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HIGH DIELECTRIC CONSTANT CUBIC AMORPHOUS HAFNIUM OXIDE

A novel form of thin film amorphous hafnium oxide (ca-HfO_x), providing exceptionally high dielectric constant and electrical resistivity, as well as low optical scatter and high refractive index, has recently been developed by researchers at the University of Cambridge. Produced by a room-temperature, high deposition-rate process, the desirable electrical and optical properties of this new amorphous material, opens up exciting possibilities for next generation electronic and optoelectronic devices. Particularly suitability for transparent, flexible and plastic electronics, the deposition process is also compatible with CMOS and large-area electronics and paves the way for further component miniaturisation and advances in nano-electronics.

Key potential benefits

- Compatible with plastic electronic applications due to the low temperature, low stress deposition process
- Compatible with high-volume, low-cost semiconductor manufacturing requirements due to the high deposition rate
- Excellent device-to-device uniformity due to the amorphous structure
- Further miniaturisation of memory and transistor devices due to the high dielectric constant, enabling higher capacitance/unit area to be achieved
- More efficient solar cells and waveguide components due to the absence of scatter from grain boundaries

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Background

Hafnium oxide (HfO_x) is a high dielectric constant (*k*) oxide that is being increasingly employed in different industries. Although an amorphous microstructure is preferable to a polycrystalline microstructure due to the absence of grain boundaries, until now films of amorphous HfO_x have had relatively low dielectric constant of ~20, similar to monoclinic HfO_x. A key advantage of a high dielectric constant is that a thin film of such a material used as the gate dielectric in a field effect transistor, will result in a device with a higher capacitance per unit area for the same geometry. Therefore, either a higher on-state current can be driven, or a lower gate voltage used, or a thicker dielectric layer employed to reduce leakage currents. Amorphous dielectrics are favoured because they are more homogeneous, allowing improved device-to-device uniformity, and the absence of grain boundaries results in higher effective resistivity, as well as less optical scatter. These high density, amorphous HfO_x thin films also have potential as barrier layers in flexible electronic applications.

Commercialisation

We are seeking commercial partners for collaborative development and licensing of this technology. The material is protected by patent application No. GB 1105664.5 .

Technology

For the first time, sputter-deposited thin films of amorphous HfO_x with very high *k*~30 have been achieved. Structural characterisation suggests that the high *k* is a consequence of a previously unreported cubic-like short range order in the amorphous HfO_x. The films possess high electrical resistivity of 10^{14} Ωcm, a breakdown strength of 3 MV cm^{-1}, a refractive index of 2.05 and an optical bandgap of 6.0 eV. Deposited at room temperature and high deposition rate (~25 nm min^{-1}), these high-*k* amorphous HfO_x films are highly desirable for future electronic and optoelectronic applications.

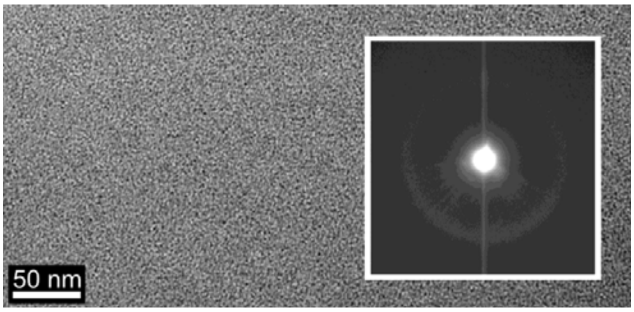

Figure 1. A plan-view transmission electron microscope (TEM) image of a typical as-deposited *a*-HfO_x demonstrating the amorphous nature of the *a*-HfO_x layer and the absence of nano-crystallites. An electron diffraction pattern is inset which shows diffuse halos; this is consistent with the fully amorphous nature of the *a*-HfO_x layer.

Table 1. Summary of key properties of an *a*-HfO_x thin film. Properties of RF magnetron sputtered HfO_x, deposited at room temperature, and high quality RF PECVD silicon nitride dielectric deposited at 300°C are also included for comparison.

Parameter	a-HfO_x	rf magnetron sputtered HfO_x	Rf PECVD SiN
Substrate Temperature (°C)	25	25	300
Deposition Rate (nm min^{-1})	25	1.6	6.2
Refractive index, *n*	2.05	1.73	1.9
Band gap, E_G (eV)	6.04	-	5.3
Resistivity, ρ (Ω cm) at 1MV cm^{-1}	1.4 x 10^{14}	3.8 x 10^{13}	1 x 10^{14}
Breakdown Field, E_{BD} (MV cm^{-1})	3	3.5	10
Dielectric Constant, *k*	30	18.2	7.5
Structure	Amorphous	Nanocrystalline monoclinic	Amorphous

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