Atomic Layer Deposition of Novel High Dielectric Constant Materials

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August 2, 2007

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Motivation for Research

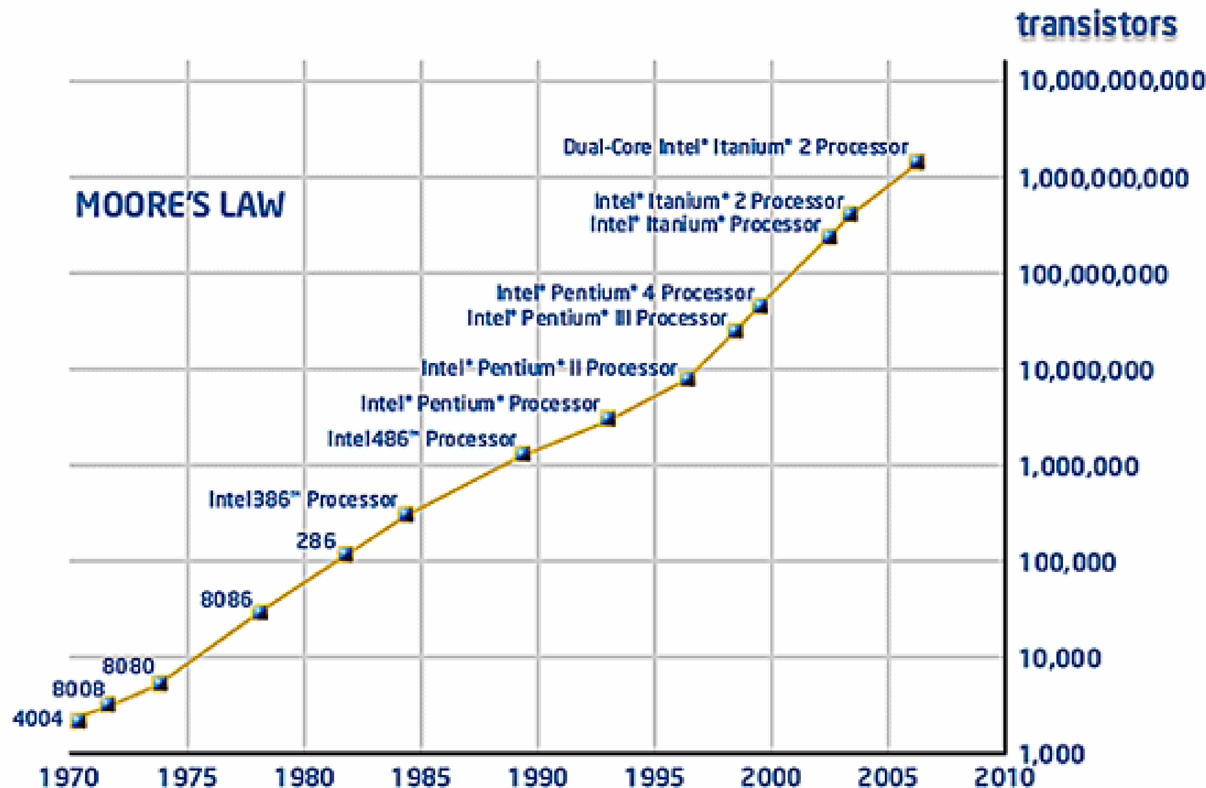
- To work with new high dielectric constant (k) materials such as and HfO_2 and Y_2O_3 to replace SiO_2 in semiconductors
- To run experiments on the atomic layer deposition (ALD) reactor to examine thin film growth rate
- To analyze the resulting thin films on silicon using spectral ellipsometry, Fourier Transform Infrared (FTIR) spectroscopy and X-ray Photoelectron Spectroscopy (XPS)

Hypotheses

- A self-limiting reaction between an yttrium precursor, an oxidizer, and the silicon substrate
- Good film uniformity on the substrate (using a spectral ellipsometer)
- Absence of organic compounds in the resulting film structures (using FTIR spectroscopy)
- Stoichiometry of the high-k material and the bonding states of the elements (using XP Spectroscopy)

