# Analysis of Leakage Current of Low-k Materials for Use As ILD

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Many low-k materials have been developed and reported in various places. The first criterion to be examined in deciding whether or not a material is suitable for an ILD process is leakage current. The leakage current of the gate insulator is carefully scrutinized because it is a good indicator of MOS transistor performance. CVD-$SiO_2$ (TEOS) and $SiO_2$-like films are widely used as ILDs because they have good electrical characteristics and exhibit a very low leakage current ($I_{leak} < 1$ nA/cm$^2$). This has made a thorough analysis of the leakage current mechanism unnecessary. However, many films currently under consideration exhibit a high leakage current, which also has a strong temperature dependence (>100C). So we have been investigating the leakage current mechanism, the study of which is important in developing new materials.

We have considered leakage current pass whose equivalent circuit is shown in fig. 1. The circuit should bring Cmax frequency dependence. Traps and charges considered in this study are described in the figure$^{1)}$. When a relative low frequency is applied to samples, only mobile charges (including electrons) contained in the films can follow the frequency, so that a charge distribution is changed. When a high frequency the mobile charges can not follow is applied, the distribution should not be changed. This means that different voltage shift between when high and low frequencies are applied can be shown. The resultant different voltage shift, □V, coincides with the difference of Vfb at different frequencies, □Vfb. And then the □Vfb should reflect existence of mobile charges.

The leakage current was measured using an MIS structure with Al electrodes 1 mm in diameter. In addition, the C-V characteristics were measured, and the flat-band voltages, $V_{fb}$, at 1 MHz and 10 KHz were obtained. Measurements can be also made on samples heated up to over a hundred degrees C.

Strong temperature dependences of the leakage currents of low-k films have been measured. These suggest the presence of mobile charges contained in the films. The number of mobile charges in the film can be reflected from the difference between Vfb at two applied frequencies: □Vfb = Vfb @ 1MHz – Vfb @ 10 KHz. Figure 3 shows dependence of the □Vfb on the current densities of the films. Films showing high □Vfb indicates a large leakage current. This tendency becomes more pronounced at a high temperature (150C). One reason that many low-k films exhibit a large leakage current at high temperatures is the presence of mobile charges in the film.

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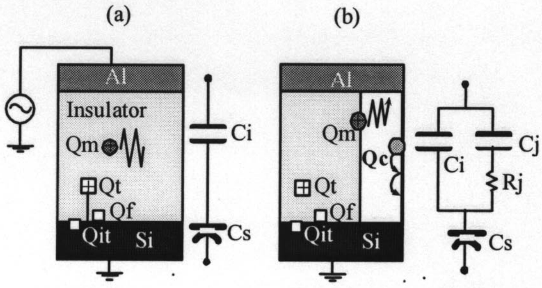
**Reference**: 1) S. M. Sze, "Physics of Semiconductor Devices" JOHN WILEY & SONS

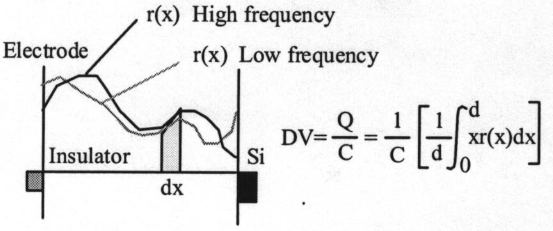


$C = \frac{CiCs}{Ci + Cs}$
Cmax=Ci

$Cmax = Ci + \frac{Cj}{1 + w^2 t^2}$
t=RjCj
C: low freq. > high freq.

Qc: Charge carrier Qm: Mobile ionic charge
Qt: Trapped charge Qf: Fixed charge
Qit: Interface trapped charge

Fig. 1 Conventional treatment (a) and a treatment with leakage pass (b)



$$DV = \frac{Q}{C} = \frac{1}{C}\left[\frac{1}{d}\int_0^d xr(x)dx\right]$$

DVfb(high) - DV(low) = Vfb(high) - Vfb(low) = dVfb

Fig. 2 Charge distribution and dVfb

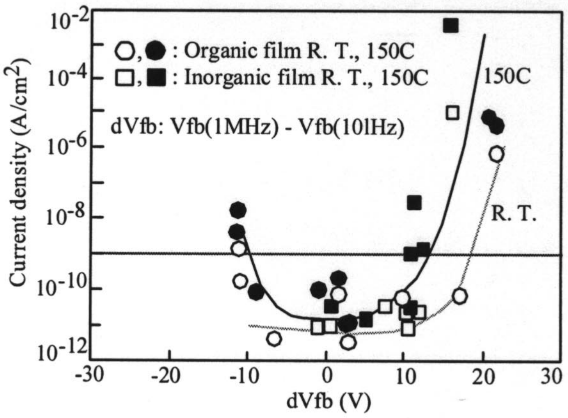


Fig. 3 Dependence of current density on dVfb

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