A MICROWAVE DIELECTRIC RESONATOR METHOD FOR QUALITY ASSESSMENT OF LARGE AREA GRAPHENE

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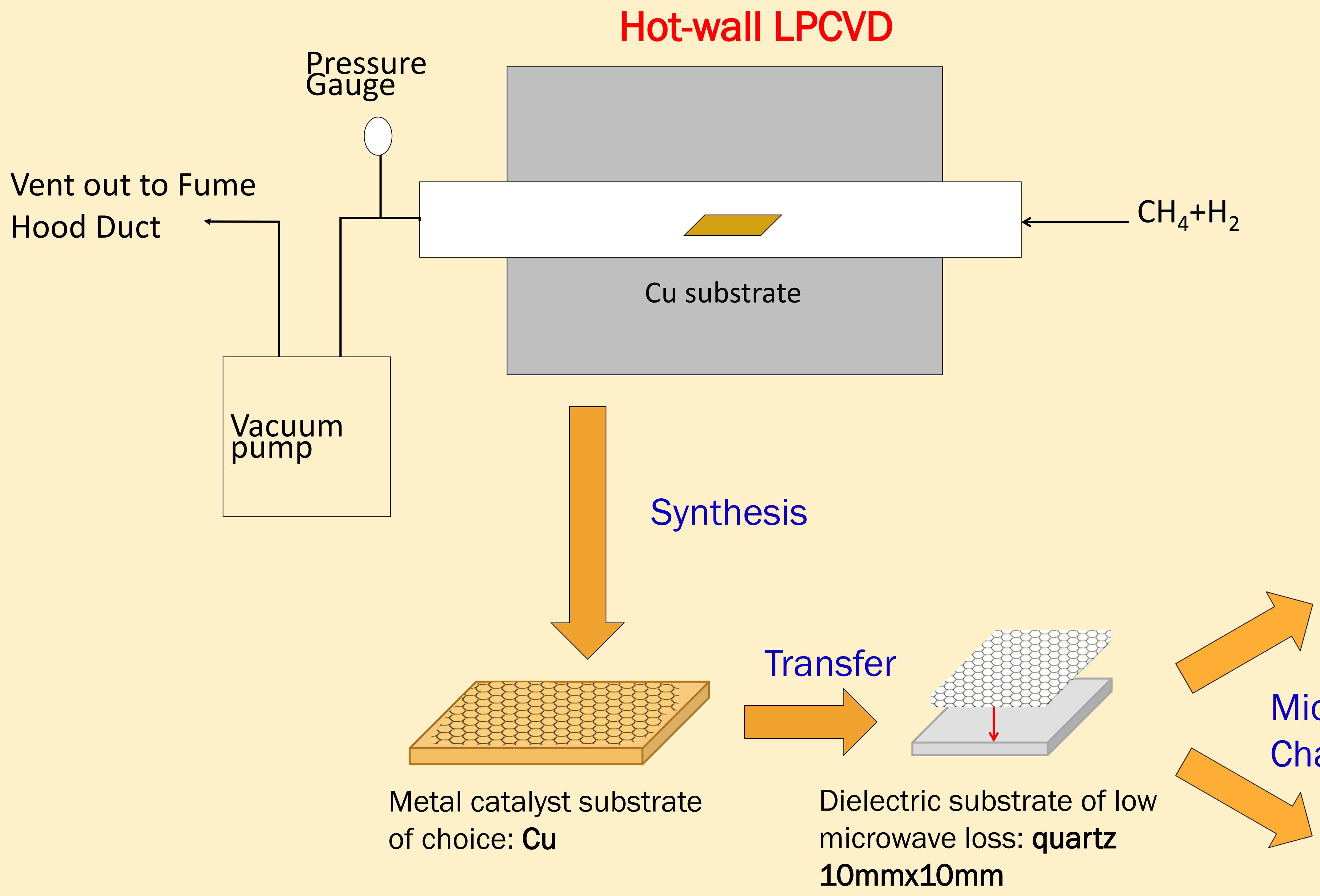
