Total Dose Hardness of TiN/HfO_x/TiN Resistive Random Access Memory Devices

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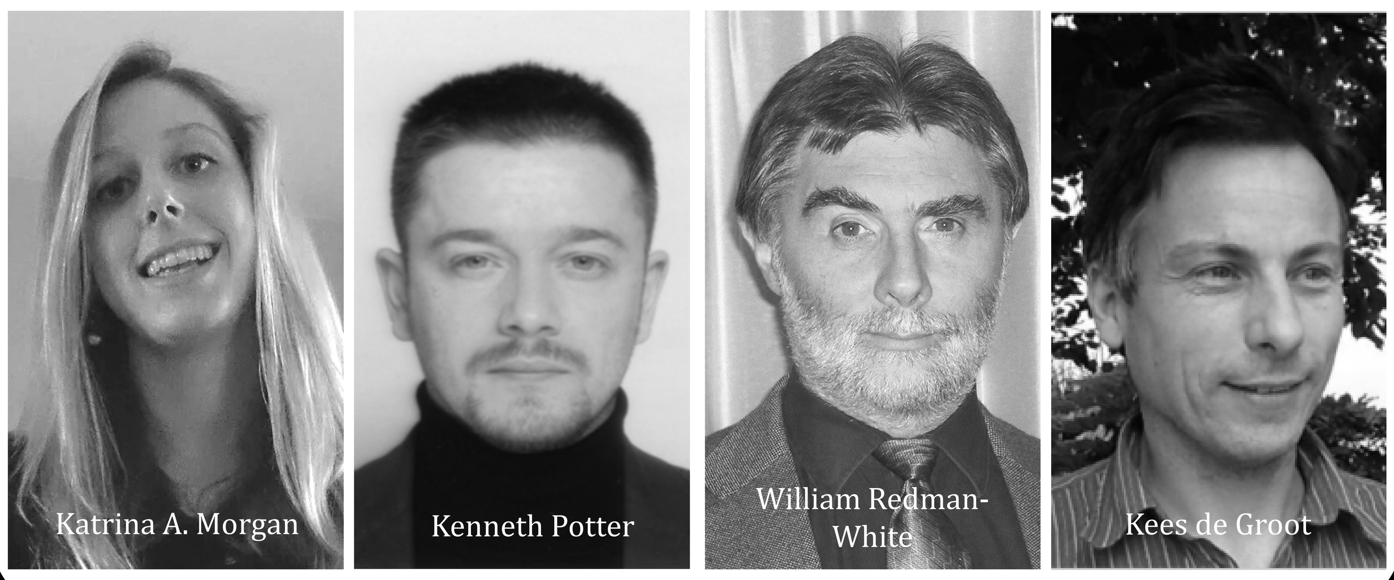
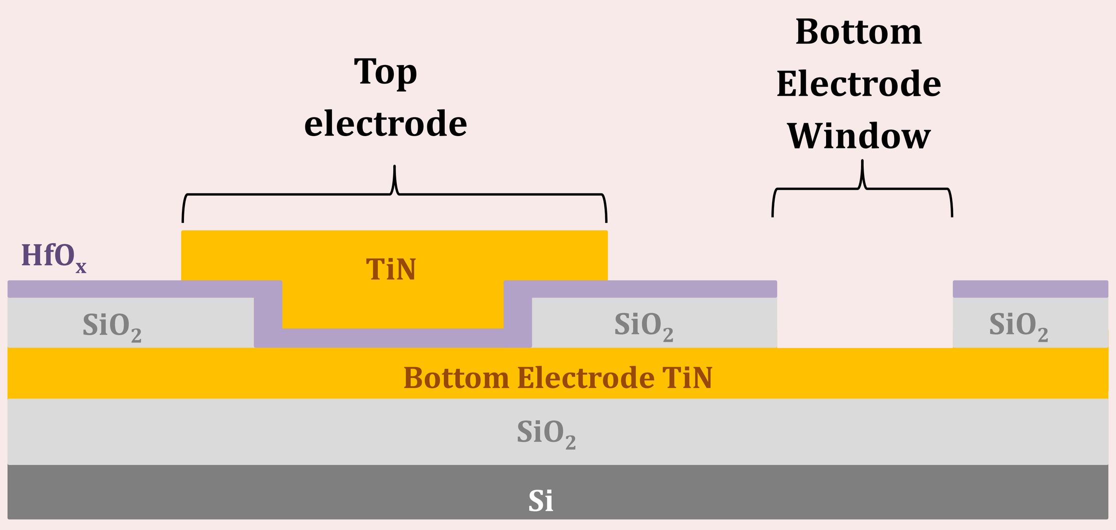


