

THE APPLICATION OF SILICON DIOXIDE AS AN ELECTRET MATERIAL

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ABSTRACT

We have investigated silicon dioxide for its electret properties. It appears that thermally grown silicon dioxide has a large lateral surface conductivity, resulting in a rather poor electret behaviour. This can be adequately reduced by a chemical surface modification resulting in an excellent silicon dioxide electret.

Our experiments have shown that corona-charged SiO₂ layers are much better resistant to high temperatures than Teflon-FEP electrets. A 1.1 μm thick SiO₂ layer, charged up to 150 V, yields a time constant of the charge decay in excess of 400 years at ambient laboratory conditions.

INTRODUCTION

Up to now mainly fluor carbon polymers, such as Teflon-FEP and Teflon-PTFE have been used as the electret material in microphones. Although Teflon is an excellent electret material its application techniques are hardly compatible with the use of new technologies, such as chemical etching techniques in the construction of a silicon subminiature electret microphone. For that reason it is worthwhile to investigate other materials employed in integrated circuit technology for their electret properties.

Preliminary measurements have been carried out on SiO₂ and Al₂O₃ samples. Based on these results and those reported in literature [1] as well as the fact that SiO₂ is a standard material in our laboratory, we have further investigated the electret properties of SiO₂ only.

In this paper it will be assumed that the *lifetime* of an electret is equal to the *time constant* of the charge decay, i.e. the period in which the electret charge has decayed to 63% of its initial value.

EXPERIMENTAL

All SiO_2 samples have been prepared by wet-thermal oxidation of 2-inch (100) 5-10 Ω cm p-Si wafers. In the first experiments we have charged 1.1 μm thick SiO_2 samples. These samples showed a charge decay, measured by the Monroe Isoprobe 244 electrostatic voltmeter, in the order of days which is unacceptable for microphone applications. In order to investigate the observed charge decay a steep charge profile has been created on a SiO_2 sample. The measured decay is shown in figure 1. The left side has been charged up to 150V, while the right side remained uncharged. As is clear from the figure, the charge is spreading relatively fast and evenly over the surface. This can be understood by assuming a relatively large lateral surface conduction. This lateral surface conductivity is mainly determined by a physical adsorption of polar groups (mainly water) to the silanol groups at the interface [2]. These physically adsorbed OH-groups may be removed by a chemical surface modification, in which the polar silanol groups are substituted by apolar groups, which do not adsorb polar H_2O -groups [3]. This modification may be accomplished by treatment of the SiO_2 surface with Hexamethyldisilazane (HMDS). By this treatment the oxide surface is completely covered with a mono-layer of chemically bonded apolar CH_3 -groups. Due to this treatment the adsorption of polar H_2O -groups has become very unlikely which

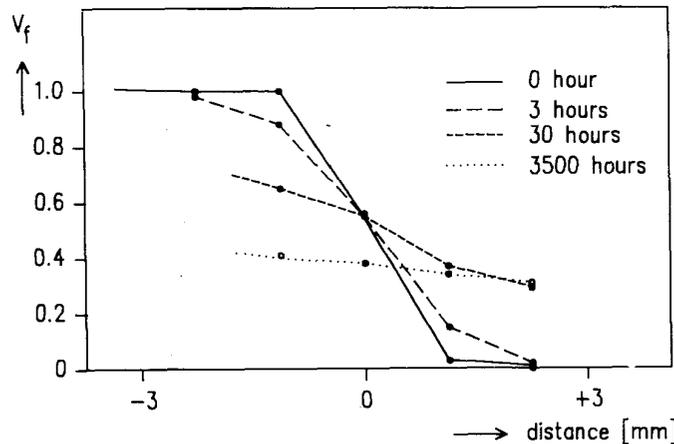


Figure 1 Normalized electret voltage as function of position and time showing the effect of the lateral surface conduction on a virgin 1.1 μm thick SiO_2 electret.

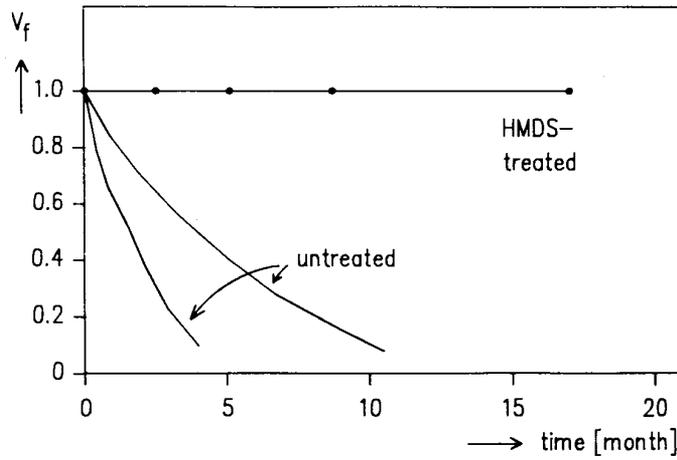


Figure 2 The normalized measured electret voltage decay at ambient laboratory conditions of some SiO_2 electrets with and without a HMDS treatment.

results in a very low surface conductivity. The results of this treatment are shown in figure 2. The lower curves represent the charge decay of a number of untreated SiO_2 electrets, which have been charged up to 150 V. The upper line represents the decay of a 150V-HMDS-treated SiO_2 electret.