Moore’s Law

- According to Moore’s Law, the number of transistors per microprocessor should double every two years



www.intel.com/technology/mooreslaw/index.htm

Capacitance

- Equation for capacitance:

$$C = \frac{k\, \varepsilon_0\, A}{t}$$

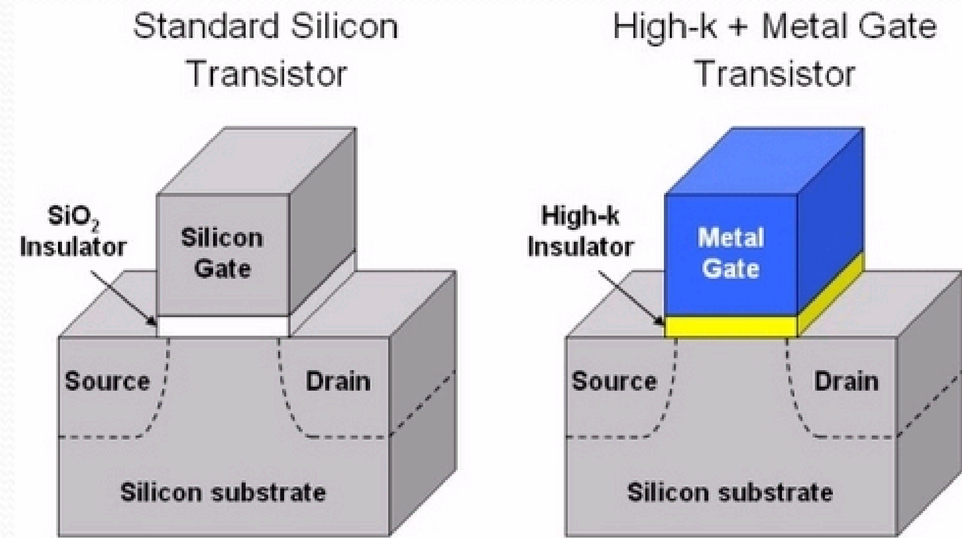
C = capacitance

k = dielectric constant

ε_0 = permittivity of free space in vacuum

A = area

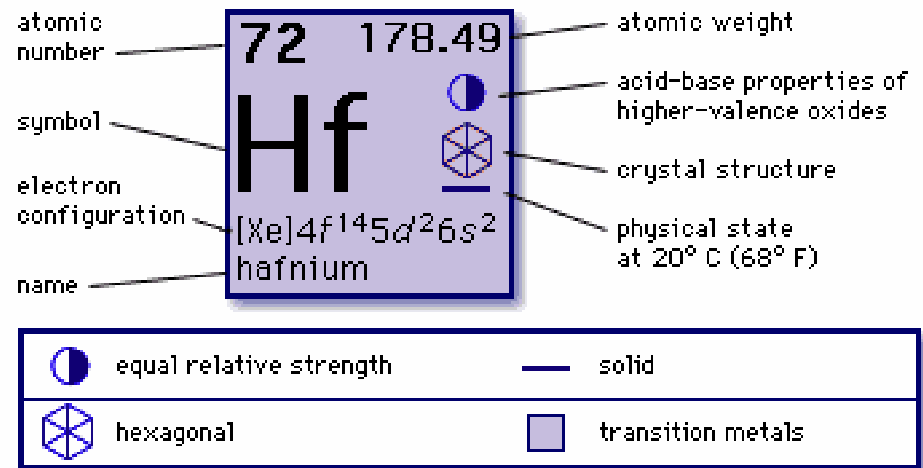
t = thickness



www.dvhardware.net/news/inter_higk-k_metal_gate_transistor.jpg

New High-k Dielectric Materials

- We are currently working with hafnium oxide and yttrium oxide to produce a dielectric layer gate oxide of ~ 45 nm