TiN / HfO_x / TiN resistive random access memory (RRAM) has been fabricated. Pulsed and sweep electrical measurements were performed before and after Co60 gamma irradiation. All devices are shown to be radiation hard up to 10Mrad(Si) and independent of stoichiometry.

TiN/ HfO_x / TiN Resistive RAM Device Structure



- Device area: 1μm² to 100 μm²
- Reactive sputtering of SiO_2 and TiN
- Atomic Layer Deposition (ALD) of HfO_x at 300˚C and 350˚C

Irradiation of Resistive RAM Devices

- RRAM offers a new type of non-volatile, high density memory [1]
- Switching mechanism is not yet fully understood although in hafnium oxide, it is thought to be related to the movement of oxygen vacancies [2]
- Resistance of the device is altered by the migration of defects → reliability of these devices must be addressed when used in an irradiative environment
- Irradiation has shown to create additional oxygen ions and vacancies [3,4] which can lead to increase in trapped holes creating a path for electron transport [5]

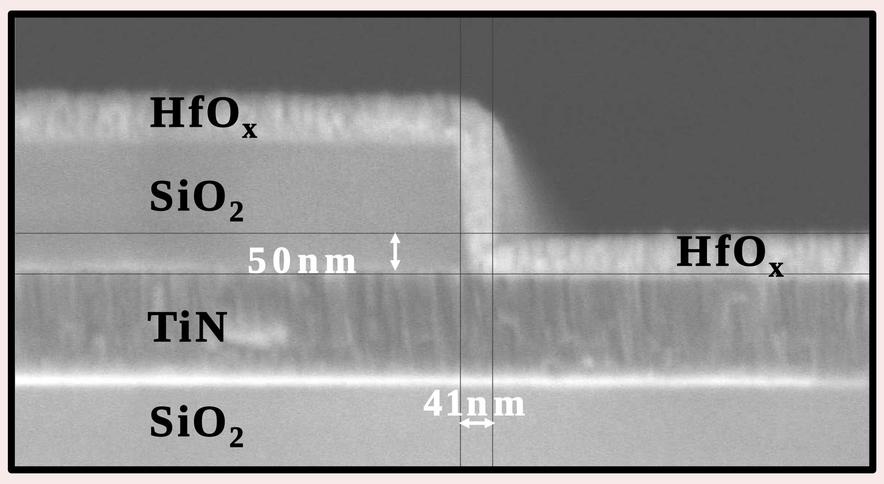
50nm thick oxides were deposited with different stoichiometry, controlled by atomic layer deposition (ALD) temperature.

Material Characterisation

Hafnium oxide layers were deposited at two different temperatures, 300˚C and 350˚C, and characterized using X-ray diffraction (XRD), scanning electron microscopy (SEM) and X-ray photoelectron spectroscopy (XPS).

