

***In situ* stress, strain and dielectric measurements to understand electrostriction in anodic oxides**

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Internal stresses in anodic oxide films may influence their reliability. In addition, the coupling between the internal stress and the oxidation behaviour may be important to understand the formation mechanism and the breakdown of anodic oxides. Internal stresses in anodic oxide films arise from two distinct contributions. The first one is due to the volume changes caused by the migration of ions during film growth. The second one, electrostriction, is due to the electric field: polarization of the anodic oxide film deforms it and the internal stress changes. The influence of these two contributions has been recognized in the past but many contradictory results have been reported. For instance for electrostriction, ellipsometry measurements have shown that the thickness of anodic oxides increases with the square of the electric field, while other groups reported non-quadratic dependence [1,2]. Furthermore, the internal stress decreases (compressive direction) with the electric field, consistent with the intuition that the thickness of the oxide film decreases with electric field, as predicted by the Maxwell stress [3].

We precisely determined the electrostrictive behaviour of anodic niobium and silicon oxide by combining measurements of the internal stress, thickness and dielectric measurements *in situ* by curvature, spectroscopic ellipsometry and electrochemical impedance measurements. Remarkably, these oxides behave differently. For anodic niobium oxide, the internal stress decreases (compressive stress) with the electric field whereas it increases (tensile stress) for anodic silicon oxide. We derive the constitutive electrostriction equation describing the relationship between deformation, internal stress and electric field from energy conservation equations we apply to dense anodic oxide films and predict a quadratic relationship between the internal stress and the electric field. Experimentally, we measure a quadratic dependence for anodic silicon oxide but not for anodic niobium oxide. We attribute the latter to a dependence of the dielectric constant on deformation and electric field. The reason for this will be further discussed.

[1] W.D. Cornish, L. Young, *Proc. R. Soc. London, Ser. A* 335 (1973) 39.

[2] J.L. Ord, W.P. Wang, *J. Electrochem. Soc.* 130 (1983) 1809.

[3] D.H. Bradhurst, J.S.L. Leach, *J. Electrochem. Soc.* 113 (1966) 1245.