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High Quality SiO_2 Obtained From diluted SOG for Low Temperature TFT Fabrication Process.

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Currently, the flexible electronics research field is of high interest because of the development of low cost products, such as solar cells and LCDs. Low temperature deposition processes are required in order to use flexible substrates. Nevertheless, the performance of the electronic devices built at temperatures below 350 °C is not as good as in CMOS technology. Thus, physical and electrical properties of semiconductor and insulator materials deposited at these low temperatures must be improved. In this work, characterization of SiO_2 annealed at 200°C obtained from diluted Spin On Glass (SOG) is presented. The optical and electrical characterization showed that the refractive index (*n*) and dielectric constant (*k*) values are similar to those of thermally grown SiO_2. TFTs based on a-SiGe:H were fabricated to demonstrate the quality of the dielectric here obtained

Introduction

Electronic devices and systems fabricated on flexible substrates are getting the attention within both the research and the industrial communities. The development of rollable light-weight displays, flexible solar cells and inexpensive flexible electronics were enabled by the use of flexible substrates. Furthermore, the fabrication cost of electronic devices on flexible substrates can be reduced compared to existing planar or flat-panel technology because the implementation of high-throughput roll-to-roll technology. In this technology, a roll of thin plastic or metal foil used as the substrate can be kilometers long and meters wide compared to a silicon wafer diameter of 10–12’’ in integrated circuit technology, or a glass sheet size of about 2m x 2m in a flat-panel display (FPD) manufacturing process (1, 2).

One approach to integrate high-performance devices on low temperature substrates is to reduce the fabrication temperature of thin-film transistors (TFTs) based on inorganic amorphous, nanocrystalline or polycrystalline materials to a level compatible with the thermal budget of the low-cost substrates (3-5). This approach offers the advantage of a wider variety of substrate materials available, as low-cost plastics or paper. Besides, other lower thermal budget materials can be integrated in the process, such as adhesives or polymers. Moreover, materials science, device physics and equipment are already well established, as in a-Si:H technology.

On the other hand, the temperature range used in industrial a-Si:H TFTs technology on Glass is of 300 °C to 350 °C which is higher than that used on plastic and low-cost flexible substrates. Therefore, it is necessary to reduce the temperature of the fabrication process. It is well known that TFTs fabricated at low-temperatures (≤ 200°C) have poor stability, higher off-current and higher values of subthreshold slope than those deposited at higher temperatures (3, 4). Thus, in order to get better performance of Low-temperature TFTs, semiconductors and insulator materials deposited at low-temperatures needs further research.

The present work shows that Spin On Glass (SOG) may be used a dielectric material deposited/cured at low temperature (200°C) for the fabrication of TFTs. SOG is an interlevel insulator that is supplied in liquid form. The advantages of SOG include a low defect density in the films deposited, low process cost, excellent for planarization applications, filling gaps and smoothing the surface with multiple coatings The SOG solution form an arrangement of silicate polymers with a Si-O structure, these polymers are in an alcohol solvent system. The datasheet of SOG suggest an annealing in the range of 400 – 900°C to obtain a SiO_2 thin film. However, for flexible substrate applications it is necessary to use much lower temperatures for curing. To study the deposition of SiO_2 films using SOG cured at 200°C, two solvents (2-propanol and deionized water - DI) were used as diluents for the SOG in order to observe its effect on the electrical, optical and compositional characteristics of the SiO_2 films produced.

