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Thin Layers of Oxide Coating in Very-Large-Scale Integration

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***Abstract*— Scaling of very-large-scale integration (VLSI) circuits develops in the direction of increasing the surface of a crystal, packing density of elements on crystals, and miniaturization of components. These processes are limited by the necessity to provide high microelectronic reliability and sufficient percentage yield. For this reason, it is important to study the characteristics of thin oxide coating, as well as to investigate the degradation processes of metal oxide semiconductor (MOS) structures, made via nitriding gate oxide with the exposure to hot electrons and ionizing radiation.**

***Keywords*— silicon oxide, nitriding, thin coating, degradation, ionizing radiation**

I. Introduction

Modern VLSI circuits contain a large number of elements on a crystal. The progress in increasing the degree of integration is achieved by enlarging the crystal surface area, however, the most efficient way is raising the packing density of elements on a crystal, decreasing the size of components [1-3]. These processes are limited by the problems of providing high microelectronic reliability and sufficient percentage yield of production. Certain limitations of reliability result from growing electric field strength in devices, made with the technology of metal insulator semiconductor (MIS), in which supply voltage does not go down in proportion to the decrease in sizes of components. This leads to the degradation of devices, related with the impact of hot carriers and breakdown of very thin coating of gate isolation oxide. Consequently, it seems worthwhile to research the characteristics of oxide films when decreasing their thickness, as well as study the degradation of MOS structures when nitriding the gate oxide with the exposure to hot electrons and ionizing radiation.

Thin films of silicon dioxide are used in VLSI as a gate dielectric in MIS transistors, as a dielectric layer of condensers in MIS dynamic storage, and as an ultrathin tunnel isolator in reprogrammable ROM, based on MNOS and SNOS structures [4-6]. The first two fields of application of thin coating are of utmost importance. The thickness of thin oxide coating, used in VLSI, varies from a few units to dozens of nanometers.

Physical parameters of the system silicon dioxide- silicon are well explained for the cases when the layer of silicon dioxide is a lot thicker than the thickness of transition silicon dioxide- silicon. For thin layers of the system, as revealed by the measurements [7-10], up to the thickness of 4 nm the height of the barrier turns out to be the same as for the «thick» system, however, starting from 3,5 nm of the barrier height it decreases, the effective mass of an electron and the effective charge increase.

Rising electric field strength, affecting the oxide coating, leads to generating hot carriers, shifting the threshold voltage of MIS field transistors, increasing leakage currents, decreasing the conductivity of devices. The average kinetic power of electrons depends on electric field strength. Decreasing the thickness of oxide coating can impact the intensity of degradation of device characteristics, these effects fast accumulate when the thickness of coating is less than 10 nm, with further thinning of oxide films the degradation intensifies. The declining thickness of an oxide layer accelerates the breakdown mechanism of coating which depends on time. In general, there are three types of breakdown of oxide films [11, 12]. The first type is breakdown at lower electric field strength. It occurs fast. Pinhole defects of coating, resulting mostly from impurities before oxidizing, are the areas where an oxide film is damaged, these places are prone to breakdown. The second type is breakdown at medium values of electric field strength. This breakdown usually wears down the dielectric coating. Typically, they occur in the areas where the substrate contains metal impurities. These impurities get onto oxide and form so called weak spots. The concentration of these defects decreases when the thickness of oxide coating declines. With a few nanometers' thickness of a film this type of breakdown ceases to matter. Unlike the first type – at lower electric filed strength, which occurs more frequently when the thickness of oxide coating decreases. The third type of breakdown is an internal breakdown of a non-defective oxide film. It is common at higher levels of electric field strength. This breakdown occurs when positive particles, generated by currents of hot electrons, penetrate oxide coating. When decreasing the thickness of oxide layer this breakdown may occur at lower values of electric field strength.

