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Structural Properties of Ultrathin Al_2O_3 Films on Si

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Abstract: The growth of thin and ultrathin Al_2O_3 films on Si surfaces has become the largest for the development of industrial processes towards the next generations of Si based electronics due to increased difficulty in scaling CMOS (Complementary Metal Oxide Semiconductor) for Integrated Circuits (Ics). Access to XRD (X-Ray Diffraction), SAM (Scanning Atomic Microscopy) and NMR (Nuclear Magnetic Resonance) facilities, using structural, atom-atom bonds studies of the process steps, allow us to analyze details of the reaction dynamics and structural properties of the Al_2O_3, ^{29}Si and SiO_2 films. The obtained results show Al_2O_3 is amorphous film without any intermediate SiO_2 layer between Al_2O_3 / Si.

Key words: Thin film % Nano transistor % Nano structure % Al_2O_3 and NMR % XRD techniques

INTRODUCTION

According to the International Technology Roadmap for Semiconductors (ITRS) anticipations, some issues, such as boron diffusion, leakage current through the ultrathin gate oxide film cause increased difficulties in further scaling CMOS technology for ICs. We have thus needed to find several guiding principles of materials and device requirements that provide directions for research. Many workers have established within the starting material groups to examine and track the alternative materials technologies under consideration for implementation in conjunction with traditional CMOS scaling.

Al_2O_3 is one of the emerging materials in the semiconductor industry which can fill this gap due to its amorphous structure [1-2], good band gap energy [3], higher dielectric constant respect to the silicon dioxide dielectric constant [4-5], mobility enhancement [6-7], thermal management and thicker EOT (Equivalent Oxide Thickness) [8-10].

We have demonstrated the series of experiments to grow thin Al_2O_3 films on silicon substrate and parallels to that studied the Al-O-Si, Al-Si, Al-O and O-Si bonds and film structural properties by using XRD, NMR and SAM photoemission techniques. The obtained results indicate that the use of Al_2O_3 to replace SiO_2 as gate dielectric can reduce the scaling problems, such as the gate leakage current by several orders of magnitude while maintaining excellent interface quality.

Experimental Details: Although Cuha [1] and Morgan [2] and some other researchers [7-10] have established the growth of device quality Al_2O_3 / Si interfaces using atomic beam epitaxial growth and atomic layer deposition of Al_2O_3 directly on top of Si (100) surfaces, we could grow Al_2O_3 at high pressure and temperature in the furnace.

In this work, the silicon samples are 5 Ohm-Cm, 1 Cm by 1 Cm n-type (p-doped) Si, cut from a 2 mm thick silicon wafer. These samples were then cleaned by DC-current heating samples at above 1000° C in the furnace without any other treatment. A powder of Al_2O_3 and the Al wire are used for this study. The silicon samples have been

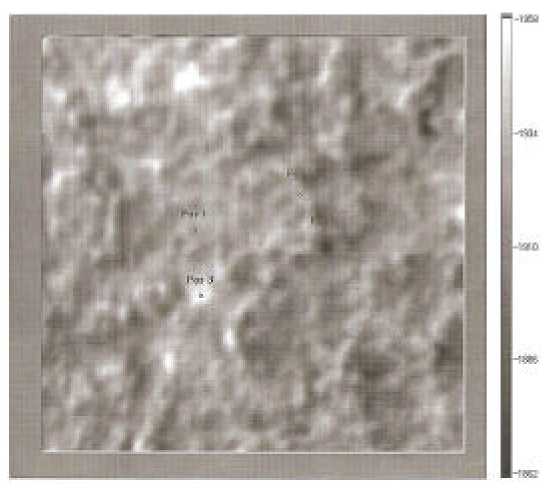

Fig. 1: AES of Al_2O_3 film. There are several peaks due to some significant transitions, which the huge peak has been usually considered in discussions

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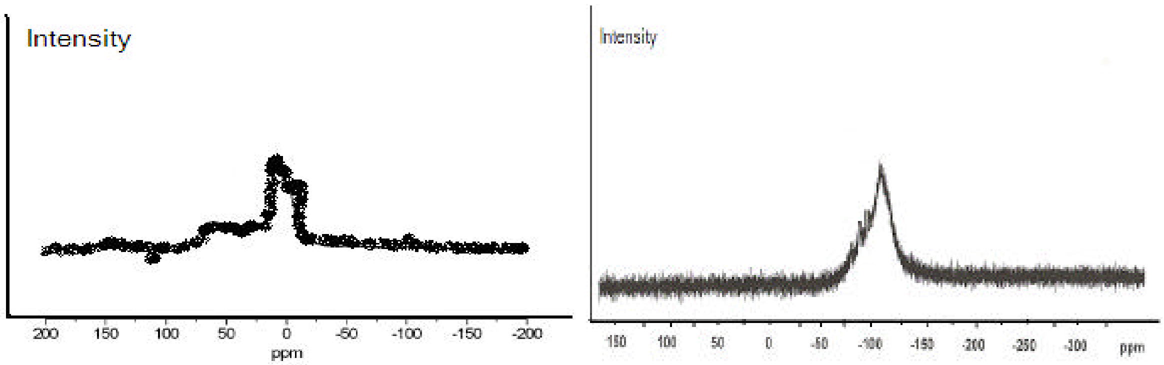

Fig. 2: ^{29}Si NMR spectra of Al_2O_3 (Up) and SiO_2 (Down) samples

polished on one side as purchased and cleaned with acetone in an ultrasonic bath and then rinsed with distilled water.

