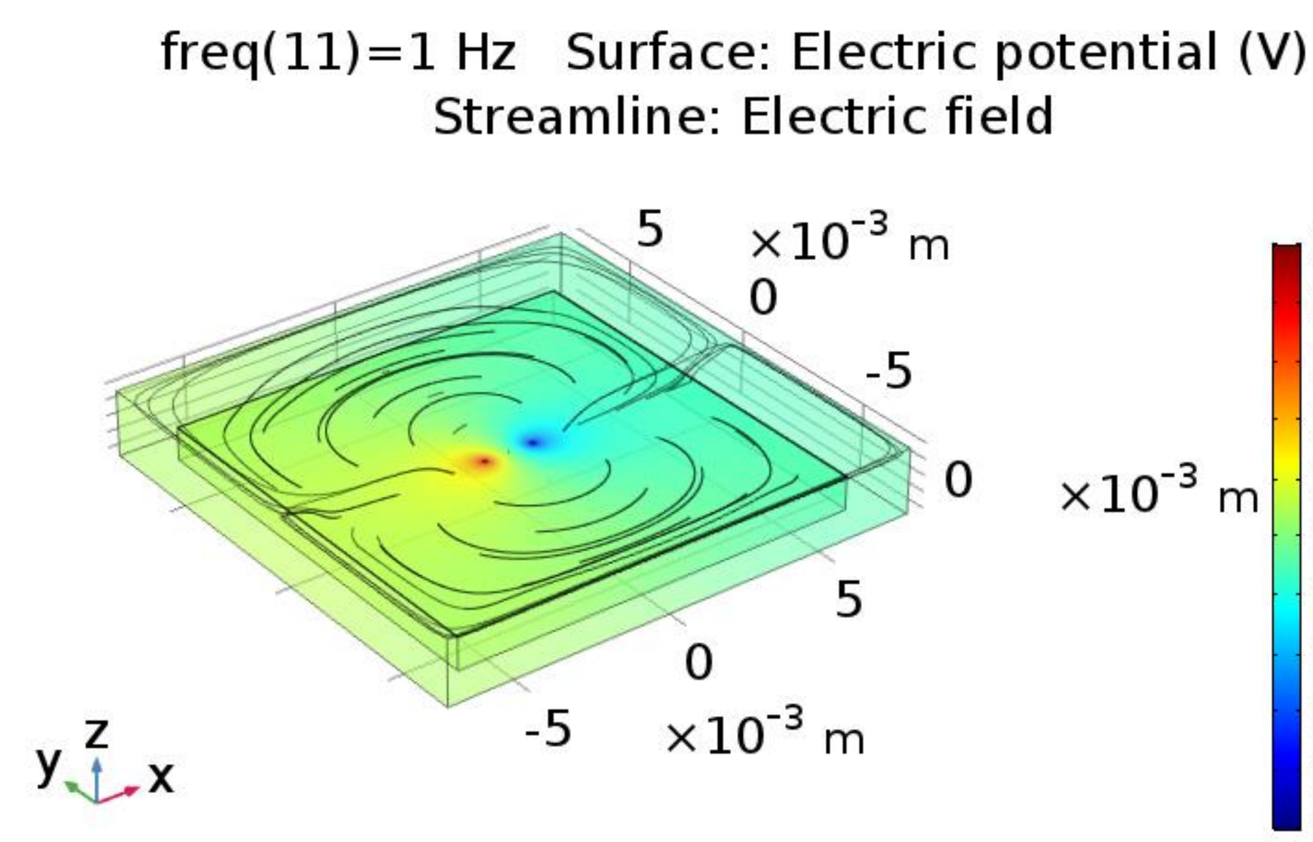

Figure 2. Simulated 3D electric potential map and electric field lines at 1 Hz for 3D simplified model using ITO film as electric shielding boundary conditions. (15 mm × 15 mm × 2 mm air, 12.7 mm × 12.7 mm × 1 mm substrate, D = 80 µm circular electrodes with a center spacing of 1.5875 mm)