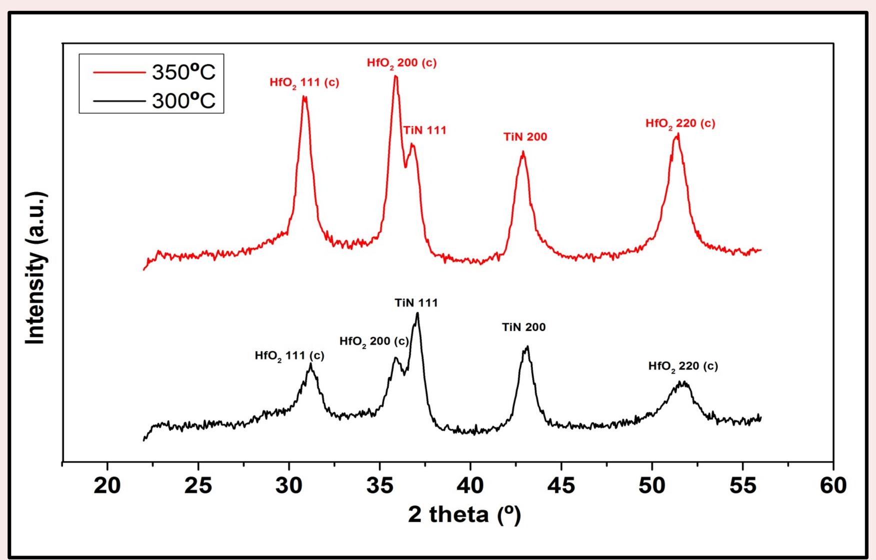
SEM

The thickness of the hafnium oxide layers were measured using SEM to be 48nm and 50nm for the 300˚C and 350˚C oxides respectively.



XRD

The crystal structure was measured using XRD where patterns were collected in grazing incidence (ϴ1=3˚). 300˚C and 350˚C both result in cubic hafnium oxide.



XPS

The stoichiometry of the layers were measured using XPS. The ratio of hafnium to oxygen was found to be 1.7 and 1.9 for the 300 ˚C and 350˚C oxides respectively.

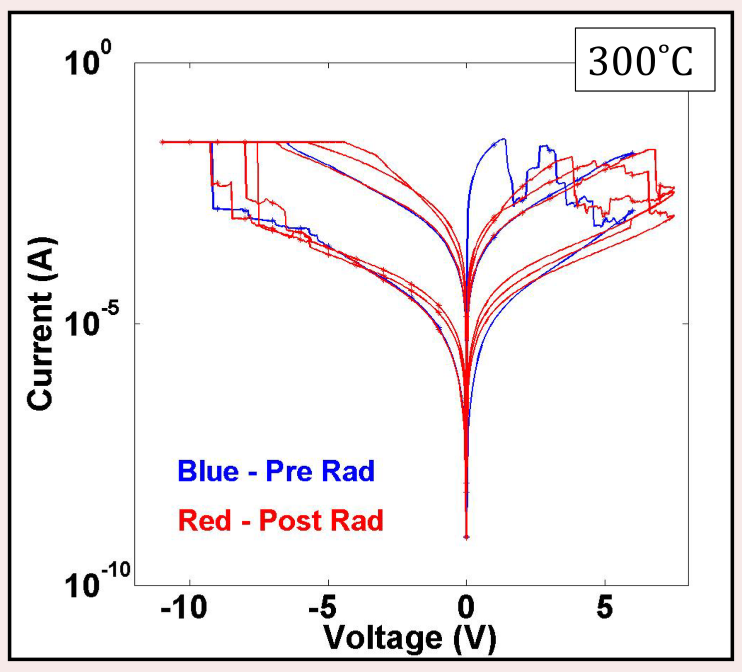
ALD Deposition Temperature (˚C)	300	350
Thickness (nm)	48	50
Crystal structure	cubic	cubic
HfO_x x value	1.7	1.9

