TANTALUM OXIDE THIN FILMS BY NEGATIVE BIAS
ASSISTED RF SPUTTERING

The microelectronics industry demands high dielectric (high-k) material for high integrated circuit density and performance. The use of silicon dioxide (SiO\textsubscript{2}) thin films as gate oxide dielectric has hit a major roadblock due to its rapid increase in tunneling current leading to high energy consumption and poor device reliability. Tantalum pentoxide (Ta\textsubscript{2}O\textsubscript{5}), a high-k material, has been found to be a promising substitute for SiO\textsubscript{2} due to its properties of high permittivity, large refractive index, excellent step coverage, and tolerable dielectric strength. Ta\textsubscript{2}O\textsubscript{5} thin films will find application such as storage capacitors in dynamic random access memory (DRAM) and gate oxide in field effect transistors (FET). Recently research activities have been focused on improving the synthesis and applications of this high-k material. However, studies that have been carried out till date have revealed that an interfacial layer can easily form during deposition or post-annealing of Ta\textsubscript{2}O\textsubscript{5} films thereby canceling the benefits of the high dielectric constant provided by the material. In addition, controlling the interfacial layer formed between Ta\textsubscript{2}O\textsubscript{5} and Si has been found to be difficult. The formation of a very thin interlayer of low-k material is one of the major challenges faced in the use of metal-oxide films as high-k gate dielectrics. This interfacial layer causes a decrease in the capacitance of the stack, resulting in the degradation of the electrical property of the device.

To address this, a research team headed by Paul Chu at the Department of Physics and Materials Science, City University of Hong Kong (Hong Kong) has developed a negative bias-assisted growth technique to fabricate Ta\textsubscript{2}O\textsubscript{5} thin films and to study the interfacial characteristics of Ta\textsubscript{2}O\textsubscript{5}/Si thin films under different substrate biases. The team aimed at improving the structural and dielectric properties of Ta\textsubscript{2}O\textsubscript{5}/Si thin films while the interfacial characteristics do not degrade.

The deposition of the Ta\textsubscript{2}O\textsubscript{5} thin films were carried out in a radio frequency (RF) magnetron sputtering system (RF power 50 w) using n-type,100 mm Si (100) wafers (resistivity of 4 ohm cm to 7 ohm cm) as substrate and 99.9% pure Ta disk (50 mm diameter) as the target material. A gap of 3.5 cm was maintained between the target and the substrate. The substrate temperature was controlled by a heating assembly and monitored throughout the process. Initially the sputtering chamber was pumped down to a pressure under 3×10\textsuperscript{-3} Pa. After this the target was pre-sputtered using pure argon (Ar) plasma (0.1 Pa) to improve the properties of the thin film. Following this the chamber was pumped down again to a pressure under 3×10\textsuperscript{-3} Pa. The chamber was then filled with 20% O\textsubscript{2} (oxygen as reactive gas) and 80% Ar (sputter enhancing gas). A pressure of 0.5 Pa was maintained during the deposition time of 120 minutes. During this a negative bias was introduced for the substrate to deposit thin Ta\textsubscript{2}O\textsubscript{5} films on Si substrates at low substrate temperatures.

The group observed that the thickness of the interfacial layer remains about the same at different substrate biases. Further as the deposition temperature increases, the interfacial layer between Ta\textsubscript{2}O\textsubscript{5} and Si (100) thickens slightly.
"Our results suggest that substrate bias assistance is an effective method to improve the structural and dielectric properties of Ta$_2$O$_5$/Si thin films while the interfacial characteristics between Ta$_2$O$_5$ thin films and Si substrate do not degrade, which will accelerate the application in the microelectronics industry," Chu tells Technical Insights.

The process avoids the high deposition or annealing temperature, which aggravates the thermodynamic instability at the Ta$_2$O$_5$/Si interface. It is beneficial to the fabrication of novel metal oxide semiconductor (MOS) devices with high dielectric materials.

Chu adds, "The process will make Ta$_2$O$_5$ films a suitable potential substitute for silicon dioxide as storage capacitors in DRAM, gate oxide in field effect transistors (FET), and so on."

Requirements by the microelectronics industry such as MOSFETs and DRAMs are stringent, and even though the research team has demonstrated the process, a better understanding of the process as well as more device stability tests are required before it can be commercialized. The research team in the City University of Hong Kong is working to develop the commercial technology.

"The next step is to further develop this process and test the thermal stability as the gate dielectrics in the device application," says Chu.

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