An influence of technological parameters of plasma-chemical deposition of SiO$_2$ films on their electro-physical properties

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Abstract. In this article a formation process of dielectric films on silicon (100) and silicon carbide using plasma-chemical deposition is described. Experimental relationships of SiO$_2$ films thickness and main technological parameters are presented. Values of electro-physical parameters of films are measured.

1. Introduction

Formation of high quality dielectric coatings is an increasingly important problem, which needs an efficient solution. Such coatings are widely used in microelectronics as:

- protecting and passivating layers on surfaces of products;
- masking layers for selective plasma and liquid etching;
- layers for side-wall local isolation during formation of gate block of MOS-transistors.

In modern microelectronics most widely used are thin films of SiO$_2$ and Si$_3$N$_4$. In this work the objects for testing are films of amorphous SiO$_2$, deposited onto (100)-Si and 6H-SiC substrates using method of plasma-chemical deposition in a mixture of vapors of oxygen and hexamethyldisiloxane (HMDS) with the help of apparatus URM-053 (Russia) (figure 1).

![Figure 1. Schematic representation of reaction chamber of apparatus URM-053 (Russia) for deposition of dielectric films using PECVD.](image-url)
In PECVD technology for decomposition of reaction gas into active radicals gaseous plasma is used. Thermodynamic non-equilibrium of decomposition processes in gas discharge enables deposition of amorphous and polycrystalline films to be carried out at considerably lower temperatures, in comparison with analogous processes of gas phase chemical deposition (CVD) with thermal decomposition of reaction gas.

In PECVD process chemical activation is achieved due to decomposition of gas mixture into electrons, ions and active radicals. Radicals and ions, approaching substrate enter into a reaction in its surface yielding amorphous or polycrystalline layer of target material.

The main stages of PECVD process are:
– vaporization of initial reagent;
– chemical activation of gas molecules;
– transport of reagent to substrate using argon as a carrier-gas;
– plasma stimulated reaction yielding the solid product;
– removal of gaseous reaction products and surplus reagent from the reaction zone (figure 2).

![Figure 2. Main stages of PECVD process.](image)

2. Experimental
Three-stage process being used for plasma-chemical deposition of SiO₂ onto (100)-Si and 6H-SiC substrates. At the first stage substrates were treated in oxygen for preparation of natural SiO₂. At the second stage hexamethyldisilane (HMDS) was fed into chamber where deposition of “main” SiO₂ layer was carried out. At the third stage substrate with deposited layer was treated in oxygen, for SiO₂ structure contraction and prevention of defect formation in bulk SiO₂.

Chemical reaction on the surface of the substrate using HMDS could be presented as follows:

\[
\text{Si}_2\text{O}(\text{CH}_3)_6 + 12\text{O}_2 \xrightarrow{200-300 \, ^\circ \text{C}} 2\text{SiO}_2\downarrow + 9\text{H}_2\text{O}\uparrow + 6\text{CO}_2\uparrow.
\]

Properties and composition of layer being prepared is defined by ratio gas mixture components, discharge power, substrate temperature and conditions of ion bombardment.

The following technological parameters were varied: \(W\) – power of HF-generator of plasma; \(t_1, t_2\) – treatment time in HMDS and oxygen plasma, correspondingly. Delivery rate ratio of gas mixture O₂/HDMS (5:1) and treatment time in oxygen at the first stage \((t = 10\, \text{min})\) remained constant for all experiments. Refractive index and thickness of the film were measured with the help of ellipsometer LEF-3M (Russia) (figures 3, 4). Refractive index was of weak dependence of technological parameters for all films and was \(n \sim 1.46\).
Figure 3. Relationships of SiO$_2$ film thickness vs. treatment time in HDMS ($t_1$) at different values of HF-generator power and equal treatment time in oxygen at the third stage ($t_2 = 10$ min).

Figure 4. Relationships of SiO$_2$ film thickness vs. treatment time in oxygen at the third stage ($t_2$) under different values of HF-generator power and equal time of HDMS treatment ($t_1 = 100$ min).

From figure 3 one can see that film thickness grows with the increase of HDMS treatment time as well as with increase of power, because in the latter case amount of chemically active particles in plasma grows. In figure 4 decrease of film thickness is connected with material contraction after treatment in oxygen plasma.

Structures of the films were investigated using FIB-complex «Helios Nanolab». It has been shown that under HF-generator power of 200 W, HDMS treatment time of 120 min and oxygen plasma treatment time at the third stage of 10 min, the density of layers was ~ 2.27 g/cm$^3$.

Main electro-physical characteristics of amorphous SiO$_2$ layers were measured using probe station–immitance measuring device E7-20 (Russia), namely:

1. Specific electrical resistance strongly depends of layers purity and presence or absence of various defects;
2. Relative dielectric permeability at room temperature was 3…4;
3. Voltage proof was in the range 10$^6$…10$^7$ V/cm and depends on the concentration of defects in the film.