Application of an extended unified Schottky-Poole-Frenkel model to high-k capacitor structures used in analog integrated circuit technology

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In this abstract, the author points out that the Poole-Frenkel (P-F) and Schottky emission mechanisms actually can happen simultaneously and a unified Schottky-Poole-Frenkel model can be used to explain a lot of existing experimental data. Further extension of the model can be used to explain the I-V characteristics of high-k capacitor structures used in analog integrated circuit technology much more satisfactorily then the model without extension.

For the P-F mechanism, the leakage current through an insulator is given by

$$J_{PF} = BE\exp\{[\phi_B - ((qE)/(\pi\varepsilon o K_{PF}))^{1/2}]/(kT/q)\} \qquad (1)$$

In equation (1), B is a constant while E , ϕ_B , k, T, q, εo and K_{PF} are the electric field, barrier height of defect state, Boltzmann constant, absolute temperature, electronic charge, vacuum permittivity and the dielectric constant for the P-F effect.

Beside the P-F effect, leakage current can also be due to Schottky emission. For the Schottky emission mechanism, the leakage current through an insulator is given by

$$J_{SK} = A^{**}T^2\exp\{[\phi_B - ((qE)/(4\pi\varepsilon o K_{SK}))^{1/2}]/(kT/q)\} \qquad (2)$$

In equation (2), A** is Richardson constant while E , ϕ_B , k, T, q, εo and K_{SK} are the electric field, barrier height at metal-insulator interface, Boltzmann constant, absolute temperature, electronic charge, vacuum permittivity and the dielectric constant for the Schottky effect.

In this abstract, the author proposes a unified Schottky-Poole-Frenkel model, as shown in Fig. 1. The I-V characteristics of RNL in the proposed model is represented by eq. (1) which applies to all bias voltages and so is independent of bias voltage polarity. The I-V characteristics of the Schottky diodes D1 and D2 in the proposed model is not symmetrical but instead it has a highly conductive "forward" I-V characteristics and a much less conductive "reverse" characteristics. Eq. (2) represents the reverse characteristics of Schottky diodes D1 and D2 for relatively larger reverse bias voltages.

Fig. 1 A capacitor structure involving a high-k dielectric can be thought as two back-to-back Schottky diodes D1 and D2 with a non-linear resistor RNL in between.

The above theory can be extended if RNL is considered as a parallel combination of RNL1 and RNL2; RNL1 is governed by the P-F mechanism as shown in Eq. (1) while RNL2 comes from electrons injected by one of the 2 metal contacts. Fig. 2 shows the experimental data for $Ta/Ta_2O_5/Ta$ capacitors used in analog integrated circuit technology from Tsai et al.[1] The extended unified Schottky-Poole-Frenkel theory can be shown to explain the experimental results in Fig. 2 much more satisfactorily than the theory without extension.

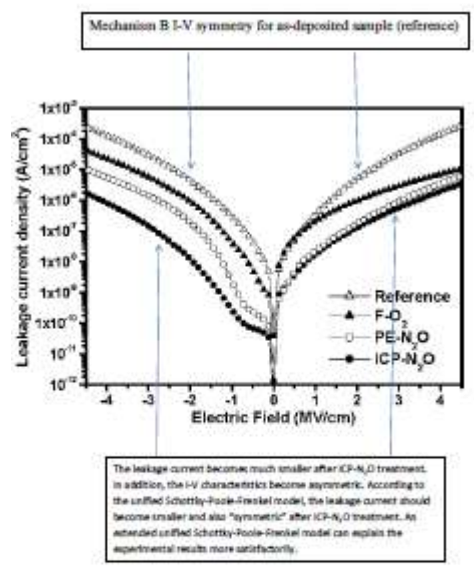

Fig. 2 Current density plotted against the electric field for $Ta/Ta_2O_5/Ta$ capacitors. The original data are from Tsai et al 2007.[1]

REFERENCES

[1] K.-C. Tsai et al., *J. Electrochem. Soc.*, **154**, H512 (2007).