Experimental observation of Poole-Frenkel saturation in ultrathin tantalum oxide capacitor structure

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In this abstract, the author points out that Poole-Frenkel (P-F) saturation can be experimentally observed in ultrathin tantalum oxide capacitors. Factors why P-F saturation has been difficult to observe experimentally will be discussed.

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 Eq. (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.

The P-F effect is basically electric field assisted ionization of deep donors in an insulator. It can be imagined that when the electric field is large enough, all the deep donors will be ionized and the P-F effect will be “saturated”, resulting in P-F saturation. When there is P-F saturation, Eq. (1) will not be obeyed and the current will become more or less constant when the electric field is further increased [1]. However, P-F saturation has been difficult to observe experimentally. Harrell and Gopalskrishnan claimed to observe experimentally by using some sort of extrapolation [2]. Habermehl et al. pointed out that P-F saturation occurs near breakdown and so P-F saturation may not be easy to observe experimentally [3]-[4].

Beside the P-F effect, leakage current can also be due to Schottky emission. It has been difficult to distinguish P-F effect from Schottky emission. Recently, the author has proposed a theory which can be used to distinguish P-F effect from Schottky emission [5].

It is not too difficult to imagine that an ultra-thin Ta_2O_5 film is better than a thick Ta_2O_5 film because an ultra-thin film to easier to oxidize completely than a thick film. In addition, it is easier to remove impurities like carbon in an ultra-thin film than a thick film by a short anneal. A polycrystalline film may have grain boundaries. Annealing in an oxidizing ambient at a temperature slightly below crystallization temperature is used to avoid formation of grain boundaries.

With the help of the author’s theory to analyze experimental data, P-F saturation was observed as shown in Fig. 1.

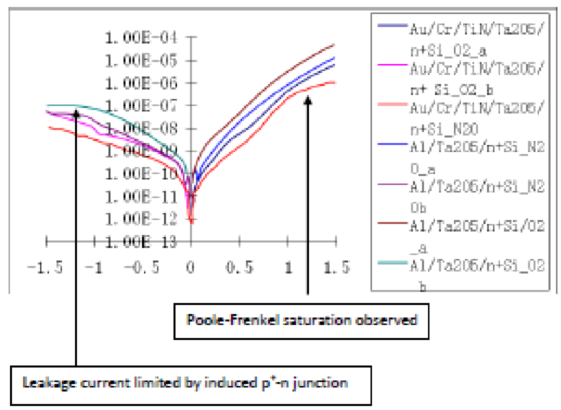

Fig. 1 Current plotted against the bias voltage applied to the metal gate for $TiN/Ta_2O_5/n^+$-Si and $Al/Ta_2O_5/n^+$-Si capacitors. Ta_2O_5 was deposited by chemical vapor deposition on n^+-Si and annealed by rapid thermal annealing (RTA) in O_2 or N_2O at 700°C for 30 s. Poole-Frenkel saturation can be clearly seen for $TiN/Ta_2O_5/n^+$-Si capacitor with RTA in N_2O at 700°C for 30 s at positive bias voltage above 1 V. Diameter of capacitor is 1 mm.

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