

Comment on "Theory and analyses of the ac characteristics of defect thin-film insulators"*

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A theory of metal-insulator-metal thin films proposed by Nadkarni and Simmons is examined in relation to earlier treatments. Attention is drawn to approximations inherent in the theory and physical processes not considered by the authors.

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In a recent interesting paper,¹ Nadkarni and Simmons (NS) present what they term "the theory of the ac properties of the MIM (metal-insulator-metal thin film) system containing Schottky barriers at the metal-insulator interface". We feel that the theory presented by NS is only one of a number of models which offer an approximate description of a complex system. In this paper, we draw attention to some earlier models related to that of NS and to physical features omitted in the NS treatment.

NS propose that an MIM system be represented by an equivalent series circuit of three parallel RC sections corresponding to two Schottky barriers and the bulk of the insulator. NS then immediately drop one RC section as corresponding to a forward biased barrier with comparatively small impedance. The remaining two-section circuit, with temperature and voltage being independent parameters, is precisely the usual two-layer Maxwell-Wagner model of interfacial polarization.² The experimental plot of dielectric loss ϵ'' against (effective) permittivity ϵ' as frequency is varied (Fig. 6 of Ref. 1) is indeed characteristic of the Maxwell-Wagner model.

Equivalent circuits of the Maxwell-Wagner form were suggested for MIM systems in earlier papers by Parker and Wasilik³ and Maddocks and Thun.⁴ Both sets of authors were aware of the probable presence of Schottky barriers in MIM systems and the latter explicitly mention that the depth of the depletion layer, and thus the barrier capacitance, are voltage dependent. The novel elements in the NS paper are thus explicit inclusion of the voltage and temperature dependence of the Schottky barrier resistance, as well as that of the barrier capacitance and computation of theoretical curves for capacitance and loss tangent as functions of temperature and frequency. While there is qualitative agreement between the theoretical and experimental curves obtained by NS, we do not feel that they are in fact "identical in nature".

The theory set forth by NS is necessarily approximate and incomplete since their model equivalent circuit is a considerable idealization of the physical reality. In actuality, the system is a distributed one and there is no distinct dividing line between the Schottky barrier region and the bulk. In contrast, NS take for the capacitance of the Schottky barrier that computed for uniform exhaustion of charge carriers in a well-defined boundary region.⁵ In a recent article, Henisch⁶ details some of the physical features which tend to complicate this simple picture.

The physical situation may be particularly complicated if mobile ions or ion vacancies are present, in addition to mobile electrons. Argall and Jonscher⁷ interpreted their ac measurements on aluminum oxide and silicon oxide thin films in terms of blocked nonelectronic charge carriers at the electrodes. Ionic space charge and electronic space charge would be strongly coupled and would require a coherent treatment, well beyond the NS model.

The potential-dependent differential capacitance [Fig. 5(a) of Ref. 1] obtained for silicon oxide is suggestive of additional physical processes which may occur. Pleskov⁸ has derived a similar curve for the differential capacitance of electron surface states on a semiconductor surface. Macdonald⁹ discusses similar results in considering the specific adsorption of charge carriers at an electrode.

In electrolyte and semiconductor theory, it is desirable, when possible, to satisfy mass and charge transport equations and Poisson's equation throughout the conduction region. This has been accomplished in two-electrode situations, thus far, only under a rather restricted set of conditions which do not allow the existence of Schottky-type barriers.¹⁰ While approximate solutions are certainly desirable and may well be useful for the Schottky barrier situation, it would be unfortunate if an approximate model, such as that of NS, was accepted at face value as the final solution to the problem.

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