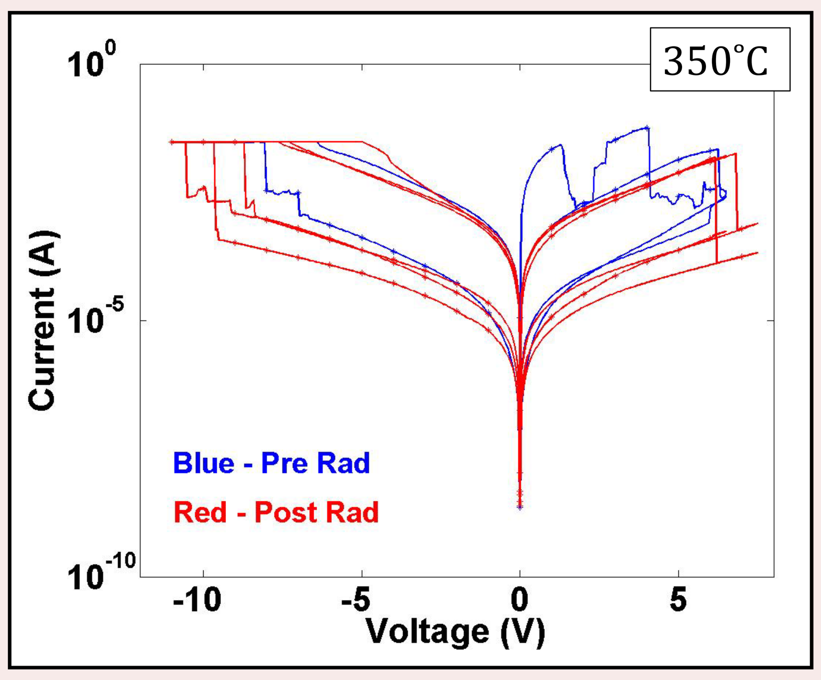
Electrical Measurements – Post Irradiation

Voltage sweep and pulsed measurements were undertaken after irradiation.

Voltage Sweep

- Same electrical parameters as pre irradiation
- Devices left in LRS, HRS and virgin states before irradiation, then re-measured after radiation

