A temporal study of the ionic behavior during an electrical charge/discharge cycle in an electrolytic capacitor with carbone nanotubes

Jami Torki[1], Ali Sari[1] and Charles Jobuert[1]
[1]Université Claude Bernard Lyon 1, Ecole Centrale de Lyon, INSA Lyon, CNRS, Ampère, F-69100, Villeurbanne, France

Mathematical modeling and numerical simulations are widely used to understand ion migration in fields such as chemistry or energy storage. The model equations that describe ion migration in electrolytes can be derived from relatively simple principles while having complex forms. The theory used involves the Planck-Nernst equation [1]. Numerical simulations have confirmed the validity of the analytical expressions [2], and allow us to study in detail the behavior of ions in the electrolyte. Despite the complexity and non-linearity of ion behavior, we propose here a method to determine the temporal response of any Aluminum Electrolytic Capacitor (AEC). An operating model for a prototype is established by characterizing the dynamics of ionic charge transport under an electric field. Indeed, this work is based on the modeling, design and experimental characterization of a new energy storage system using carbon nanotubes. This model will have for the final objective to define the limits of operation and performances of the prototype.

AEC consists of two aluminum electrodes (anode and cathode), an oxide layer acting as a dielectric and an electrolyte. In AEC the electrolyte is used as conductor which can bring the negative potential closer to the dielectric via ionic transport. In order to characterize the electrolytic capacitors operating, the temporal evolution of the relaxation, resulting from the diffusion of the ions during the discharge of the electrolytic capacitor, is simulated. The model is a theoretical 1D model of an AEC. Two facing electrodes separated by an aluminum oxide dielectric with a thickness of 60 nm followed by 100 µm of the electrolyte are considered.

We studied the distribution of ion concentration, potential and electrical field in the electrolyte during transient regime. The analysis of the transient regime makes it possible to characterize the behavior of the ions subjected to strong electric field during the charge of the AEC. In order to analyze the temporal dynamics of the system, the simulation carries out a time study of 200 ns with a time step of 0.1 ns. Two phenomena are at play. First, the excitation phenomenon linked to the application of the potential and secondly the so-called relaxation phenomenon when no potential is applied. The total potential difference in the simulation has a "slot" type pulse shape. During the first nanosecond, the potential difference will vary from 0 V to 20 V in the system.

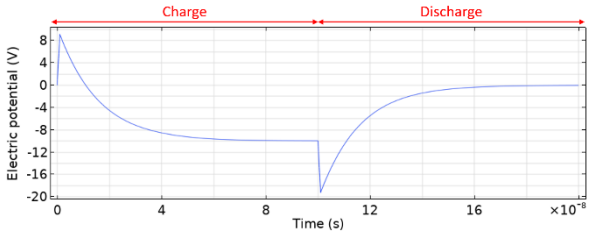

Figure 1 : Evolution of the electric potential at the interface between the dielectric and the electrolyte.

When a potential difference is applied between the two electrodes, the positive (and reciprocally negative) ions of the electrolyte will migrate towards the negative electrode (and reciprocally positive). However, due to the presence of the dielectric, the ions will accumulate at the dielectric-electrolyte boundary. As indicated by the Poisson equation [1], the accumulation of these electric charges will influence the electric potential at this point as depicted in **Error! Reference source not found.**.
In order to deduce the time constant of the evolution of the electric potential of the system, the temporal evolution of the electric potential during the charging and discharging of the capacitor is interpolated. In order to carry out this type of interpolation, algorithm based on the nonlinear least squares method is used. The latter was able to determine the coefficients allowing us to deduce the value of the time constant. A detailed study of these time constants is performed. A temporal characterization of the ionic behavior with respect to the applied potential difference gives information on the frequency response of the ionic conductor. This is an important point for many electronic components. Therefore, particular attention to the temporal characterization of these phenomena has been paid.

The present paper provides insights into the importance of the dynamics of ions in the electrolyte and their influence on the electric potential.

Reference

[1] F. Beunis, F. Strubbe, M. Marescaux, J. Beeckman, K. Neyts, and A. R. M. Verschueren, "Dynamics of charge transport in planar devices," Phys. Rev. E, vol. 78, no. 1, Jul. 2008.

[2] J. Torki, A. Sari and C. Joubert, " Modeling the distribution of ions in a electrolytic " mESC IS 2021, 5th Int. Symposium on Materials for Energy Storage and Conversion, Turkey, 2022.

Jami Torki obtained his B.S in Physics Department from Bourgogne University, Dijon France, in 2018. He received his Master's degree from University Claude Bernard Lyon 1, France in 2020. He is currently a PhD student in Electrical Engineering Department in University Claude Bernard Lyon 1. His thesis is on the modeling, design and experimental characterization of a new energy storage system using Carbon Nanotubes.

Presentating author : Jami Torki, e-mail: jami.torki@univ-lyon1.fr tel: +33 6 08 76 31 98