Substrate dependence of ruthenium atomic layer deposition

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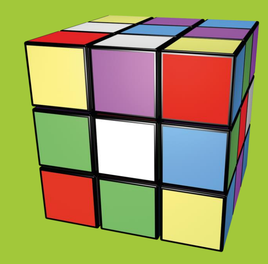

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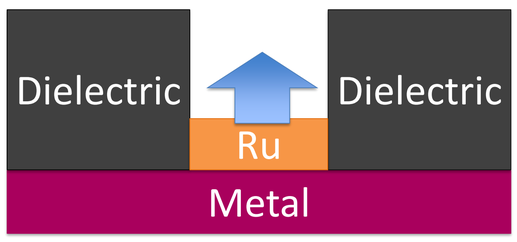
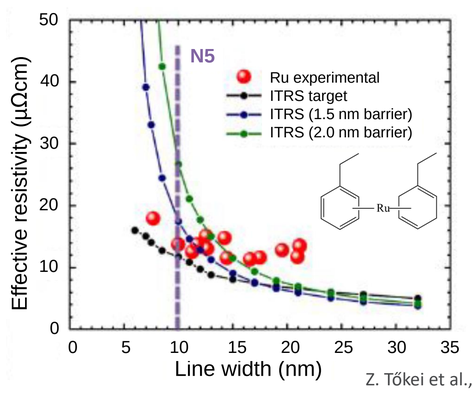
1. Introduction



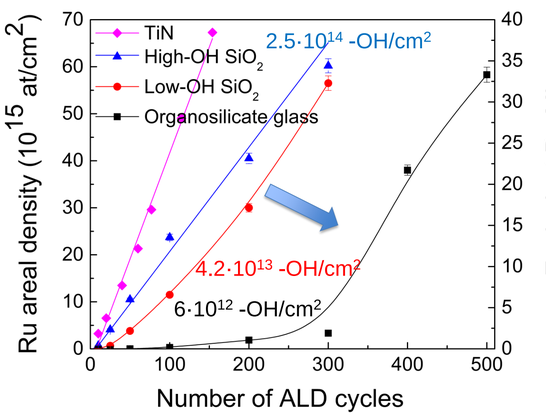


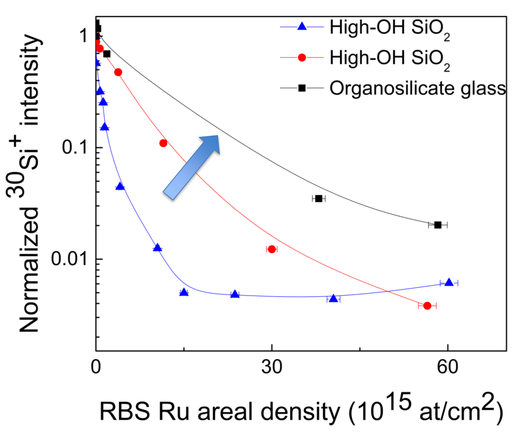
Z. Tőkei et al., VLSI 2016

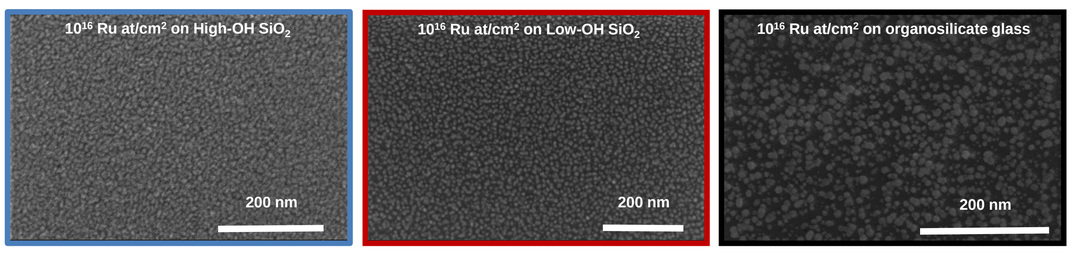
- Ru promising conductor in <10nm nano-electronic devices
- Void-free filling of small features can be facilitated by bottom-up growth
- Need for selective deposition on the bottom of a feature (metal) and not on the sidewall (dielectric)

2. Substrate dependence of Ru ALD

- Substrate-dependent Ru ALD process
  - (ethylbenzyl)(1,4-cyclohexadienyl)-ruthenium and oxygen (EBECHRu/O_2)
- High nucleation density and fast film closure on Si-OH terminated substrate
- Low nucleation density and slow film closure on Si-CH_3 terminated substrate