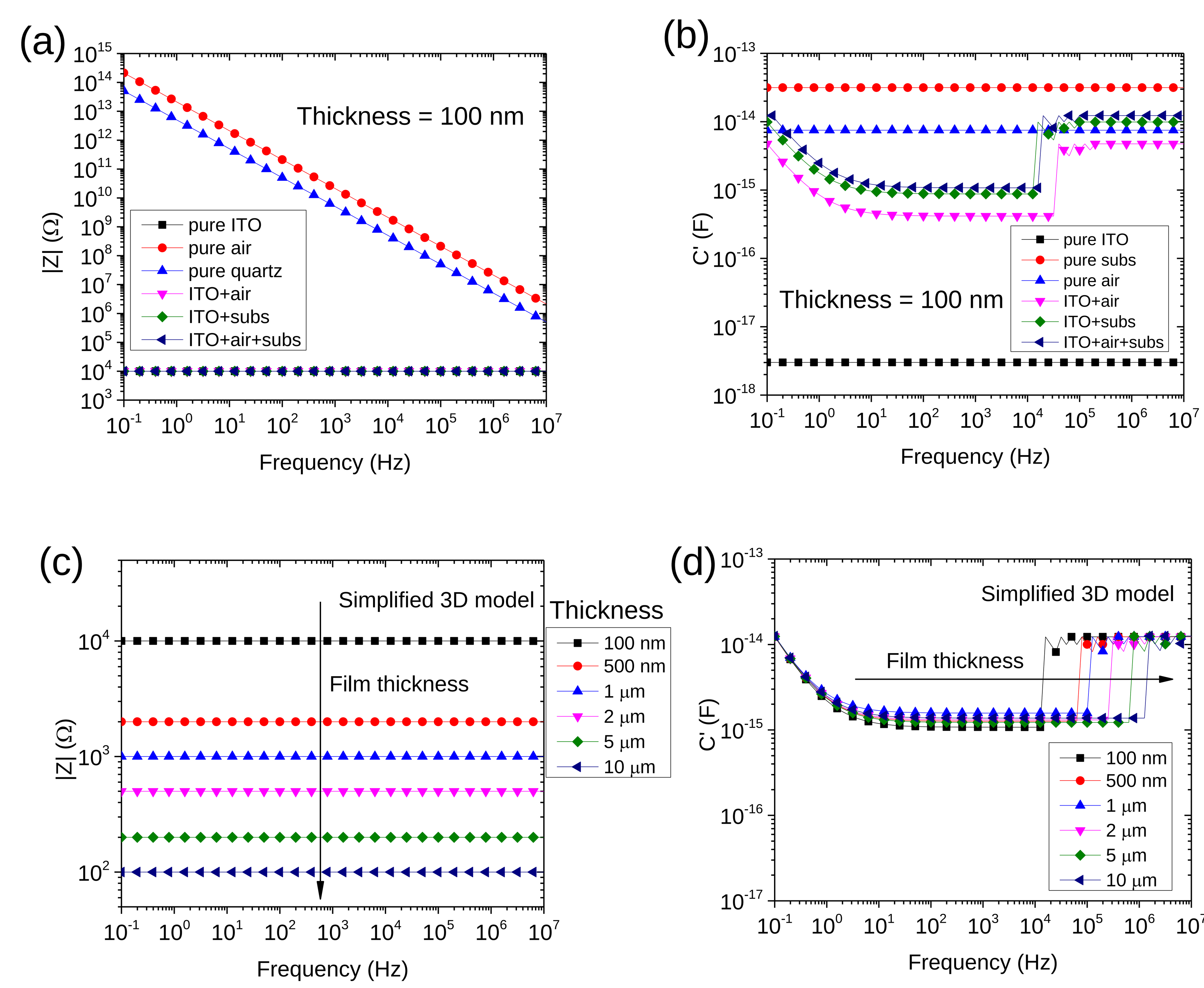

Figure 3. (a) |Z| and (b) C' for pure ITO film, pure air block, pure quartz substrates, combination of ITO film with quartz substrate, combination of ITO film with air, combination of ITO with both substrate and air; (c) |Z| and (d) C' for ITO films with different thickness on quartz substrate in air environment simulated in simplified 3D models. (15 mm × 15 mm × 2 mm air, 12.7 mm × 12.7 mm × t nm ITO film, 12.7 mm × 12.7 mm × 1 mm substrate, D = 80 µm circular electrodes with a center spacing of 1.5875 mm)

Conclusions: The insulating substrate and surrounding air environment were found to have a substantial effect on the resultant capacitance but minimal influence on the impedance of the films. The impedance values of ITO films decrease with increasing film thickness in an inverse proportional relationship, whereas a sudden drop of capacitance happens at higher frequency with increasing film thickness.

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