Experimental

Silicon wafers were used as substrates and before the SOG deposition they were chemically cleaned. First, the wafers were cleaned in trichloroethylene for 10 min, followed with acetone also for 10 min. in ultrasonic bath. Later, the samples were cleaned with the RCA1 solution (NH_4OH:H_20_2:H_20=1:1:5 at 75°C for 15 min.), followed with the RCA2 solution (HCL:H_20_2:H_20=1:1:6 at 75°C for 15 min.). Finally, after rinsing the wafers with deionized water, buffered HF was used for 10 s. to remove the thin native oxide on the silicon surface. After that, the SOG was deposited on the silicon wafers with the following procedure: For measurements of the refractive index: Liquid application of SOG by spinning at room temperature on the silicon wafers at 3000, 4000 and 5000 revolutions per minute (RPM) for 30 s. For Fourier transform infrared (FTIR) spectroscopy: Liquid application of SOG at room temperature at 3000 RPM for 30 s. In the fabrication of MOS Capacitors, Liquid application of SOG at room temperature at 3000 RPM for 30 s was used. After spinning the SOG, annealing at 100°C for 15 min. to reduce humidity and evaporate most of the solvents, followed by a final curing time of 6.5 Hrs at 200°C in N_2 gas.

Results and Discussion

To measure refractive index it was used a Gaertner ellipsometer L117 using a laser of 623.8 nm of wavelength. The IR absorption spectra of the films were measured with a “BRUCKER” FTIR spectrometer, Model Vector-22. For the determination of dielectric constant k, MIM (Metal- Insulator- Metal) structures were fabricated. Then, its capacitance was measured with a PM 6303 automatic RLC meter and using the equation [1], k was calculated.

$$C = \frac{k\varepsilon A}{d} \qquad [1]$$

In this equation ε is permittivity, A is the area of the capacitor, d is the insulator thickness and k is the dielectric constant. The MIM structures also were used to calculate

the insulator breakdown field. MOS capacitors were made with diluted SOG on p-type silicon wafers. The MIM structures and MOS capacitors have an area of 0.015006 cm^2.
Figure 1 shows the refractive index as function of the spinner speed for the SOG deposition, for three different solutions: A) Undiluted SOG, B) SOG diluted with DI and C) SOG diluted with 2-Propanol. The refractive index of undiluted SOG films shows a strong dependence with the spinner speed. At low spinner speed refractive index is low, close to 1.25 (for 3000 RPM), while increasing the spinner speed it increases as well, to about 1.6 (for 5000 RPM).
On the other hand, the films produced from diluted SOG do not show a significant change on refractive index. A possible reason is that the solvents used as diluents for SOG provide an easier way for the evaporation of the organic materials contained in the SOG solution. The refractive index value of the films produced from diluted SOG is close to that of thermally grown stoichiometric SiO_2, while the undiluted SOG resulted with a higher refractive index than that of the thermal SiO2 because of the presence of organic materials that could not evaporated form the film at this temperature of 200°C.