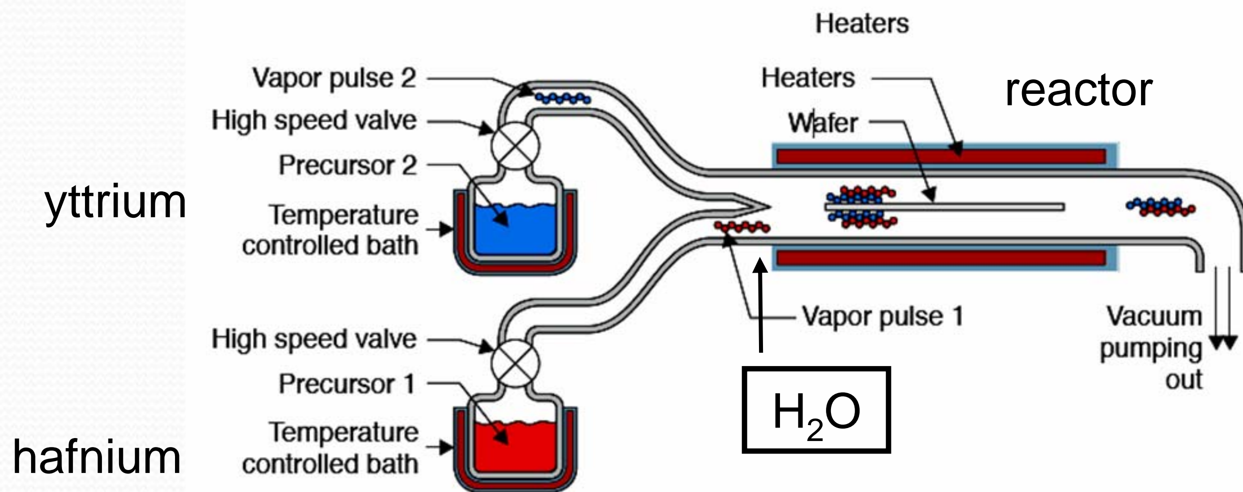


- Hafnium oxide has a k value of 20-25

- Yttrium oxide has a k value of 15-18

Atomic Layer Deposition (ALD)

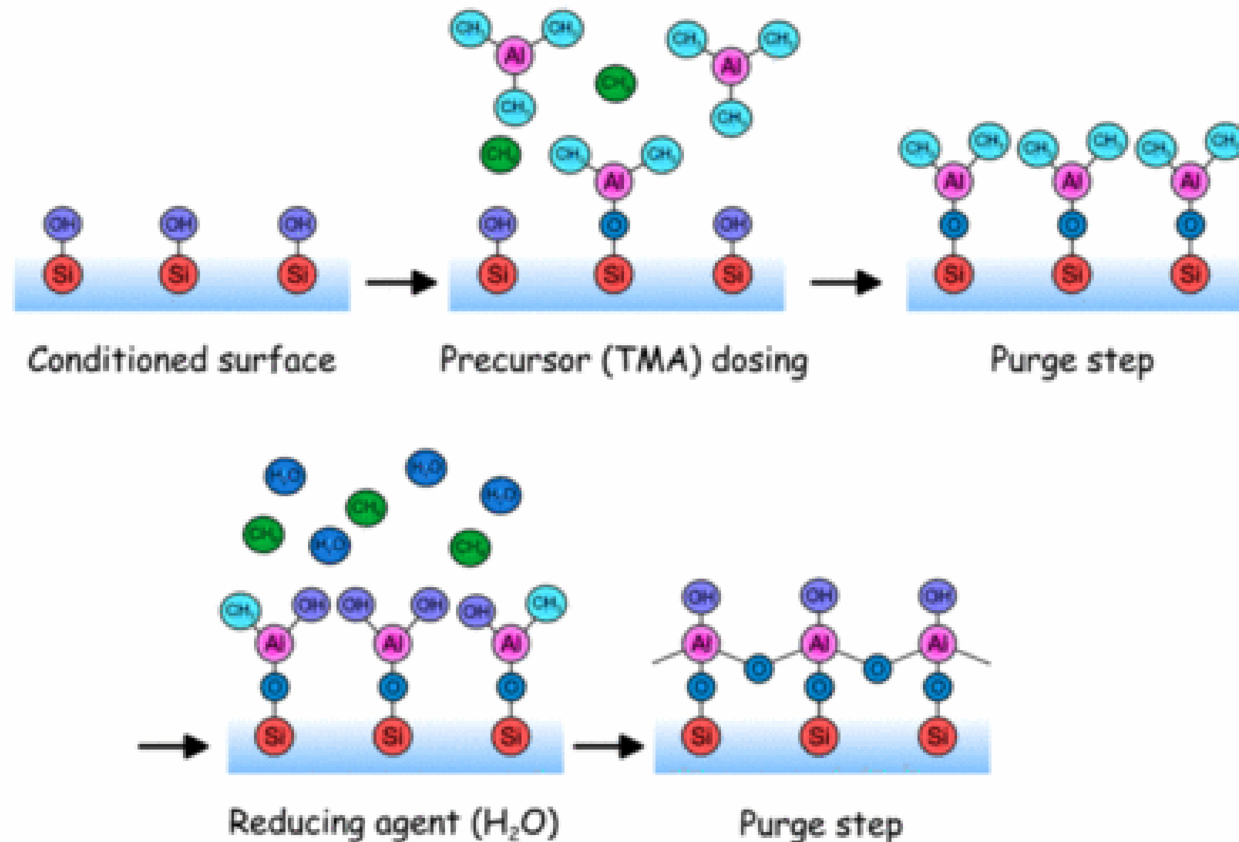
- Uses pulses of gaseous reactants (precursor and oxidizer) alternately fed into the reactor
- Produces one atomic layer at a time on substrates
- Film thickness depends on number of deposition cycles