II. Experiment and results

Decreasing the sizes of VLSI components is related with the necessity to reduce the thickness of gate oxide of transistors. It is established that there is a connection between the length of a transistor channel, thickness of gate oxide, depth of transition, width of source and drain. The Fig. 1 shows the dependence of the minimal length of a channel from the thickness of gate oxide at the depth of transition of 300 nm and different concentration levels of substrate

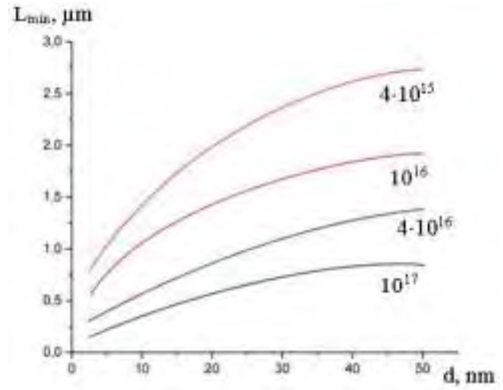

Fig. 1. Dependence of the minimal length of channel from the thickness of gate oxide at different concentration levels of substrate (cm^3).

Modern technologies enable to generate precise thickness of gate oxide. The natural limitation of the thickness of gate oxide in MIS VLSI is the increasing tunnel current through oxide coating. The gate tunnel current grows exponentially when decreasing the thickness of gate oxide, though the relation of this current to drain is not considerable [13, 14]. The results of modelling the modifications of drain currents and tunnel currents of electrons when changing the thickness of gate oxide, for two different lengths of channel, have demonstrated that increasing the length of a channel leads to the drain current decline, whereas the tunnel current grows. Therefore, the relation of tunnel current to drain current decreases in proportion to the squared length of a channel which can only support the trends of miniaturizing the VLSI components [15].

The Fig.2 shows the dependence of the leakage tunnel current of condensers from surface charge density, at different thickness of oxide films. There has been a study of degradation of MOS structures with nitriding the gate oxide at the exposure to hot electrons and ionizing radiation. Two factors have been examined that cause degradation and which are affected by nitriding in a different way. The thermal oxide on a silicon plate with the diameter of 100 мм, p- type (100) had the thickness of about 10nm. The oxide was thermally nitrated at the temperature of 900–1200°C for 10, 30 and 60s. MOS structures were made with this oxide coating as a gate dielectric, according to the standard polysilicon process. The radiation of silicon was delivered by the power of 50 keV with X-rays dose of up to 0,5 millirad. Assessment of changing parameters after radiation was based on voltage-capacitance characteristics, obtained in high frequency and quasi static modes.

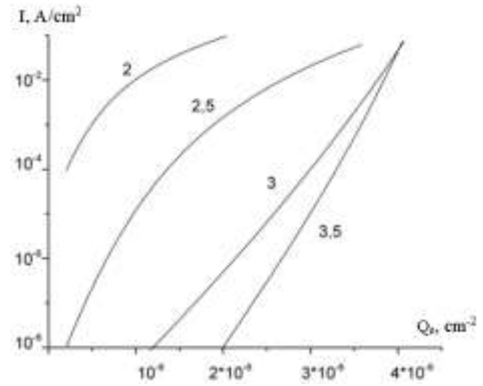

Fig. 2. Dependence of leakage tunnel current of condenser from surface charge density, at different thickness of oxide coating (nm).

