FORMALISMS OF THE COMPLEX IMPEDANCE SPECTROSCOPY

Open Engineering Collaboration^{*†}

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Abstract

The Complex Impedance Spectroscopy (CIS) technique is used to characterize materials with electrical and ferroelectric properties. In this paper, we present the 4 formalisms for analyzing the data obtained by the CIS.

keywords: complex impedance spectroscopy, materials characterization, complex impedance, complex electrical module, complex dielectric permittivity, complex admittance.

Introduction

1. Ferroelectric ceramics have properties that are investigated by the non-destructive technique called Complex Impedance Spectroscopy (CIS).
2. There are 4 formalities for analyzing CIS data, namely: Complex Impedance (Z^*), Complex Electrical Module (M^*), Complex Dielectric Permittivity (ϵ^*), and Complex Admittance (Y^*) [1, 2].

^{*}All authors with their affiliations appear at the end of this paper.

[†]Corresponding author: andre@selfchargebox.com | Open Engineering Collaboration.

Methods

3. A systematic literature review was carried out in the area of materials science and engineering.

Results and Discussion

4. **First formality for analyzing CIS data: Complex Impedance formalism (Z^*)** [3].
5. Z^* is the ratio of electrical current (Eq. 6) to electrical voltage (Eq. 7), where θ_0 is phase angle between $i(t)$ and $V(t)$.
6. $i(t) = I_m \sin(\omega t + \theta_0)$
7. $V(t) = V_m \sin(\omega t + \theta_0)$
8. If $\theta_0 = 0$, then Z^* is purely resistive and does not depend on the frequency:
9. $Z' = \frac{V(t)}{i(t)}$
10. If $\theta_0 \neq 0$, then Z^* has resistive and reactive properties, similar to an RC circuit (resistor–capacitor circuit):
11. $Z^*(\omega) = \frac{R}{[1+(\omega\tau)]} - j \frac{R\omega\tau}{[1+(\omega\tau)^2]} = Z'(\omega) + jZ''(\omega)$
12. **Second formality for analyzing CIS data: Complex Dielectric Permittivity formalism (ϵ^*)** [4, 5].
13. $\epsilon^* = \epsilon' + i\epsilon''$
14. ϵ' of materials with thickness (d) and area (A) is described by:
15. $\epsilon' = \frac{dZ''}{\omega\epsilon_0 A |Z^*|^2}$
16. ϵ'' of materials with thickness (d) and area (A) is described by:

17. $\varepsilon'' = \frac{dZ'}{\omega \varepsilon_0 A |Z^*|^2}$

18. The ratio between (17) and (15) is called dielectric loss and is related to heat dissipation.

19. $\tan(\delta) = \frac{\varepsilon''}{\varepsilon'}$

20. **Third formality for analyzing CIS data: Electrical Module formalism** (M^*) [6, 7].

21. M^* is a function of the material's capacitance (C_0):

22. $M^* = j\omega C_0 Z^*$

23. **Fourth formality for analyzing CIS data: Complex Admittance formalism** (Y^*) [8].

24. Y^* is defined as the inverse of Z^* . Y' is called conductance and Y'' is susceptibility.

25. $Y^* = Y' + Y'' = \frac{1}{Z^*}$

Final Remarks

26. The 4 formalisms are listed according to Table 1, where μ is the interrelation factor $\mu = j\omega C_0$.

		M	Z	Y	ε
	M	M	μZ	μY^{-1}	ε^{-1}
27.	Z	$\mu^{-1} M$	Z	Y^{-1}	$\mu^{-1} \varepsilon^{-1}$
	Y	μM^{-1}	Z^{-1}	Y	$\mu \varepsilon$
	ε	M^{-1}	$\mu^{-1} Z^{-1}$	$\mu^{-1} Y$	ε

Table 1: Relationship between formalities of the CIS technique [9].

Open Invitation

Review, add content, and co-author this paper [10].

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Agreement

All authors **agree** with [11].

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The Open Engineering Collaboration

André Luis Bonaventura, (lead author, andre@selfchargebox.com)^{1,2}

Rangel Graudiston Aredes, (rangel.aredes@gmail.com)¹

Eduardo Antonelli, (antonelli@unifesp.br)¹

¹Advanced Ceramic Laboratory, Science and Technology Institute, Universidade Federal de São Paulo; ²Self Charge Box, StartUp, São José dos Campos - SP - Brazil.