Electrical Methods for Estimating the Correlation Length of Insulator Thickness Fluctuations in MIS Tunnel Structures

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Abstract

The techniques for extraction of the correlation length of insulator thickness fluctuations from the data of electrical experiments with thin MIS (Metal-Insulator-Semiconductor) structures are discussed. The procedure of statistical treatment of currents flowing in a random selection of MIS tunnel diodes is developed, targeting the estimation of this length. Another proposed method is based on the analysis of the soft-breakdown-related current jumps. For verification, a comparison is made to the correlation length yielded by microscopy measurements.

1. Introduction. Definition of correlation length

Tunnel-thin films of different dielectric materials attract now much attention. Evidently, the smaller the thickness is, the more critical are its variations along the structure [1]. One of important problems in this field is diagnostics of fluctuation parameters.

For a local film thickness d, Gauss distribution with the nominal value d_n and the standard deviation σ_d is adopted (e.g. [2]). However, spatial variation cannot occur arbitrarily abruptly. If x is a coordinate in the insulator-semiconductor interface plane, the covariance between the thicknesses at the distance l is

$$\mathrm{cov}(l) \equiv \frac{\left\langle \left(d(x)-d_n\right)\cdot\left(d(x+l)-d_n\right)\right\rangle}{\sigma_d^2} \qquad (1)$$

The correlation length λ can be defined as the value of l for which the covariance (1) is reduced to some small value cov_{crit} taken on agreement.

The length λ, like σ_d, is an overall quality indicator for a dielectric layer. Practically, λ should be short, so that the condition $L >> \lambda$ could be satisfied. L denotes a linear device dimension ($L \sim S^{1/2}$, where S is area).

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Below we propose two novel methods to estimate this parameter λ from electrical measurements.

2. Samples. Reference value of λ

As a testing bench, $Al/SiO_2/Si$ MIS diodes with d_n = 2.7 nm and σ_d = 0.28 nm are taken. For modern oxide technology, such a deviation is very large, but it makes benefit accentuating the studied effects.

The thickness profiles $d(x)$ were recorded to within a constant term, using the atomic force microscope. As the Si surface accessed to after etching the oxide was rather smooth, the SiO_2 relief (Fig. 1) was assumed to reflect the thickness fluctuations. The covariance was calculated handling with $h(x)$ as if it were $d(x)$ and using $\langle h \rangle$ at place of d_n. This yielded the value of $\lambda \sim$ 40–70 nm serving as reference.

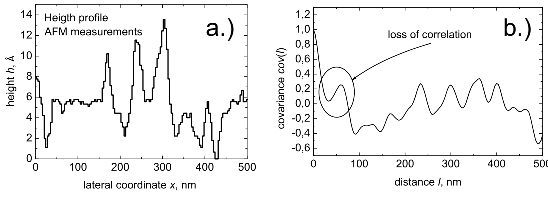

Figure 1: Oxide topography and covariance function.

3. Statistical method for the estimation of λ

For the finite σ_d and λ, the tunnel current I should exhibit a sample-to-sample variations.

In [3], we calculated the dependence of a standard deviation of quantity I/S, $\sigma_{I/S} = \sigma_{I/S}(L/\lambda)$, usable for estimation of λ. But it is more convenient to deal with the factor $\mu = \sigma_{I/S} / \langle I/S \rangle = \sigma_I / \langle I \rangle$ (Fig. 2) which is less sensitive, than $\sigma_{I/S}$, to bias V, nominal thickness d_n, doping level etc. The sole parameter strongly affecting the shape of $\mu(L/\lambda)$ is σ_d.

The value of μ measured for our small-sized MIS diodes is about 0.18 (s. histogram). From the main Fig. 2, we deduce the L/λ ratio of 200 and therefore, λ ~ 50 nm, which agrees to the reference result.

Interestingly, a close λ was obtained by processing the data of [4]. In that work $\mu = 0.102$, $L = 2.3$ μm, σ_d ~ 0.2 nm; so we get L/λ ~ 50 and λ ~ 40 nm.

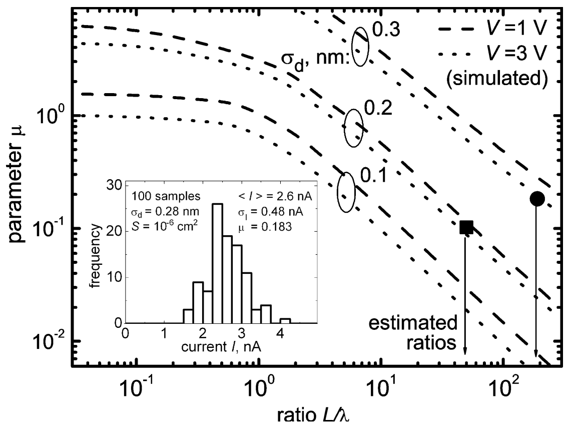

Figure 2: The curves $\mu(L/\lambda)$. Circle - the parameter μ of a current spread in our work (Inset); square - in [4].

4. Breakdown method for the estimation of λ

In [5], the current at high bias was shown to drop after the oxide soft breakdown (SB). It is because the SB spot resistance exceeds the initial tunnel resistance of the same cell. At very high $|V|$, the broken thinnest cell λ×λ is almost excluded from the current transport; its conductivity increases with $|V|$ according to power law while the tunnel resistance exponentially.

Experimentally, one can find the relative current decrease $\xi = |I - I_0|/I_0 = \Delta I/I_0$, where I_0 and I are the currents before and just after the SB. Further, the areal fraction η is calculated for the known σ_d and current fraction ξ. Then the SB spot size is $\lambda \sim l_{SB} = (\eta \cdot S)^{1/2}$.

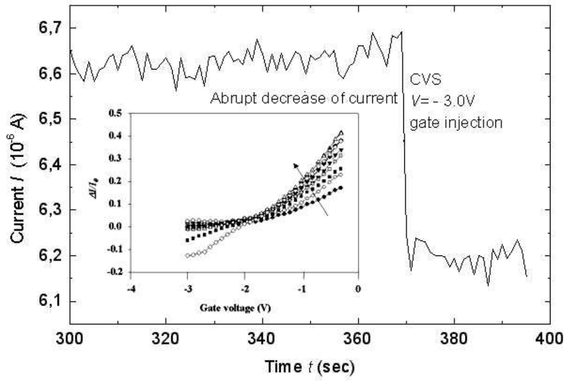

Figure 3: Current drop at CVS [constant-voltage stress] and the $\Delta I/I_0$ vs. V curves for a sequence of SB (Inset).

Fig. 3 shows the behaviour of a current in an MIS tunnel structure at high-voltage CVS. The values of I are much larger than in Fig. 2 due to larger area: $S = 1.26 \cdot 10^{-3}$ cm^2. As seen in inset, $\Delta I/I_0 > 0$ only at low $|V|$, whereas for high $|V|$ there is a current decrease. At the main Fig. 2, the relative current reduction is $\xi \sim 10^{-2}$. In case of $\sigma_d = 0.28$ nm, 1% of total current should flows through only 10^{-8} ($\eta = 10^{-8}$) of a device area [5]. So $\lambda \sim (10^{-8} \cdot S)^{1/2}$ ~ 40 nm, i.e. nearly the reference value.

5. Conclusion

Two methods for estimating the correlation length λ of the insulator thickness fluctuations, based on the electrical measurements, have been proposed and verified on samples with large thickness deviation.

One may admit, however, that the accuracy of new methods will be insufficient for very small σ_d. For this reason, they might be potentially more interesting for tunnel-thin films of insulating materials for which the technology level is inferior to that of SiO_2.

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