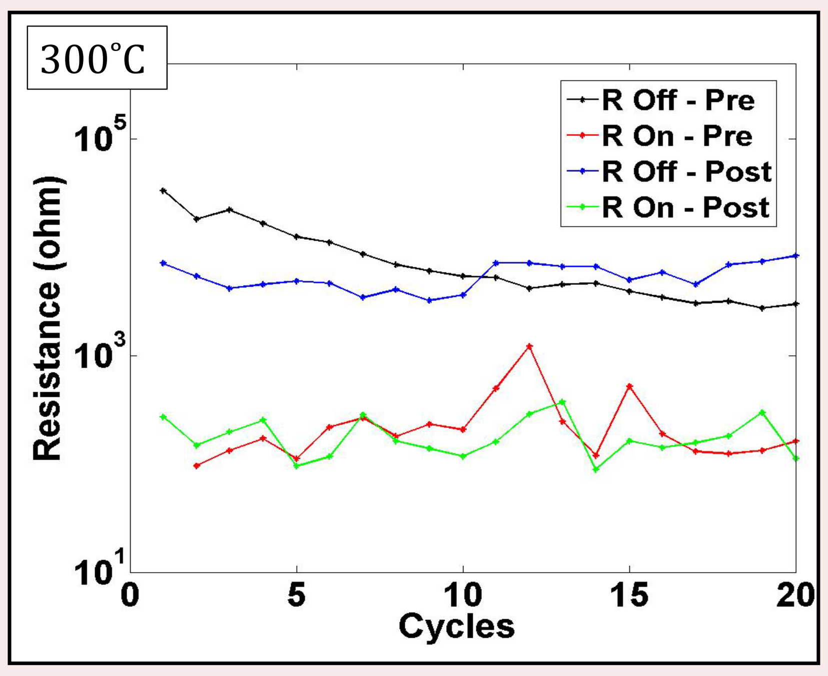


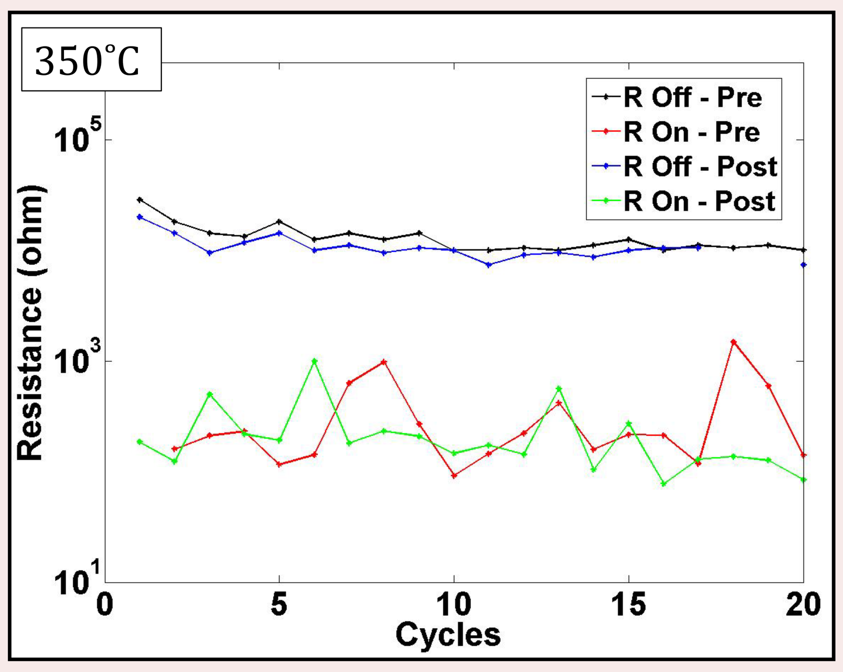


ALD Deposition Temperature (˚C)	Pre Roff (Ω)	Post Roff (Ω)	Pre Ron (Ω)	Post Ron (Ω)	Pre Roff/Ron	Post Roff/Ron
300	$5.2x10^4$	$3.1x10^4$	$2.4x10^3$	$2.3x10^3$	22	14
350	$5.1x10^4$	$5.9x10^4$	$1.4x10^3$	$1.8x10^3$	36	33

Voltage Pulsed

- 20 pulses, irradiation, 20 pulses
- Devices left in LRS, HRS and virgin states before irradiation, then re-measured after radiation





ALD Deposition Temperature (˚C)	Pre Roff (Ω)	Post Roff (Ω)	Pre Ron (Ω)	Post Ron (Ω)	Pre Roff/Ron	Post Roff/Ron
300	$7.7x10^3$	$5.5x10^3$	$2.6x10^2$	$1.8x10^2$	30	30
350	$1.1x10^4$	$8.0x10^3$	$3.4x10^2$	$2.2x10^2$	32	36

- Changes in ratio within the margin observed by un-irradiated control batch
- Radiation hard up to 10Mrad(Si)
- Radiation response same for the different stoichiometries

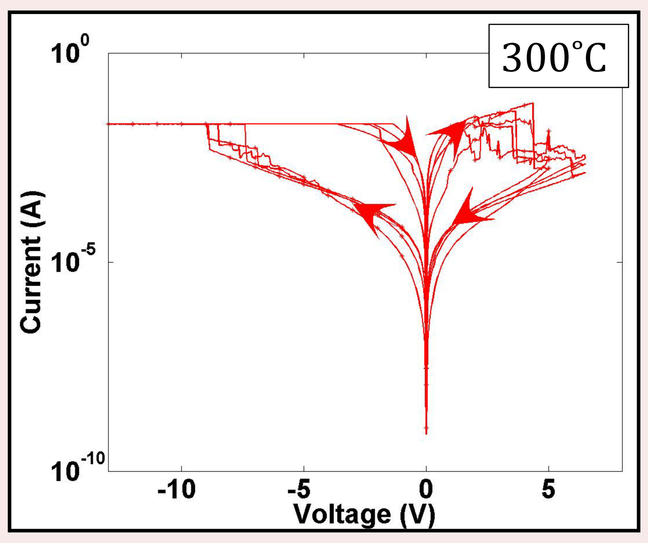
Electrical Measurements - Pre Irradiation

Voltage sweep and pulsed measurements were undertaken before irradiation.