www.icknowledge.com/misc_technology/Atomic%20Layer%20Deposition%20Briefing.pdf

ALD Process

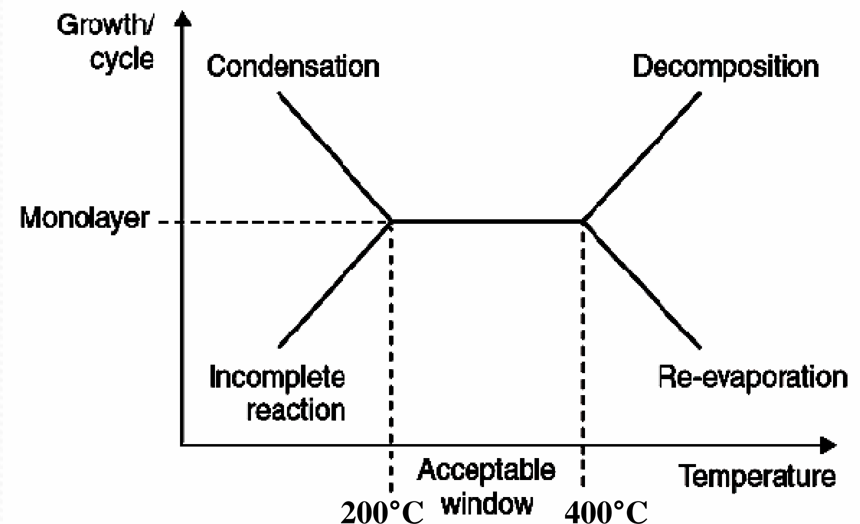
- “One Cycle”
- Precursor
- Purge (N_2)
- Oxidizer (H_2O)
- Purge (N_2)



http://www.cambridgenanotech.com/

Acceptable Temperature Window

- ALD reactions usually occur between 200-400 °C in the reactor
- Above 400 °C, the chemical bonds are not stable and the precursor may decompose
- Below 200 °C, the reaction rate is reduced

