Entropy production in electro-thermal dielectric breakdown in solid materials

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In the present work we applied the non equilibrium thermodynamic theory in the analysis of the dielectric breakdown process. From the thermodynamic viewpoint all phenomena in nature have a tendency to reduce their energy, is the case of the propagation of electrical tree structure. As the tree channel front moves, the intense field near the front moves electrons and ions irreversibly in the region beyond the tree channel tips where electromechanical, thermal and chemical effects cause irreversible damage and from the non equilibrium thermodynamic viewpoint: entropy production. From the non equilibrium thermodynamics analysis the entropy production are due to the product of fluxes J_i and conjugated forces X_i: $\sigma = \sum_i J_i X_i \geq 0$. We consider that the coupling between fluxes can describe the dielectric breakdown in solids as a phenomenon of transport of heat, mass and electric charge. Where J_q, J_μ and J_Φ are the fluxes of heat, matter and electric charge respectively. The forces of transport conjugate to the fluxes are the thermal force: $[\nabla(1/T)]$, the chemical force: $[-(1/T)\,\nabla(\mu\, T)]$ and the electrical force: $[-(1/T)\,\nabla\Phi]$. L-coefficients are the phenomenological coefficients, L_{ij} are the coupling coefficients, $L_{ij} = L_{ji}$ by the Onsager Theorem. The diagonal coefficients are described by λ (thermal conductivity) D (diffusion coefficient) and κ (the electrical conductivity) following the classical laws of Fourier, Fick and Ohm respectively. Coupling coefficients are small in some cases but large in others. Large coupling coefficients may lead to a low Entropy production. When an insulating material is subjected to an electric field, the material gets heated up due to conduction current and dielectric losses due to polarization. The conductivity of the material increases with increase in temperature and a condition of instability is reached when the heat generated exceeds the heat dissipated by the material and the material breaks down. If we consider only the electric current and heat flux in terms of the local electric field $E = -\nabla\Phi$ and local temperature field $\nabla(1/T)$ in a system where there is no transport of mass $J_\mu = 0$.

[l] P.L. Damming, L.A. Herrera, Comp. Mat. **44**, 330 (2008).

[2] J.L. Vicente, A.C. Razzitt, Phys. Rev. E **57**, 1 (1998).

[3] H.F. Neff, A.M.N. Lima,E.U.K. Mel, IEEE Trans. on **17**, 872 (2010).

[4] I.M. Irurzun, P. Bergero, V. Mola, Chaos Sol. & Fract. **13**, 1333 (2002).

[5] J.L. Vicente, A.C. Razzitte, Physica A **261**, 309 (1998).