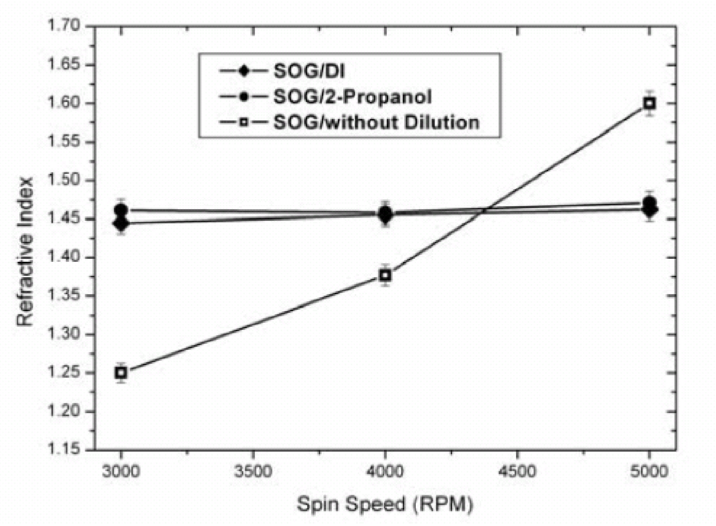

Figure 1. Refractive index of SOG vs. Spin speed

Figure 2 shows the absorption coefficient of the films prepared from SOG. It was identified the Si-O bond (at 1072 cm^{-1}), which is also found on thermally grown SiO_2 [56]. The Si-OH (at 920 cm^{-1}), O-H (at 3490 cm^{-1}), C-H and C-O (at 1139 cm^{-1}) bonds are probably related to the organic solvent material present on the SOG (6). It was observed a considerable reduction of Si-OH (920 cm^{-1}) and O-H bonds (3490 cm^{-1}) in the films produced from diluted SOG, which is an indication of a good quality film. Again, the undiluted SOG shows traces of organic contamination because the low curing temperature used here.

The dielectric constant k, obtained from the equation 1 for the SiO_2 films prepared from diluted SOG was approximately 4.1. This was corroborated by the measurements of the MIM structures and by the C-V curves of the MOS capacitors, measured at 100 MHz, in figure 3. From the C-V curves of the MOS capacitors, it can be seen a higher slope and well defined oxide capacitance Cox for the MOS capacitor made with SiO_2 films from SOG diluted with DI, which is an indicating of good insulator properties.

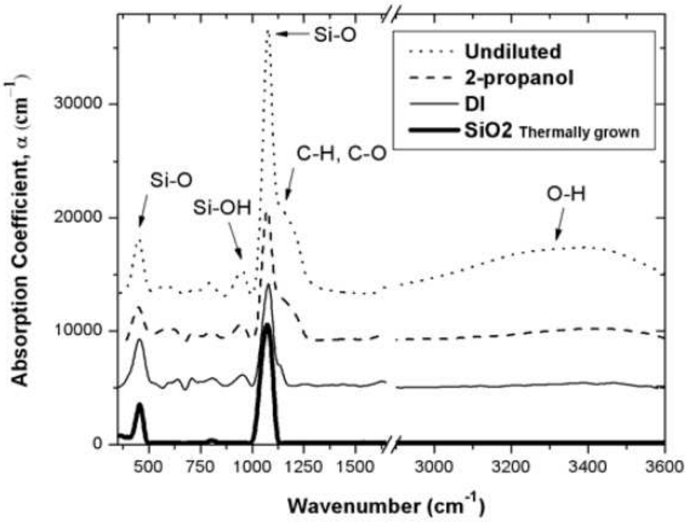

Figure 2. Absorption coefficient vs. wavenumber for diluted and undiluted SOG samples.

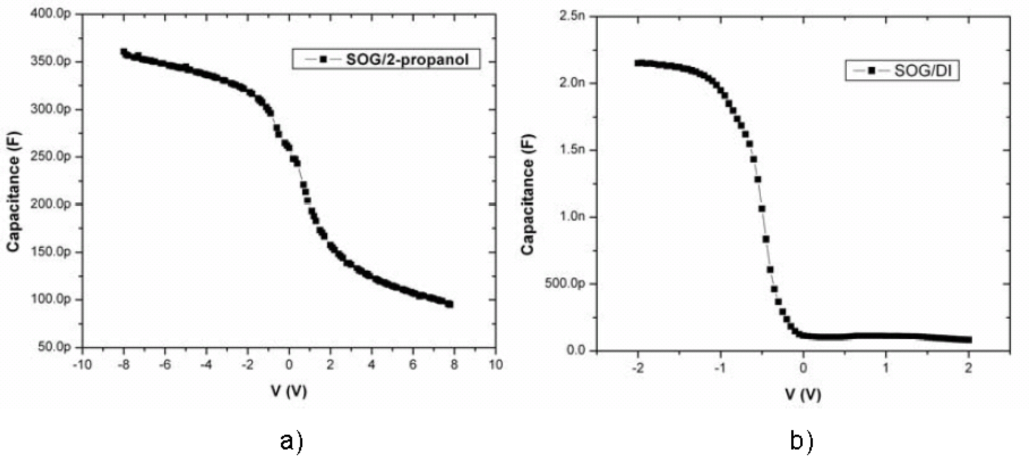

Figure 3. C-V curves of the MOS capacitors produced from diluted SOG; a) 2-propanol diluted SOG and b) DI diluted SOG.