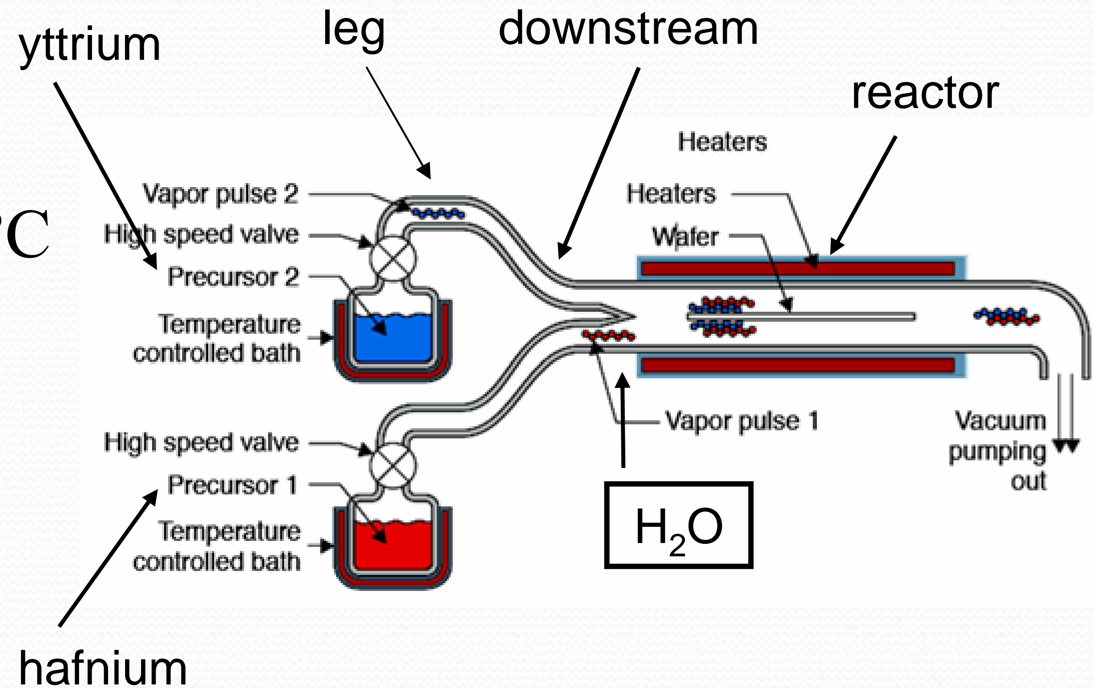


www.icknowledge.com/misc_technology/Atomic%20Layer%20Deposition%20Briefing.pdf

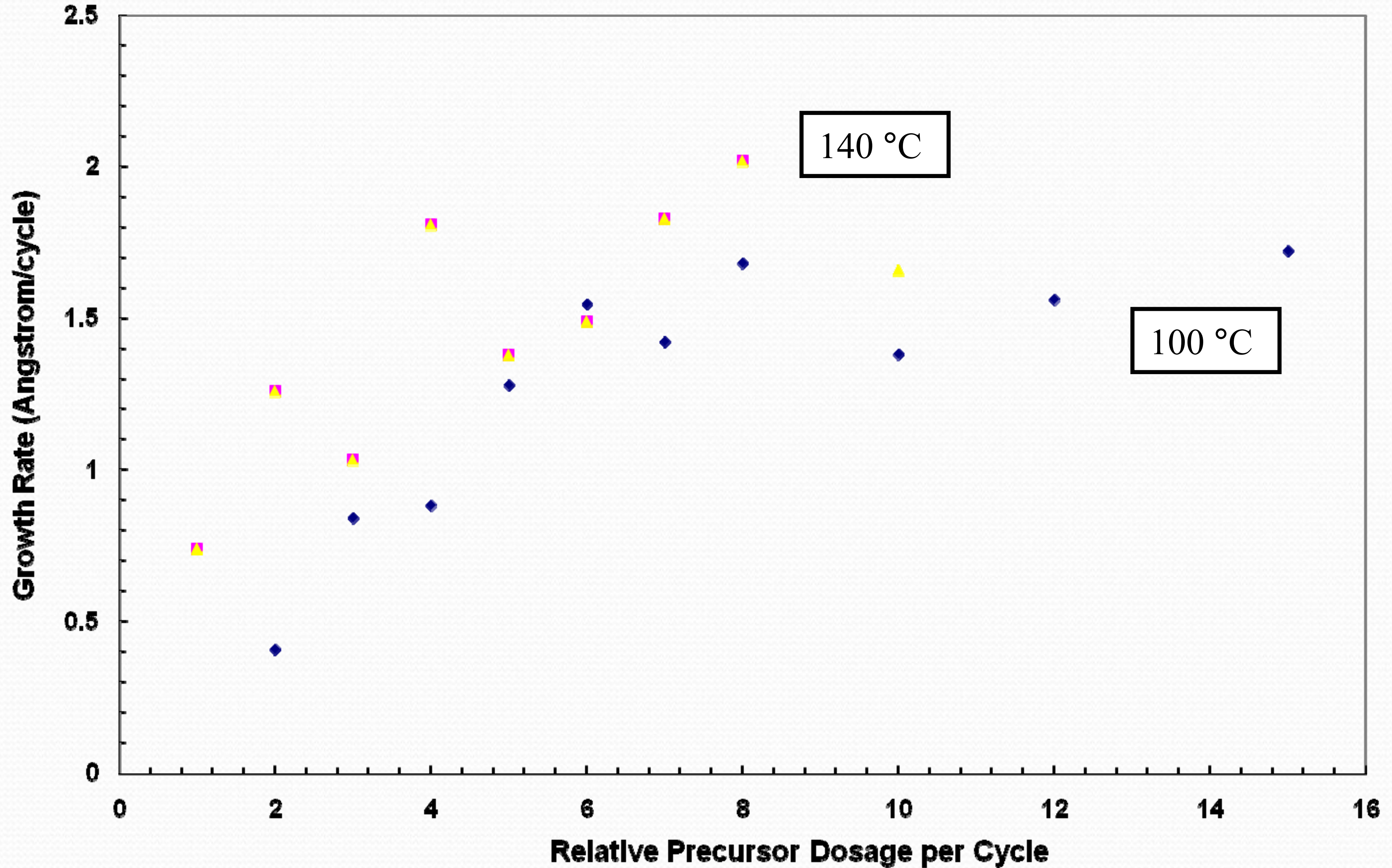
Experimental Conditions

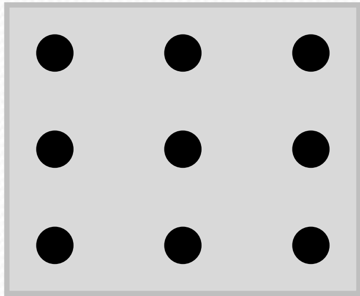
- ALD Reactor

- Downstream: 170 °C
- Precursor 2: 140 °C
- Precursor 2 Leg: 175 °C
- Reactor: 302 °C



