Diffusion Impedance Modeling for Interdigitated Array Electrodes by Conformal Mapping and Cylindrical Finite Length Approximation

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Interdigitated array (IDA) electrodes have the advantages of enhanced sensitivity and increased active electrode area and have been widely used in various applications (e.g. bio-sensing). Steady-state behaviour of IDA electrodes has been extensively researched using analytical and numerical approaches. However, the periodic-steady-state diffusion impedance of IDA electrodes has never been tackled using an analytical approach. A Warburg element is still often used in equivalent circuit modeling but fails at low frequencies due to the arising steady-state current (Fig. 1a). In this work, an analytical solution for the diffusion impedance of a symmetric IDA electrode is derived (Eqn. 1). The solution considers necessary parameters such as the electrode bandwidth (w_e), gap width (w_g) and redox species diffusivity (D) for accurate prediction of impedances at $10^5 \sim 10^{-2}$Hz. The theory is based on conformal mappings of IDA electrodes (Fig. 1b), diffusion length derivation (Fig. 1c) and the cylindrical finite diffusion impedance (Fig. 1d). EIS, CV and CA experiments were done on several fabricated chips (Fig. 1e and f) for examination of our theory. The theoretical 0Hz impedance is compared with the reciprocal of experimental steady-state current, and a correlation coefficient of R^2=0.963 is obtained (Fig. 1g). Calculated impedances also show high consistency with experimental EIS data (Fig. 1h). This proves a feasible approach for diffusion impedance calculation of IDA electrodes for accurate model fitting, steady-state current prediction and mechanism exploration.

$$Z_{diff-IDA} = \frac{2RT}{lNn^2F^2\sqrt{D}C^*\sqrt{j\omega}} \frac{1}{\int_0^{\frac{w_e}{2}} \frac{I_0(z_\delta)K_1(z_0)+I_1(z_0)K_0(z_\delta)}{I_0(z_\delta)K_0(z_0)-K_0(z_\delta)I_0(z_0)}\,dx_e} \qquad (1)$$

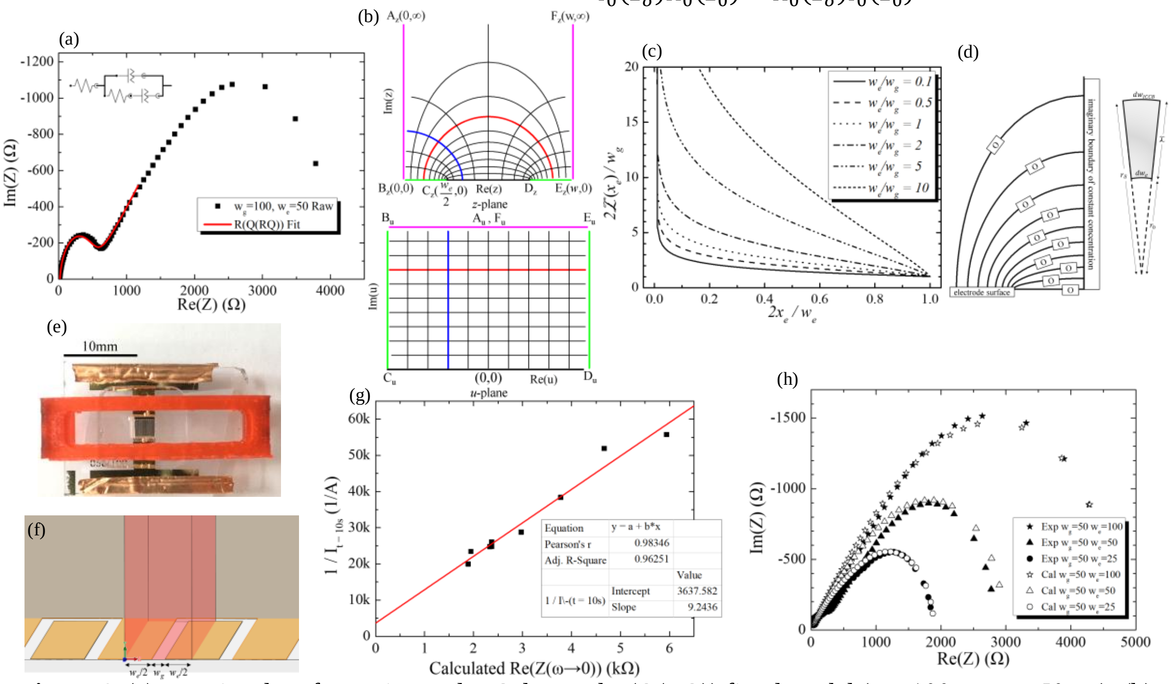

Figure 1. (a) Nyquist plot of experimental EIS data and R(Q(RQ)) fitted model (w_g=100μm, w_e=50μm); (b) conformal mapping from *z*-plane to *u*-plane; (c) dimensionless finite diffusion length plot; (d) scheme of finite cylindrical diffusion impedance; (e) photograph of fabricated IDA electrode with clipped microwell chip; (f) unit cell and definition of IDA electrode geometry; (g) reciprocal of experimental steady-state current vs calculated 0Hz impedance; (h) Nyquist plot of experimental EIS data and calculated impedances.