MSE 7140

Theory and Applications of Impedance and Dielectric Spectroscopy

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Learning Objectives:

(1) To introduce the basics of impedance and dielectric spectroscopy (IS/DS) and equivalent circuits, with an emphasis on materials and devices in the solid state.

(2) To describe the various types of relaxation and resonance spectra observed in different materials, and how these can be related to the equivalent circuit elements, as well as to dielectric polarization models.

(3) To discriminate between material factors and measurement factors and discuss pros and cons of different instrumentation. To establish signature responses associated with bulk phenomena, surface phenomena as well as internal and external interfaces in a wide range of materials. Materials considered include highly insulating and ferroelectric polymers and ceramics as well as semiconducting and conducting materials and their composites.

(4) To evaluate the effect of temperature and atmosphere on the response of materials as well as the effect of ac signal amplitude, dc bias voltage and applied pressure.

(5) To introduce the concepts of connectivity, percolation, effective medium models, and their effect on ac and dc electrical measurements of heterogeneous materials.

(6) To discuss new modeling schemes that take the size, shape and distribution of electrical paths into account in order to use IS/DS as a non-destructive method for microstructural characterization of all classes of materials and devices. To use as an NDT method for quality control as well as detection of environmental and mechanical degradation of materials and devices regardless of their end application.

(7) To provide sample spectra from ferroelectrics, CNTs, heterostructured semiconductor films as well as devices such as batteries, fuel cells, biosensors and solar cells.

(8) To present examples of cutting-edge in-situ experiments that provide imaging and quantification simultaneously with electrical testing.

Background:

The basic theory of how current, voltage and phase angle measurements over a wide frequency range (typically mHz-MHz) can give information about materials/devices features at all length scales: e.g. point defects, adsorbed layers, electrode-material interfaces, grain boundary interfaces, film thickness, interlayer boundaries, surface or bulk porosity and grain size. Newer equipment has made the GHz range more accessible but there are many more issues to contend with. Case studies for powder, bulk and thin film materials, containing metals, polymers, electroceramics, building materials, semiconductors, biomaterials and mixtures, as well as some devices (fuel cells, batteries, supercapacitors, solar cells, integrated circuits, gas sensors, etc..) are used to demonstrate the usefulness of this technique for basic electrical characterization of materials and devices for process quality monitoring, for phase transformation detection as well as for sensing of mechanical and/or environmental change or degradation.

Primary References:

1. R.A. Gerhardt, Impedance and Dielectric Spectroscopy: Understanding Equivalent Circuits and their Application to Materials Phenomena, TO BE PUBLISHED BY John Wiley & Sons.
2. V. F. Lvovich, Impedance Spectroscopy: Applications Electrochemical and Dielectric Phenomena, (ISBN: 978-0-470-62778-5) John Wiley & Sons, January 2012
3. E. Barsoukov and J.R. Macdonald, editors, Impedance Spectroscopy: Theory, Experiment, and Applications, 2nd edition (ISBN: 978-0-471-64749-2) Wiley-Interscience**,** March 2005
4. A.K. Jonscher, Dielectric Relaxation in Solids, (ISBN: 0-9508711-0-9), Chelsea Dielectrics Press, 1983.
5. A.R. von Hippel, Dielectrics and Waves, John Wiley & Sons, 1954.
6. Kwan Chi Kao, Dielectric Phenomena in Solids, (ISBN 978-0-12-396561-5) Academic Press, March 2004.
7. M. E. Orazem and B. Tribollet, Electrochemical Impedance Spectroscopy (ISBN: 978-0-470-04140-6) John Wiley and Sons, September 2008
8. Joseph F. White, High Frequency Techniques: An Introduction to RF and Microwave Engineering (ISBN: 978-0-471-45591-2), .Wiley-IEEE Press, January 2004.

Additional References:

1. R.A. Gerhardt, S.R. Taylor and E.J. Garboczi, eds., Electrically based microstructural characterization, *Materials Research Society Proceedings Volume 411*, 435 pages (1996). (ISBN: 1-55899-314-2)
2. R.A. Gerhardt, M.A. Alim and S.R. Taylor, eds., Electrically based microstructural characterization II, *Materials Research Society Proceedings Volume 500,* 395 pages (1998). (ISBN: 1-55899-405-X)
3. R.A. Gerhardt, A. Washabaugh, M.A. Alim and G.M. Choi, eds., Electrically Based Microstructural Characterization III, *Materials Research Society Proceedings Volume 699,* 365 pages (2002). (ISBN: 1-55899-635-4)
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6. A.S. Nowick and B.S. Berry, Anelastic Relaxation in Crystalline Solids, Academic Press, 1972 (Chapter 3)
7. A.K. Jonscher, Universal Relaxation Law (ISBN-0-9508711-2-5), Chelsea Dielectrics Press, London 1996.
8. J. Carlos Santamarina, K.A. Klein and M.A. Fam, Soils and Waves (ISBN: 0-471-49058-X) (Chapters 10-13), John Wiley and Sons, Ltd., 2001

Grading: Homework Assignments (30%) Lab Experiments (10%)
Term paper and presentation (25%) Exams I & II & III & Final (35%)