The current - voltage characteristics in the MIM structures were measured in order to obtain the insulator breakdown field. Figure 4 shows the breakdown field for the MIM structures containing a film produced from SOG diluted with 2-propanol and SOG diluted with DI. The maximum voltage applied to the samples was 100 V. The insulator breakdown field for the MIM structure containing a film produced from SOG diluted with 2-propanol was approximately 4.5 MV/cm, while for the MIM structure containing a film produced from SOG diluted with DI was approximately ~10.5 MV/cm, which is very similar to that found in good quality thermal oxides (8-11 MV/cm). These results of SiO_2 film produced from SOG diluted with DI show an improvement in the insulator properties when are compared to those obtained from methylsiloxane SOG deposited at 425 °C, SiO_2 deposited by CVD or PECVD, and without the residual stress that appears in SiNx films deposited by PECVD as gate insulator in TFTs (7,8).

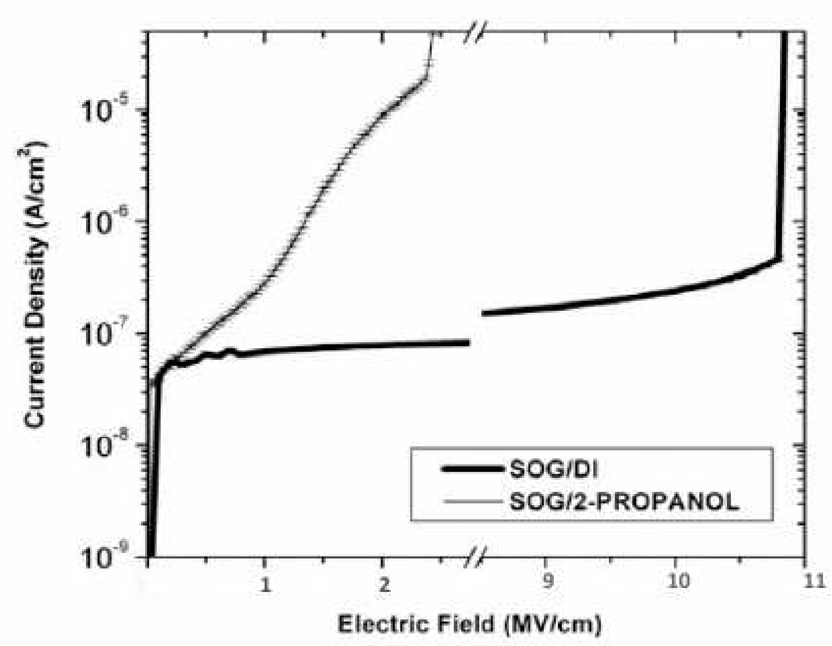

Figure 4. Breakdown field for the MIM structures containing a SiO_2 film produced from 2-propanol diluted SOG and DI diluted SOG.

So far it has been demonstrated a good quality insulator in which the highest temperature of curing is 200°C, now SOG diluted with DI will be used as the gate oxide on a-SiGe:H TFTs of inverted staggered structures as depicted in figure 5