We have then evaporated Al wire by passing current through the wire for 10 min in the Ar and O_2 atmosphere inside the quartz tube. The Al_2O_3 could be formed as demonstrated in Figure 1. Of course a Si (100) 2 × 1 surface is covered partially Al and oxidized at about 10 min.

Moreover Figure 2 shows the ^{29}Si NMR spectra of the AL_2O_3 and SiO_2 thin film and of the corresponding silica matrix samples, which shows three partially over lapping signals falling in the-300 to 150 ppm range. It perhaps indicates three different bonds, Al-O-Si, Al-O and Al-Si bonds.

DISCUSSIONS AND CONCLUSIONS

As shown in Figure 2, after depositing Al-oxide, in the first cycle, some of the oxygen atoms are bounded to silicon atoms, as evidenced from the slopping intensity. By continuing the aluminum and oxygen exposures on silicon substrate, a nearly thicker Al_2O_3 could be formed in where the all Al atoms made bonds with silicon and oxygen atoms as deposited in Figure 1, meaning the thicker layers have been grown by repeating the cycles 6 times. The sharpness of the interface seems to be at the atomic level. However, beyond this, the electrical properties due to band bending demonstrated that the charge and defect densities inside the film at the film-Si interface. Furthermore, the growth of epitaxial Al systems can be viewed as a quantum well.

This can be understood when one keeps in mind that the lower energy electron beam dissipates a large fraction of energy in the surface layer. To demonstrate this, we will irradiated the powder aluminum oxide with X-ray and study its spectrum using XRD technique (but for getting more precise results, we prefer to discuss it in the coming paper). However, re-oxidization of the reduced surface in an O_2 environment leads to discharge of the charged silicon sample as will be discussed in the future and introduced in [2]. We conclude that Al_2O_3 can be used as a good gate dielectric for the future CMIS generations due to its amorphous, pure and high-K dielectric properties.

Thin films deposited at various inductive coil powers when it increases from 0 to180W. Of course, when this power is ON, the Al target is sputtered by the Argon and oxygen .It causes the full width at half-maximum(FWHM)of the curves reduces about three degrees, meaning the population increases of the sputtered Al atoms at high energy. By getting the ^{29}Si-NMR spectrum at Figure 2, the major chemical species detected radicals which are more likely due to their excitation energy. This energy distribution of the Al atoms sputtered from the target varies in a broad range with a peak maximum at low energy and a tail at high energy.

The SAM image of Al_2O_3 is shown in Fig.1. It obviously shows the amorphous Al_2O_3 Film which can reduce the leakage current. This characteristic of a film is a key point to introduce Al_2O_3 as a good candidate for the future of CMTS devices. We pick up three points on the film surface, labeled with pos1, pos2 and pos3. They show different color contents, meaning different work functions. Pos1, pos2 and pos3 indicate Al-O, Al-O-Si and O-Si bonds respectively. However, we can certainly claim they are what we addressed. To be sure, we need the other techniques, which are XRD and NMR (shown in Figures 2 and 3).

The appearance of a broad peak on the XRD curve (Figure 3) without any visible peak implies that there is no crystal phase which confirms SAM result. As Figure 3 shows the XRD analyses of Al_2O_3 film which cast (and annealed film structure) is amorphous.

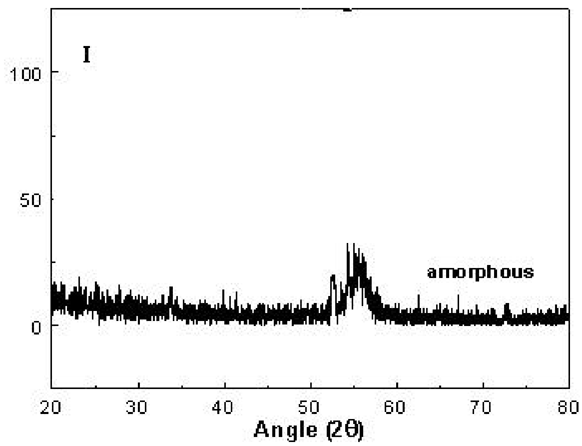

Fig. 3: XRD spectrum of Al_2O_3

CONCLUSIONS

Most CMOS Logic and memory circuits with Si have been considered important phase to enable Al_2O_3 as gate dielectric for the next CMIS generations. The growth of thin and ultra thin high-k dielectric (Al_2O_3 film) with a good interface layer between Al_2O_3 is a candidate of CMIS transistors.

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