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# Application of Atomic Layer Deposition Tungsten (ALD W) as gate filling metal for 22nm and beyond CMOS technology

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As CMOS technology downscales into sub-22 nm nodes, high-K & metal gate (HKMG) technology has become the mainstream in order to reduce leakage as well as to improve device performance. Two different HKMG integration schemes, *i.e.,* gate-first and gate-last (replacement gate) process [1], [2], which are usually adopted in the mass production fabrication. In the replacement gate process, one of the biggest challenges is to fill gate trench of high aspect-ratio with conductive metals, such as Al [3] or W [4]. The common Al gate metal sputtered using physical vapor deposition (PVD) is, however, no longer a better choice for extremely downscaled devices. Even with the help of Al re-flow process at ~425 $^{o}$C, voids in filling Al gate occasionally occurs due to the overhang at two top corners during PVD. In addition, it is known that Al Chemical Mechanical Polishing (CMP) is also tough since surface $Al_2O_3$ is hard to be removed. As a consequence, we propose to fill gate trench with W by means of atomic layer deposition (ALD) in this work. Because of the excellent filling capability of ALD as well as the mature W CMP process, an investigation of ALD W as the metal gate in the replacement gate process is, therefore, of great interest.

W films were grown in ALD chamber using two different precursors ($SiH_4$ and $B_2H_6$). The growth rate of W films using $SiH_4$ 0.67 nm/cycle is larger than that using $B_2H_6$ 0.31 nm/cycle as shown in Fig. 1. In Fig. 2, the plot of thickness vs. sheet resistance indicates that W film grown using $B_2H_6$ has lower resistivity compared to W film grown using $SiH_4$. Table I shows the compositions of as-grown W films analyzed by XPS. The much higher B content in W films grown using $B_2H_6$ should account for the lower resistivity in Fig. 2. Diffraction spectrums shown in Fig. 3 display that W film grown using $SiH_4$ is polycrystalline whereas W film grown using $B_2H_6$ is amorphous. The filling capability of ALD W films using $SiH_4$ or $B_2H_6$ is tested on devices with 22 nm gate length as shown in Fig. 4. It can be seen that W filling using $B_2H_6$ is superior to that using $SiH_4$ since it shows void-free W filling. In order to verify if ALD W filling using $B_2H_6$ affects the equivalent oxide thickness (EOT) due to B diffusion into high-K dielectric, diodes with high-K dielectric & ALD W films using both $SiH_4$ and $B_2H_6$ were fabricated. The C-V characteristics of as-fabricated both P-type and N-type diodes are shown Fig. 5. As seen, no obvious difference in leakage and EOT can be scrutinized for diodes made of high-K dielectric & ALD W films using both $SiH_4$ and $B_2H_6$.

In conclusion, ALD W using $SiH_4$ and $B_2H_6$ were investigated. In contrast to ALD W using $SiH_4$, ALD W using $B_2H_6$ shows lower growth rate, resistivity and better gap filling capability. The incorporation of B in ALD W films doesn't affect the C-V characteristics. Therefore, ALD W using $B_2H_6$ is a good gate filling metal which can be widely used in advanced devices.

**Acknowledgements**

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## References

[1] Sung Kee Han et.al. IEDM, Tech.Dig, P621, 2006
[2] Martin M. Frank et.al. IEEE, P50, 2011
[3] Y.Tateshita et.al. IEDM, P63, 2006
[4] K.Misytry et.al. IEDM, P247, 2007

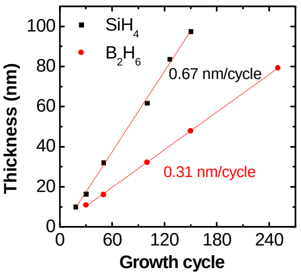

**Fig. 1** Growth rate of ALD W grown using $SiH_4$ and $B_2H_6$

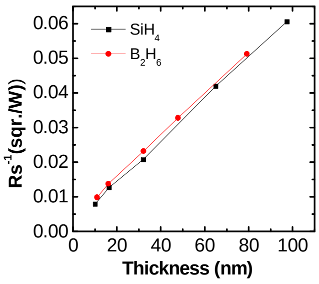

**Fig. 2** $R_s^{-1}$ vs. thicknesss plot

**Table I.** Compositions of ALD W grown using $SiH_4$ and $B_2H_6$ (at. %) by XPS

| *Composition* | *C* | *O* | *N* | *W* | *Si* | *B* |
|---|---|---|---|---|---|---|
| W ($SiH_4$) | 9.2 | 47.9 | 1.1 | 22.4 | 19.4 | N.D. |
| W ($B_2H_6$) | 18.1 | 34.4 | 3.2 | 27 | N.D. | 17.2 |

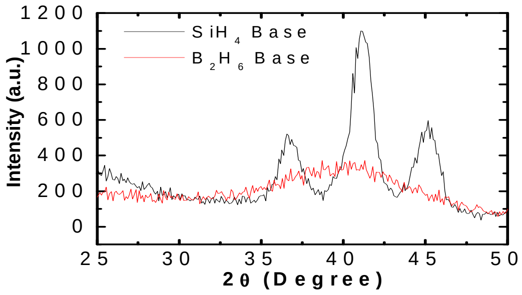

**Fig. 3** XRD spectrum of ALD W grown using $SiH_4$ and $B_2H_6$

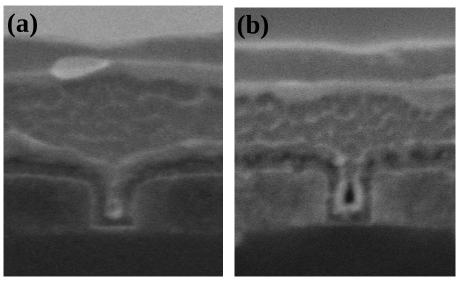

**Fig. 4** Gap filling capability of ALD W grown using $B_2H_6$ (a) and $SiH_4$ (b) tested on gate trench of 22 nm gate length

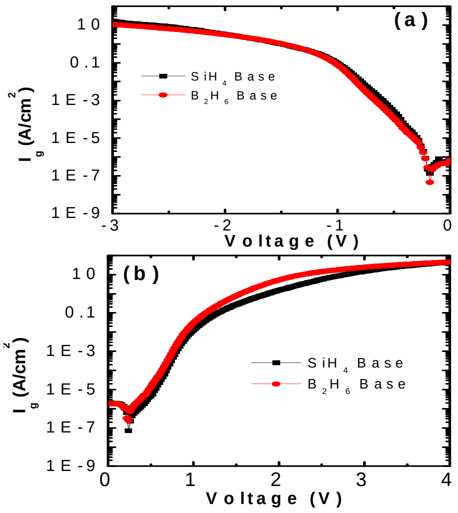

**Fig. 5** C-V characterisitics of N-type (a) and P-type (b) diodes