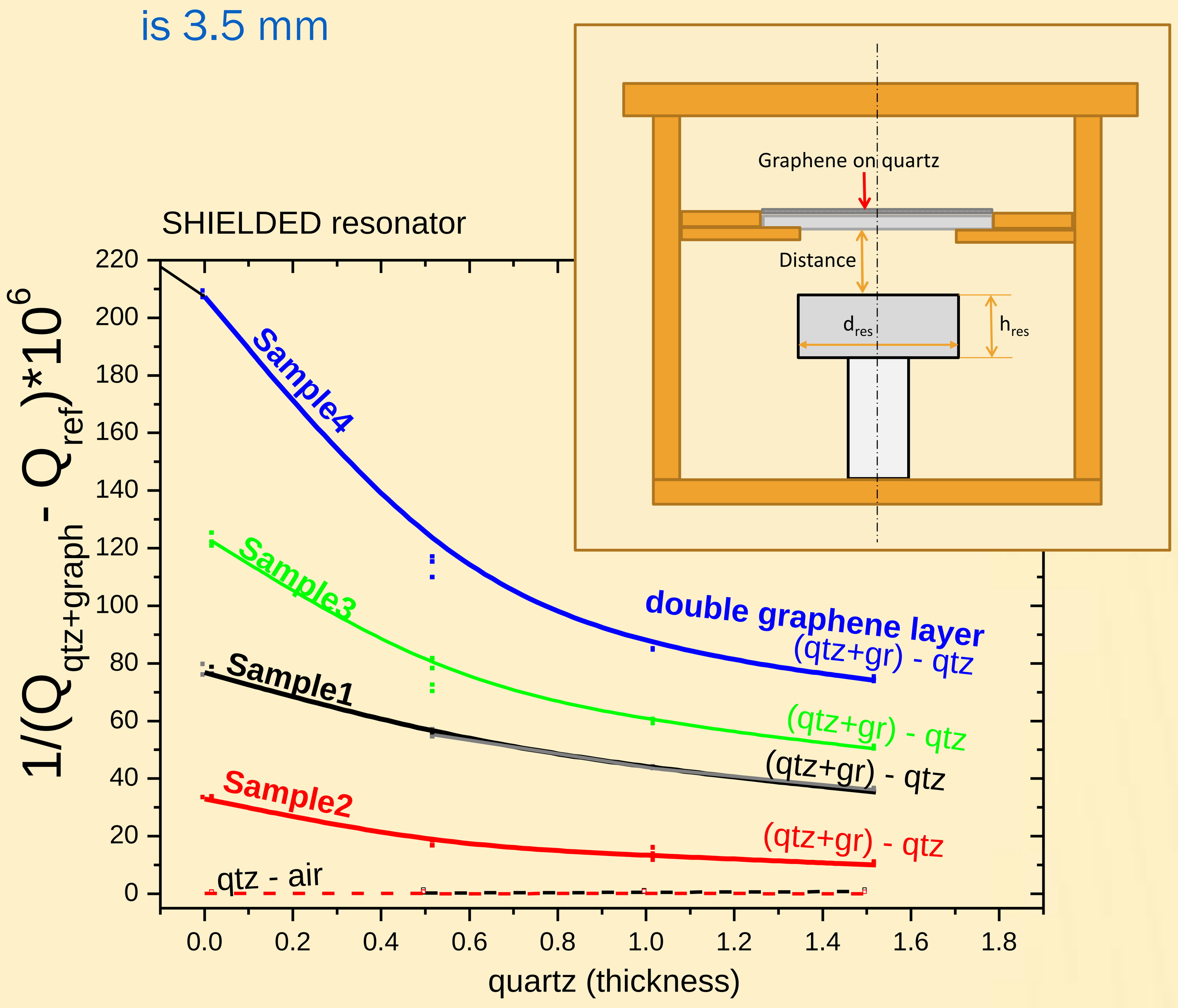
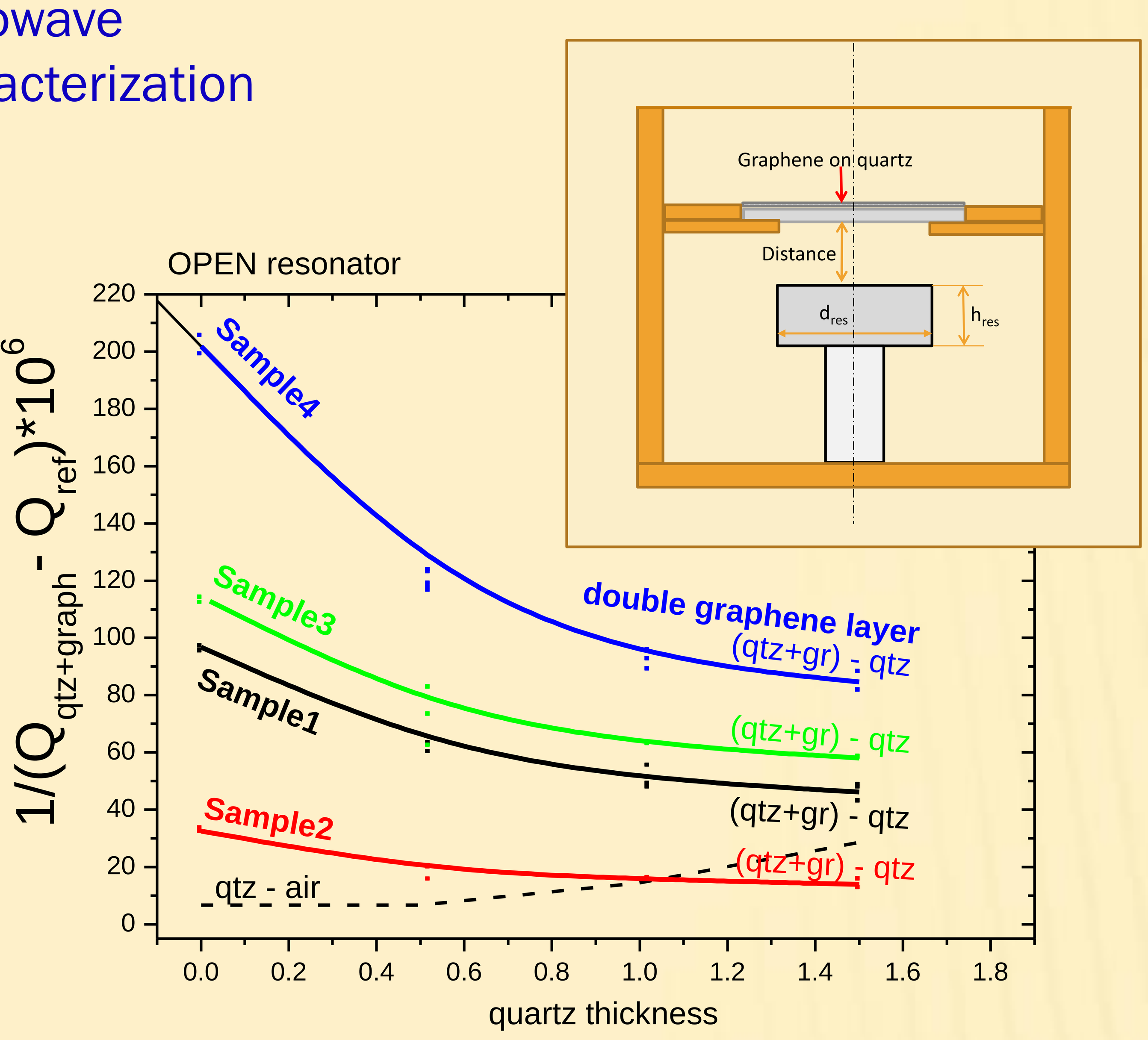