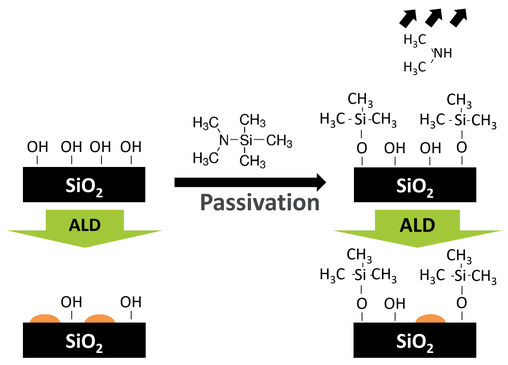


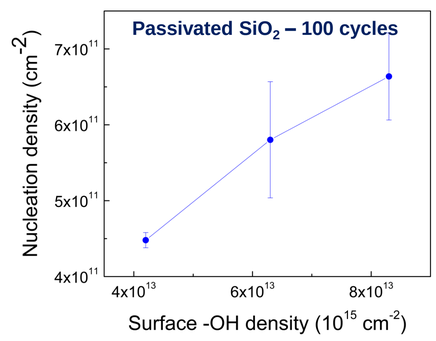




Substrate	Water CA (°)	Surface termination	Surface -OH density (10^{15} cm^{-2})	Nucleation density (cm^{-2})
High-OH SiO_2	17 ± 1	Si-OH	0.25 ± 0.01	2 10^{12} (25 cycles)
Low-OH SiO_2	38 ± 2	Si-OH, Si-O-Si	0.042 ± 0.006	7 10^{11} (25 cycles)
Organosilicate glass	103 ± 1	Si-CH_3	< 0.01	2 10^{10} (50 cycles)

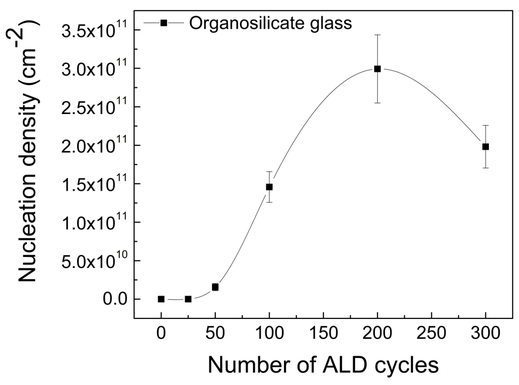
3. Reducing nucleation on SiO_2

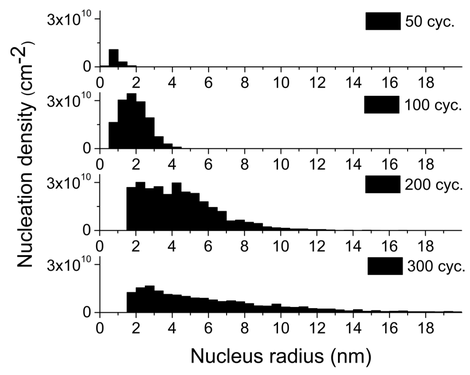


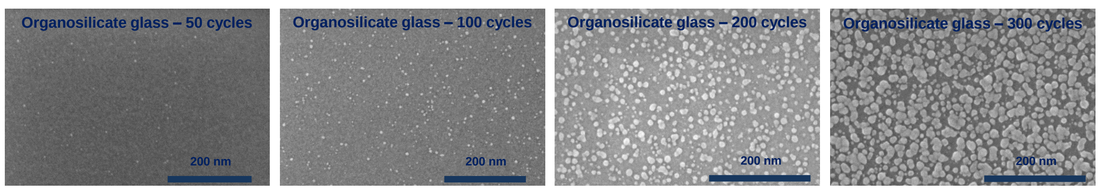


- Replacing Si-OH with Si-CH_3 lowers nuc. density

4. Nucleation and growth on organosilicate glass







- Low initial nucleation density (1.6·10^{10} cm^{-2})
- Ru continues to nucleate with increasing cycle number, resulting in a broad size distribution
- Existing nuclei grow with 0.03 nm/cycle

5. Conclusion

- EBECHRu/O_2 ALD is substrate dependent
  - Nucleates readily on Si-OH
  - Nucleation inhibited on Si-CH_3
  - Surfactant-enhanced growth on TiN
- Organosilicate glass is Si-CH_3 terminated and therefore a promising non-growth substrate with low nucleation density (10^{10} cm^{-2})