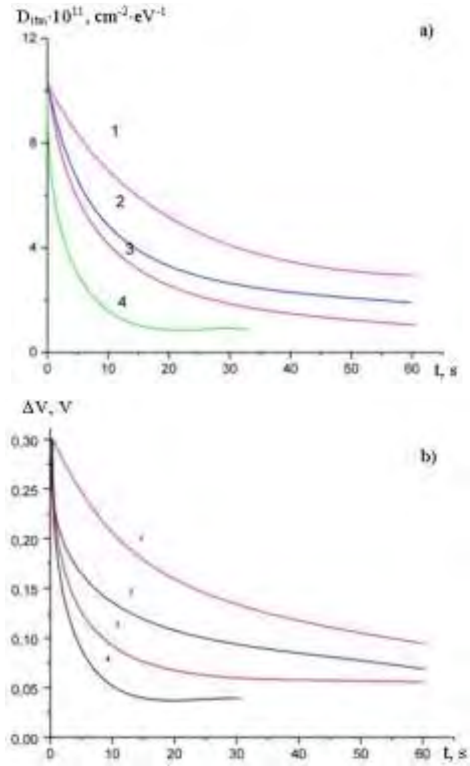

Fig. 3. Dependence of changing density of interlayers, caused by radiation 0,5 millirad a) – at different temperatures and nitriding length, b) – changes of threshold voltage as a result of radiation, in samples, exposed to nitriding, 1- 900°C, 2- 1000°C, 3- 1100°C, 4- 1200°C.

The Fig. 3a shows the dependence of changing density of interlayers, caused by the radiation of 0,5 millirad at different temperatures and nitriding length. Generation of interlayers decreases both at increasing temperatures, and growing lengths of nitriding. The Fig. 3b demonstrates changing threshold voltage ΔV as a result of radiation, as well as for samples, exposed to nitriding at different temperatures with various lengths. As can be seen in Fig. 3b the temperature of nitriding and its length decrease changes in voltage. The observed changes in voltage can result from either increasing effects of electron traps, or declining impact of hole traps. The calculations show that the length of connection Si—N in the structure Si_2N_2O equal to 0.12 nm, is shorter than the length of connection Si—O in the tetrahedron structure SiO_4, equal to 0.262 nm. Therefore, as a result of nitriding, the oxide area is limited, due to the formation of the connection Si—N.

As the length of nitriding gets longer, the connections of silicon-oxygen are destroyed and replaced by those of silicon-nitrogen. The effects of nitriding on radiation stability are determined by generating the states, caused by the spreading defects, brought by the radiation in the direction of the boundary silicon dioxide- silicon. The spreading rate of defects depends on voltage gradient at the boundary. This dependence was studied for the gate (Fig. 4). When nitriding the oxide, the radiation stability of devices rises. Lowering the temperature of nitriding or reducing its length leads to decreasing the effects.

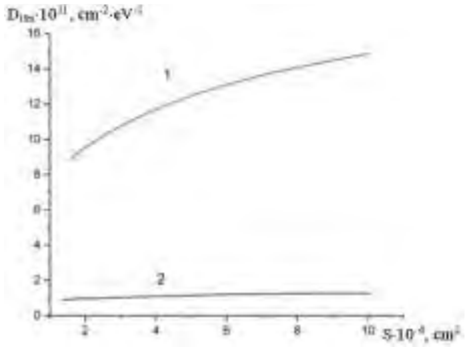

Fig. 4. Dependence of states density, caused by radiation, from the gate surface: for pure oxide (1) and for nitrated one at 1100°C for 60s (2).

It is established that density of states – D_{itm} – changes depending on the length and temperature of nitriding, (Fig. 5).

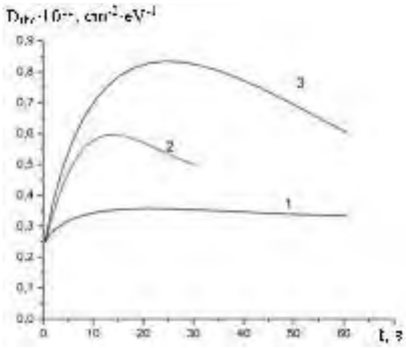

Fig. 5. Changing the density of interlayer states in relation with the length of nitriding at different temperatures: 1- 900°C, 2- 1200°C, 3- 1100°C.

III. Conclusion

The degradation of devices characteristics at the exposure to radiation and hot electrons considerably depends on the temperature and length of nitriding. When nitriding the oxide the radiation stability of devices increases, whereas when decreasing the temperature of nitriding or reducing its length the effects correspondingly decline.

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