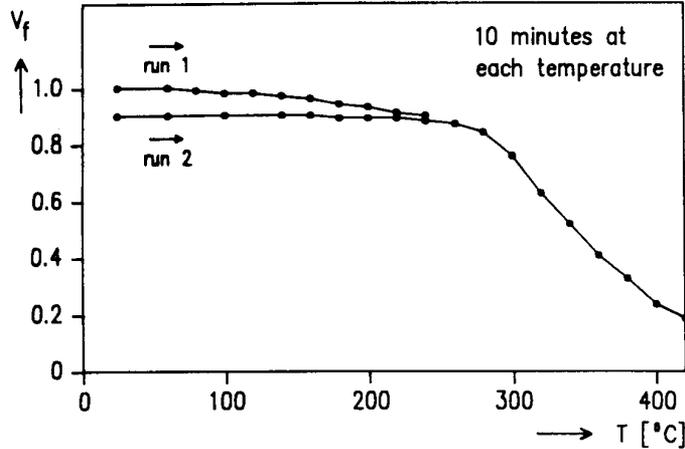


Figure 3 The measured normalized electret voltage decay of a $1.1 \mu\text{m}$ thick HMDS treated SiO_2 electret as a function of temperature.

In order to examine the temperature dependence, a HMDS-treated SiO₂ electret has been measured; the results are given in figure 3. The temperature has been increased in 20°C steps of 10 minutes each, from 20°C up to 240°C in the first run and from 20°C up to 400°C in the second run.

After each temperature step the sample was cooled down to room temperature and measured. Considering figure 3, some charge has been released in the first run at temperatures up to 240°C. During the second run hardly any charge has been released at temperatures below 240°C. It is concluded that the traps with a low activation energy had been released already in the first run and thus these traps were not active anymore during the second run. In the range from 240°C - 420°C the charge decay becomes significant again, which is due to the release of traps with a higher activation energy.

The tendency of the charge decay of the HMDS-treated SiO₂ electret appears to be comparable to that of Teflon [4]. However a higher temperature is needed for this type of electret to show the same charge decay as a Teflon electret. This suggests that the charges in a SiO₂ electret are more stable than in a Teflon electret. This is even more clear from figure 4, where the electret charge decay (trace 1) of a HMDS-treated SiO₂ electret is shown at a constant temperature

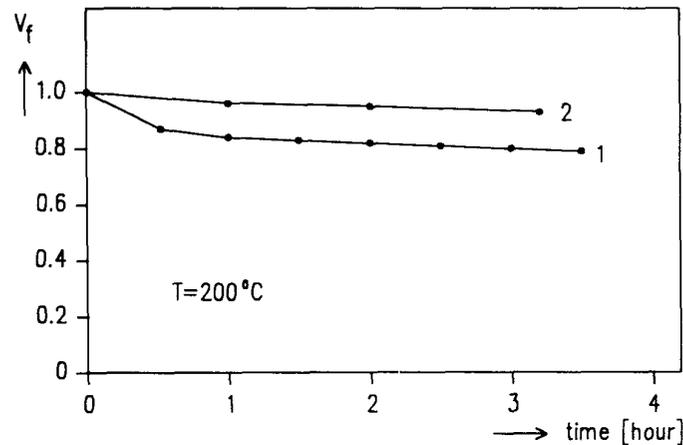


Figure 4 The normalized measured isothermal electret voltage decay of a 1.1 μm HMDS-treated SiO₂ electret at 200°C (trace 1). If this electret is subsequently charged to its initial charge level, it has become better resistant to temperature (trace 2).

of 200°C. During the first hour the charge decays rapidly, while thereafter the decay is more or less stabilized. First the traps with a relatively low activation energy release their charges. After one hour these traps are empty and a second kind of deeper traps determines the charge decay. If this sample is charged again up to 150 V, and heated in the same way, trace 2 is found. The same phenomenon has been observed for Teflon electrets [5].

CONCLUSIONS

It has been demonstrated that an untreated SiO₂ layer is a poor electret mainly due to a large lateral surface conduction.

However a 1.1 μm thick SiO₂ layer turns into an excellent electret if the surface conductivity has been reduced by an appropriate chemical surface modification. This surface modification is adequately accomplished by a hydrophobic conversion using HMDS.

We have not measured any charge decay at room temperature for a period of 17 months of well-prepared SiO₂ electrets charged up to 150 V. This results in a lifetime (time constant) of more than 400 years.

It is adequate to age SiO₂ electrets by a two or three charge-discharge cycles prior to use. By this treatment, which is known as artificial ageing, the traps which cause an initial charge decay are discharged. It may be concluded that the charge decay mechanisms of Teflon and SiO₂ electrets are very much alike, occurring however at different temperatures.

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