Ceramic resonator operating TE$_{01\delta}$-mode at 10 GHz

d_{res} =8 mm; h_{res} =2.5 mm;

Distance between the resonator and the sample is 3.5 mm





Surface impedance of graphene-on-insulator vs. thick metal

Graphene is much thinner than the skin depth δ at microwave frequencies

$$t_{graphene} << \delta = \sqrt{\frac{2}{\omega\mu_0\sigma_{graphene}}} \approx \mu\text{m}$$

Surface impedance of thick ($t > \delta$) metal

$$Z_s = \sqrt{\frac{\omega\mu_0}{2\sigma}}(1+i)$$

$$\text{losses} \propto \Delta Q^{-1} = \frac{\text{Re}[Z_s]}{Z_c}$$

$$Z_c = \frac{\omega W}{\frac{1}{2}\int_A H^2 dA}$$

Surface impedance of graphene of sheet resistance R_s on a dielectric substrate of permittivity ε_s (Z_0=377Ω)

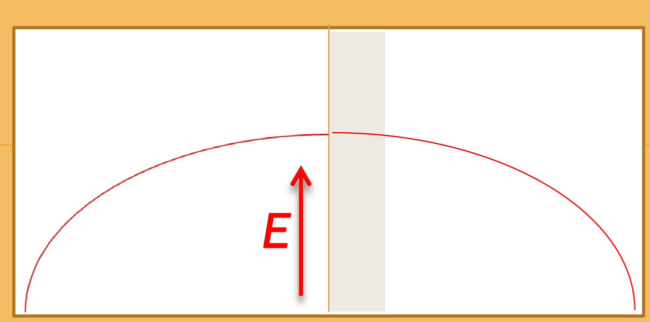
$$\frac{1}{Z_s} = \frac{\varepsilon_s^{1/2}}{Z_0} + \frac{1}{R_s}, \qquad R_s = \frac{1}{\sigma t}$$

$$\text{losses} \propto \Delta Q^{-1} = \frac{Z_c}{R_s}$$

$$Z_c = \frac{\frac{1}{2}\int_A E^2 dA}{\omega W}$$

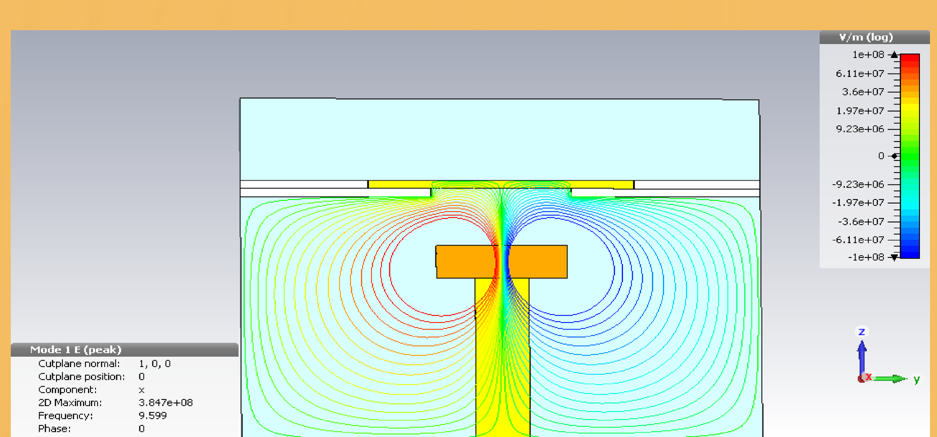
Loss contribution of resonator wall segment *A* (Z_c: characteristic impedance of the device)

Thick metal endplate

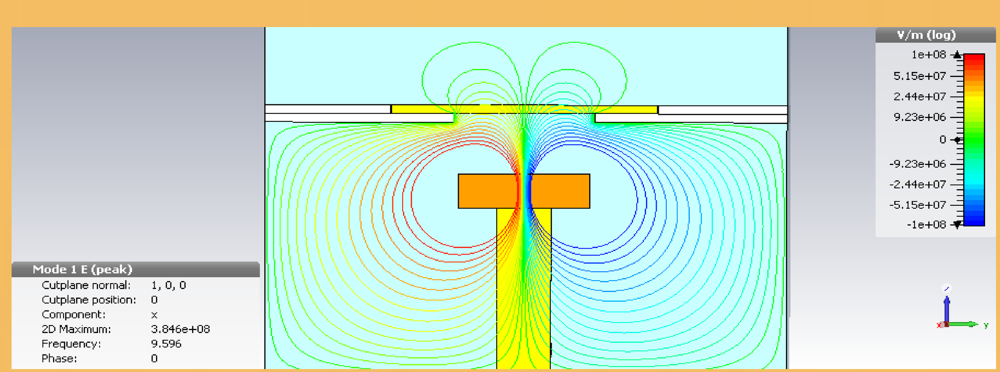


Graphene on insulating substrate

CST Microwave studio simulation of the electric field distribution in the resonator



The quartz plate with a thin metal layer on the top.



The empty quartz plate placed on top of the resonator aperture.

Sheet resistance of graphene:

$$R_S = \frac{Z_c}{\Delta Q^{-1}}$$

Where Z_c =0.075 Ω – characteristic impedance of the resonator;

ΔQ^{-1} measured inversed change of Q-factor of resonator loaded with quartz and resonator loaded with quartz + graphene.

Graphene sample	R_S in open configuration, Ω/sq	R_S in closed configuration, Ω/sq
Sample 1	947	1138
Sample 2	2927	3006
Sample 3	799	760
Sample 4	466	469

Conclusion:

Our dielectric resonator technique enables accurate and contact free determination of the integral sheet resistance of graphene on insulating substrates. The open resonator configuration enables versatile quality assessment and homogeneity control of large area graphene coatings.