Voltage Sweep

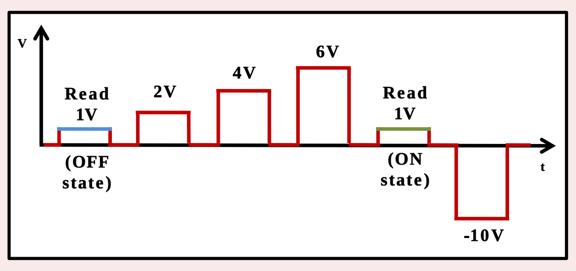
- Current compliance and forming voltage: 20mA, -17V for 300˚C and 30mA, -18V for 350˚C

ALD Deposition Temperature (˚C)	Average Roff (Ω)	Average Ron (Ω)	Average Roff/Ron
300	$1.8x10^4$	$3.5x10^2$	50
350	$7.7x10^4$	$1.5x10^3$	52

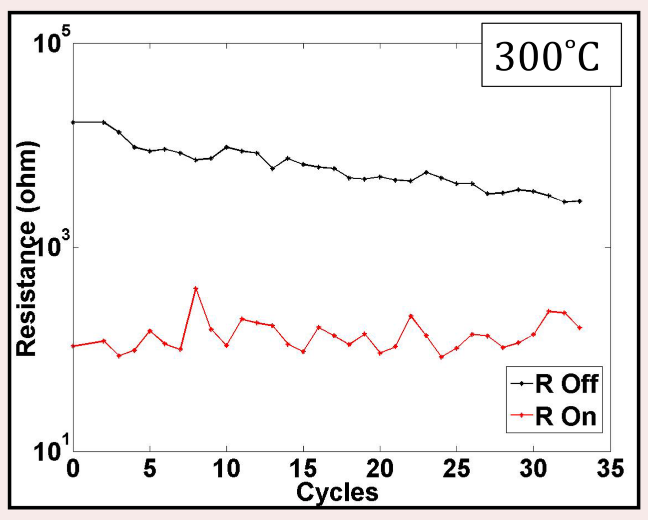


Voltage Pulsed

- 50ms pulse width
- 50mA current compliance



ALD Deposition Temperature (˚C)	Average Roff (Ω)	Average Ron (Ω)	Average Roff/Ron
300	$6.3x10^3$	$1.4x10^2$	46
350	$1.5x10^4$	$3.2x10^2$	47



- The stoichiometry variation in HfO_x results in very similar memory characteristics

Radiation Setup

- A Co60 source was used with a dose rate of 500krad(Si)/hr
- Total Doses (Si): 0rad, 100krad, 500krad, 5Mrad, 10Mrad
- All devices were unbiased during irradiation

Conclusions

- Two types of TiN/HfO_x/TiN devices have shown to have a high degree of hardness to gamma radiation up to 10Mrad(Si)
- Both 300˚C and 350˚C devices have different stoichiometries but result in similar memory characteristics, and both show high radiation tolerance
- HfO_x is a potential oxide for use in RRAM devices in radiation environments

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[3] S. Kim, O. Yarimaga, S.-J. Choi, and Y.-K. Choi, "Highly durable and flexible memory based on resistance switching," *Solid-State Electronics*, vol. 54, no.4, pp. 392-396, 2010

[4] R. Fang, Y. G. Velo, W. Chan, K. E. Holbert, M. N. Kozicki, H. Barnaby and S. Yu, "Total ionizing dose effect of gamma-ray radiation on the switching characteristics and filament stability of HfOx resistive random access memory," in *Applied Physics Letters*, vol.104, no.18, pp. 183507-1-183507-5,2014

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