Y_2O_3 Growth Rate vs. Precursor Dosage





Silicon Wafer
P-type
Boron doped
(100)

Y_2O_3 Film Uniformity

Film Thickness (A)

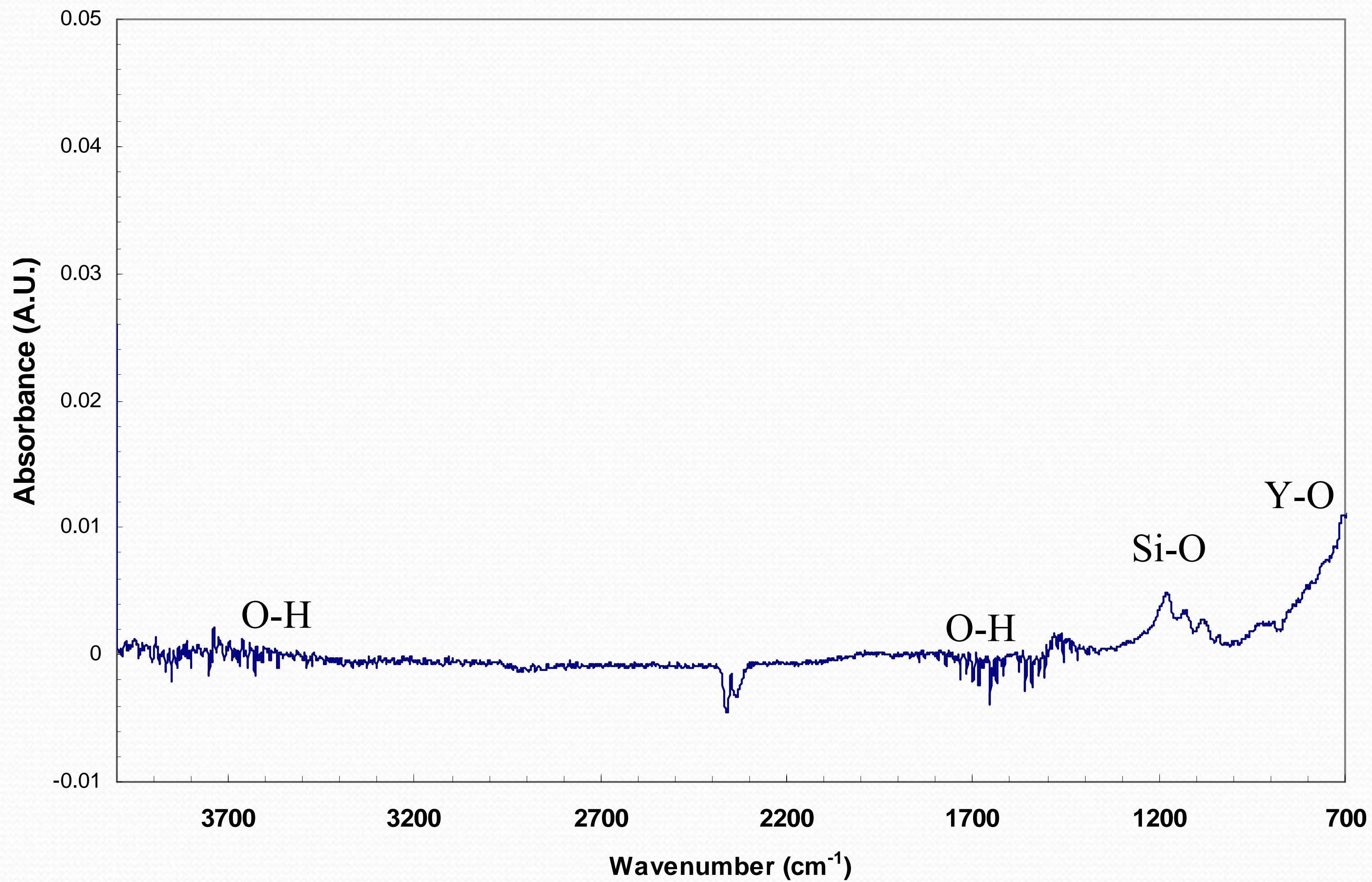
60
54
48
42
36
30
24
18
12
6
0

1
2
3

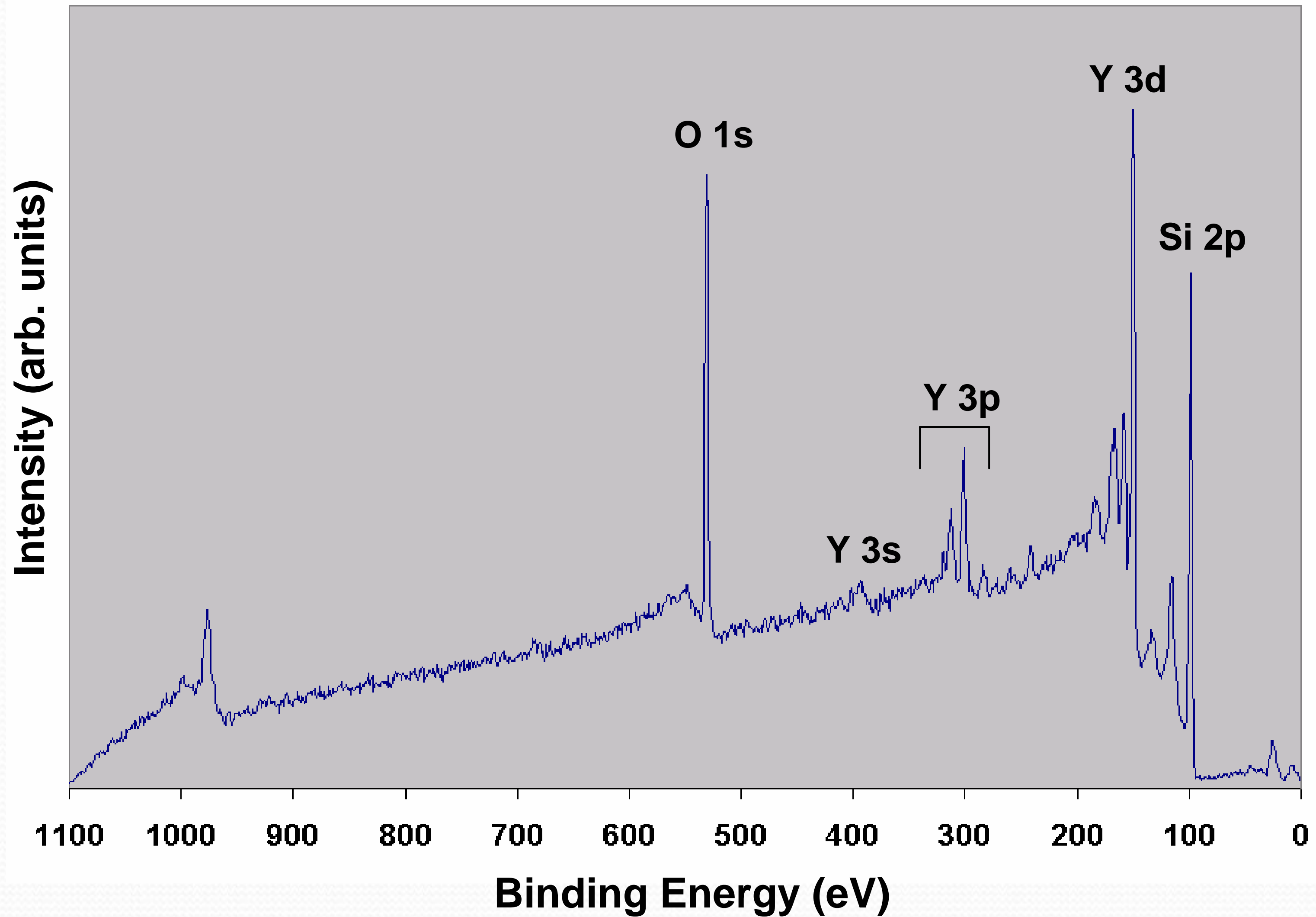
Horizontal

S3
S2
S1

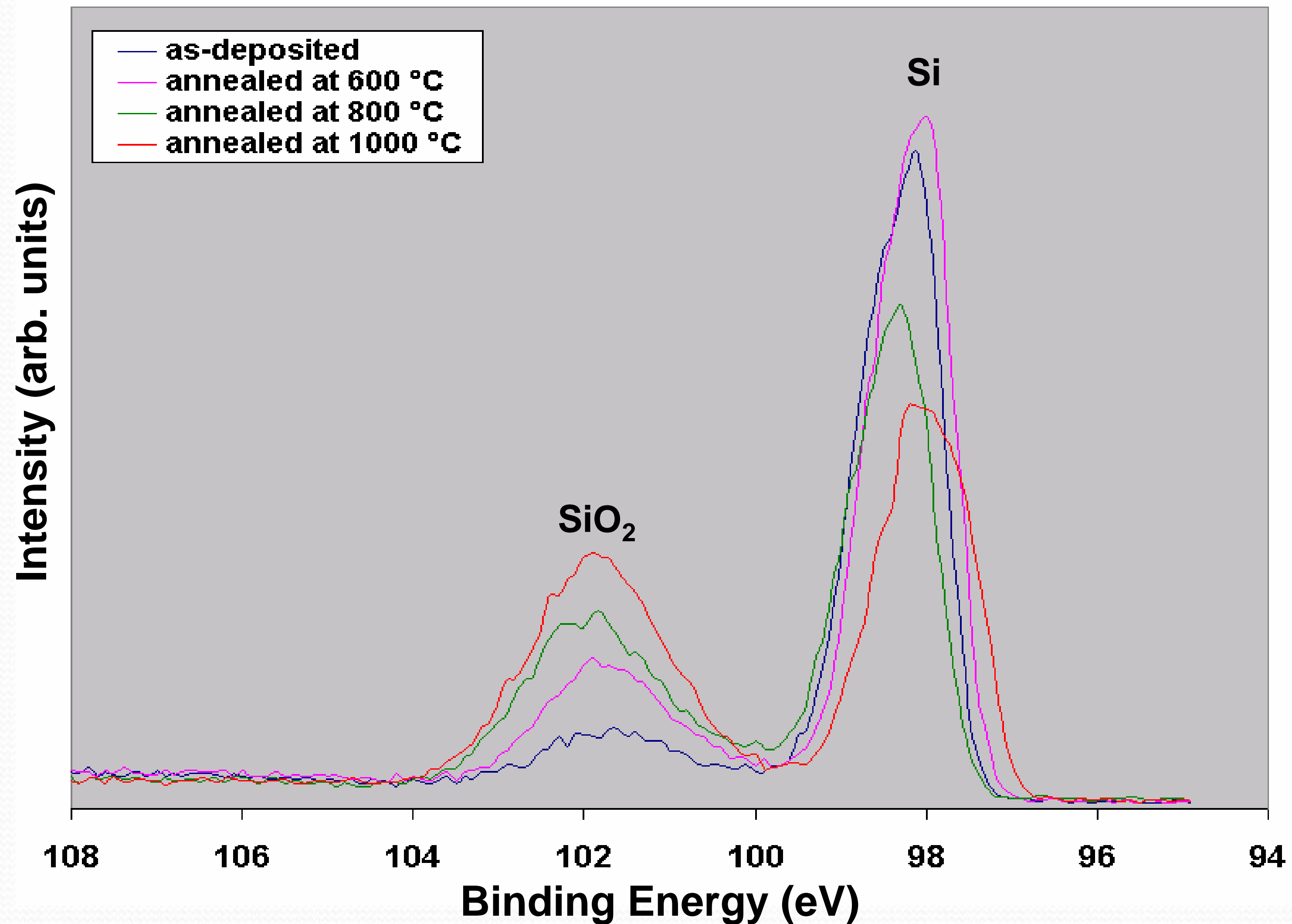
Vertical


FTIR of Y2O3 on Silicon
Absorbance (A.U.)
0.05
0.04
0.03
0.02
0.01
0
-0.01
3700
3200
2700
2200
1700
1200
700
Wavenumber (cm-1)
O-H
O-H
Si-O
Y-O

Survey XP Spectrum of Y_2O_3 on Si



XP Spectra of Y_2O_3 on Si
As-deposited and after 5 min annealing



Quantification Results

Y Atomic Concentration %: 39.2

O Atomic Concentration %: 60.8

O:Y = 60.8/39.2 = 1.5

Therefore Y_2O_3 was produced on the substrate.

Future Work

- To better define the ALD process conditions
- Using two precursors to create thin films with alternating atomic monolayers of HfO_2 and Y_2O_3

What Can We Bring Back?

- Go more in depth into the scientific method
- Not every lab is a cookie cutter
- Develop better critical thinking skills

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Acknowledgements

- National Science Foundation CMS 0731734 and NSF EEC 0703958
- Chicago Science Teacher Research (CSTR) program director: Dr. Andreas Linninger
- Mentors: Dr. Greg Jursich and Dr. Christos Takoudis
- Doctoral students: Prodyut Majumder and Manish Singh
- Program coordinator: Kedar Kulkarni