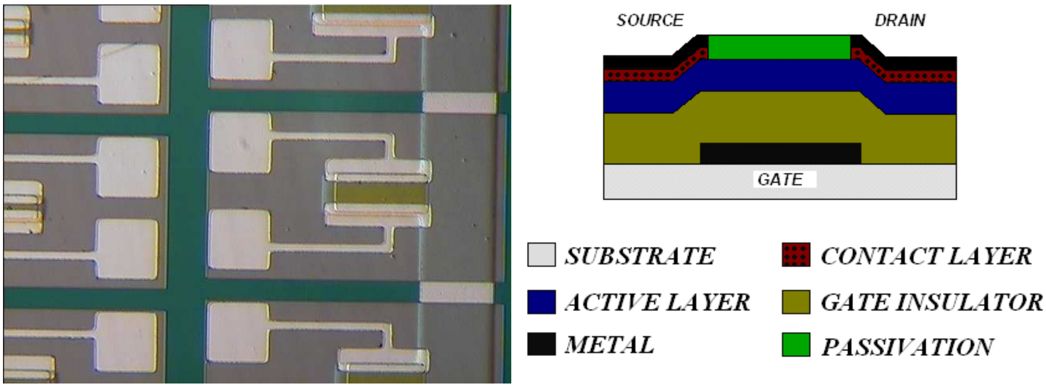

Figure 5. The fabricated TFTs using SOG as gate oxide a) and b) the inverted staggered fabricated structures.

The fabricated TFTs were measured on a semiconductor parameter analyzer HP 4156B in dark conditions and figure 6 shows its transfer characteristics a), and output characteristics b). An important figure of merit of the TFT is the subthreshold slope S, which is an indication how fast is the transition between the on and off state of the device and is obtained form equation 2.

$$S = \left[\frac{\partial \log I_{ds}}{\partial V_{gs}} \right]^{-1} \qquad [2]$$

S should be as low as possible in order to approach the behavior of an ideal switch (9).

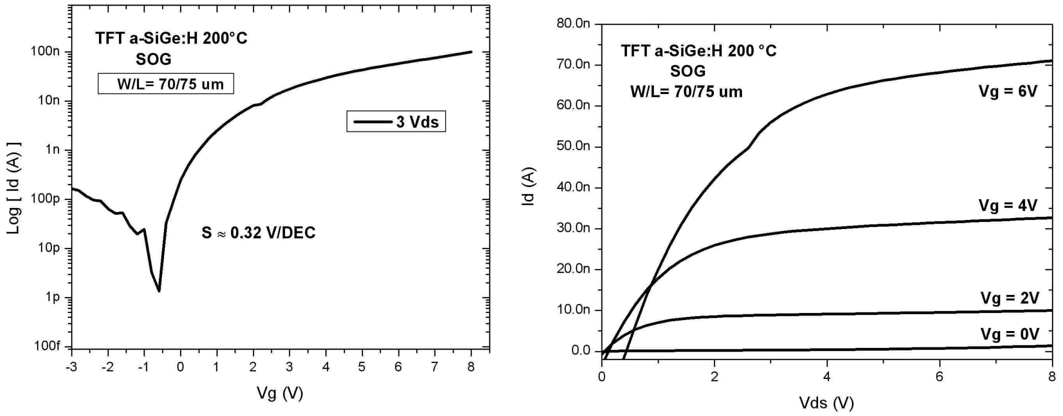

Figure 6. TFT fabricated on a-SiGe:H, a) transfer characteristics, b) output characteristics.

As can be seen form figure 6, the devices show a subthreshold slope of 0.32 V/DEC which is an improvement for TFTs fabricated at low temperatures**,** and an on/off-current ratio of 10^5, values that are an evidence of a good quality insulator-semiconductor interface.

Conclusions

The fabrication and characterization of good quality SiO_2 obtained from diluted SOG with maximum curing temperature of 200°C, was demonstrated. The refractive index and breakdown field here measured are similar to those values found on high quality thermal oxides. The fabricated devices, a-SiGe:H TFTs with (SOG) DI diluted as passivation layer and gate insulator show a subthreshold slope of 0.32 V/DEC which is an improvement for TFTs fabricated at low temperatures, and an on/off-current ratio of 10^5. These results are an evidence of a good quality insulator-semiconductor interface. The observed results are promising and suggest that DI diluted SOG films deposited at 200°C in the Laboratory of Microelectronics of INAOE may be an alternative for improving the electrical characteristics of TFTs fabricated at low temperatures.

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