

# **Silicon DRIE vs. Germanium DRIE A Comparison in the Plasmatherm VLN**

**Vince Genova**

**CNF Research Staff**

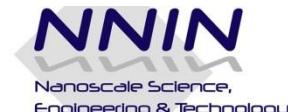
**NNCI Etch Workshop**

**Cornell University**

**5/24/2016**



Cornell University



## **What do we know about Si and Ge etching in fluorine?**

- Si-Si bonds are stronger than Ge-Ge bonds
- Ge is more easily oxidized than silicon
- Ge native oxide thickness is 4X that of silicon's native oxide
- Ge-O bond (3.66eV) is weaker than Si-O bond (4.82eV)
- Ge affinity to oxygen is much greater than silicon's affinity to oxygen
- Ge affinity to oxygen is much greater than its affinity to fluorine
- The thermal conductivity of silicon is 2X that of germanium
- Both Si and Ge react spontaneously with fluorine in the absence of ion bombardment
- SiF<sub>4</sub> and GeF<sub>4</sub> are the principal reaction products in fluorine based plasmas
- GeF<sub>4</sub> is somewhat less volatile than SiF<sub>4</sub> at typical etch temperatures
- In the case of SF<sub>6</sub>, GeS is less volatile than SiS
- Si etch rates are more strongly enhanced by ion bombardment than Ge
- Si and Ge reactions with halogens are exothermic
- Si-halogen bonds are stronger than Ge-halogen bonds
- Lower activation energy is needed for Ge fluorine based etching (not for Cl or Br)
- Etch rates are primarily determined by substrate reactivity and reaction product removal



## **More specifics of Si and Ge etching in SF<sub>6</sub>/C<sub>4</sub>F<sub>8</sub> based plasmas**

- DC biases in SF<sub>6</sub> plasmas tend to be low
- Etching is largely done by radicals
- Ions play a less significant role
- Deposition of sulfur on Si or Ge is unlikely in pure SF<sub>6</sub>, more likely in fluorine deficient plasmas
- Reactive etch layer thicknesses up to 3ML are less on Ge (GeF<sub>2</sub>, GeF<sub>3</sub>..) than on silicon (2x)
- Deposition of carbon based polymer (CxFy) is less on Ge than Si (2x)
- CxFy polymer acts to limit the in-diffusion of F and the out diffusion of etch products
- Ge sidewalls have a less effective sidewall passivation
- Sidewall passivation reduces the sticking coefficient and reaction probability of fluorine creating a Knudsen like diffusion of radicals down the feature sidewall
- Ge is affected more by ARDE due to reduction in neutral transport. (less sidewall passivation)
- SiOxFy inhibits etching while GeOxFy is more permeable to active species
- Removal of reaction products through the over layers is very important (Ge is thinner)
- Substrate surface plays a key role in etching
- Thermal conductivity or the lack thereof can influence surface mobility, reaction, and desorption



DSEIII IAT DOE:

CONSTANTS:

C4F8=150

SF6=250

AR=30

DEP. PRESSURE=25mtorr

DEP. TIME=2sec

ETCHA PRESSURE=40mtorr

ETCHA TIME=1.5sec

ETCHB PRESSURE=60mtorr

ETCHB TIME=1.5sec

LOOPS=240

TIME=20 min.

FACTORS:

DEP. POWER: 1500, 1750, 2000W

ETCHA POWER: 1500, 1750, 2000W

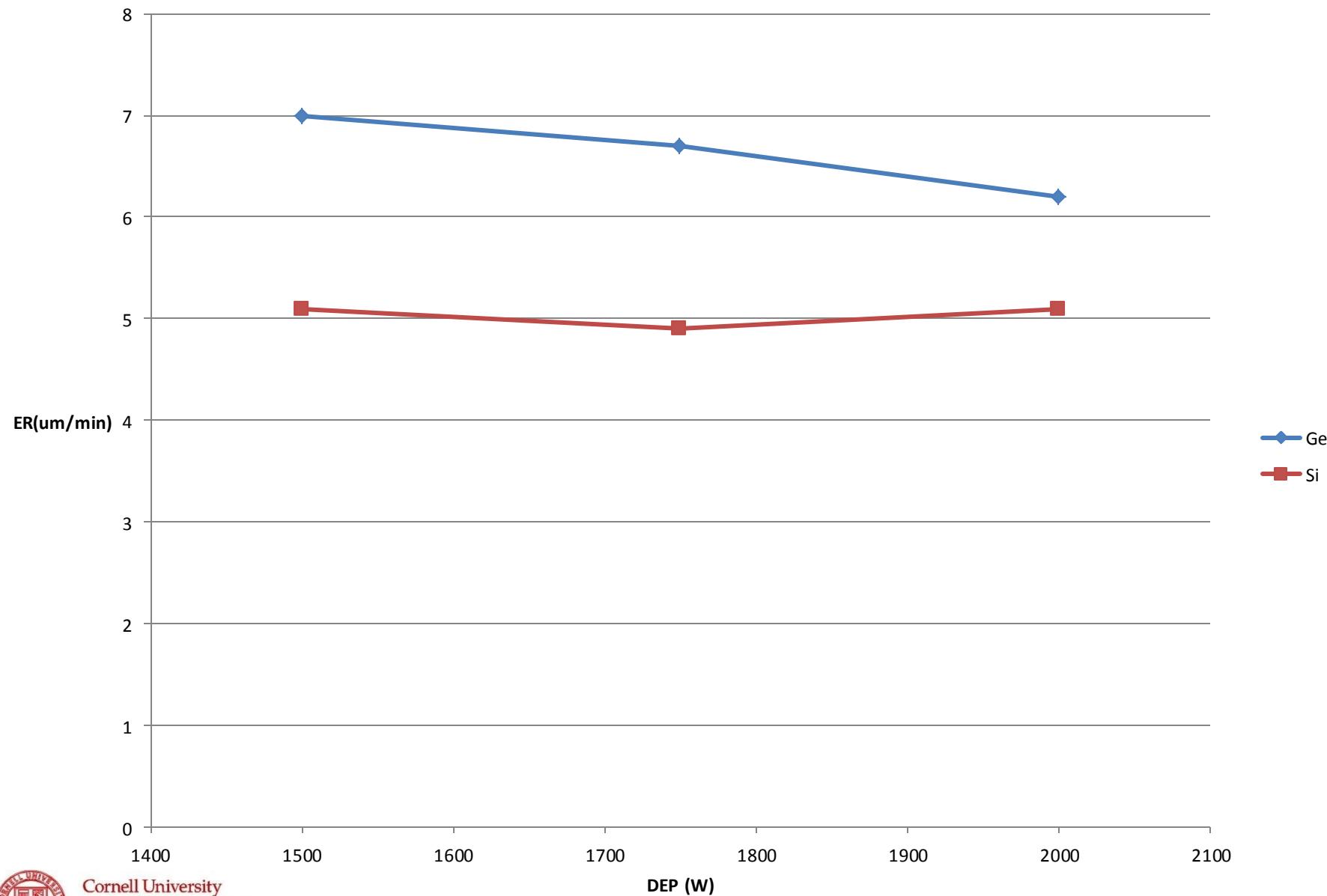
ETCHB POWER: 2000, 2250, 2500W

VOLTAGE PEAK TO PEAK: 375, 400, 425V

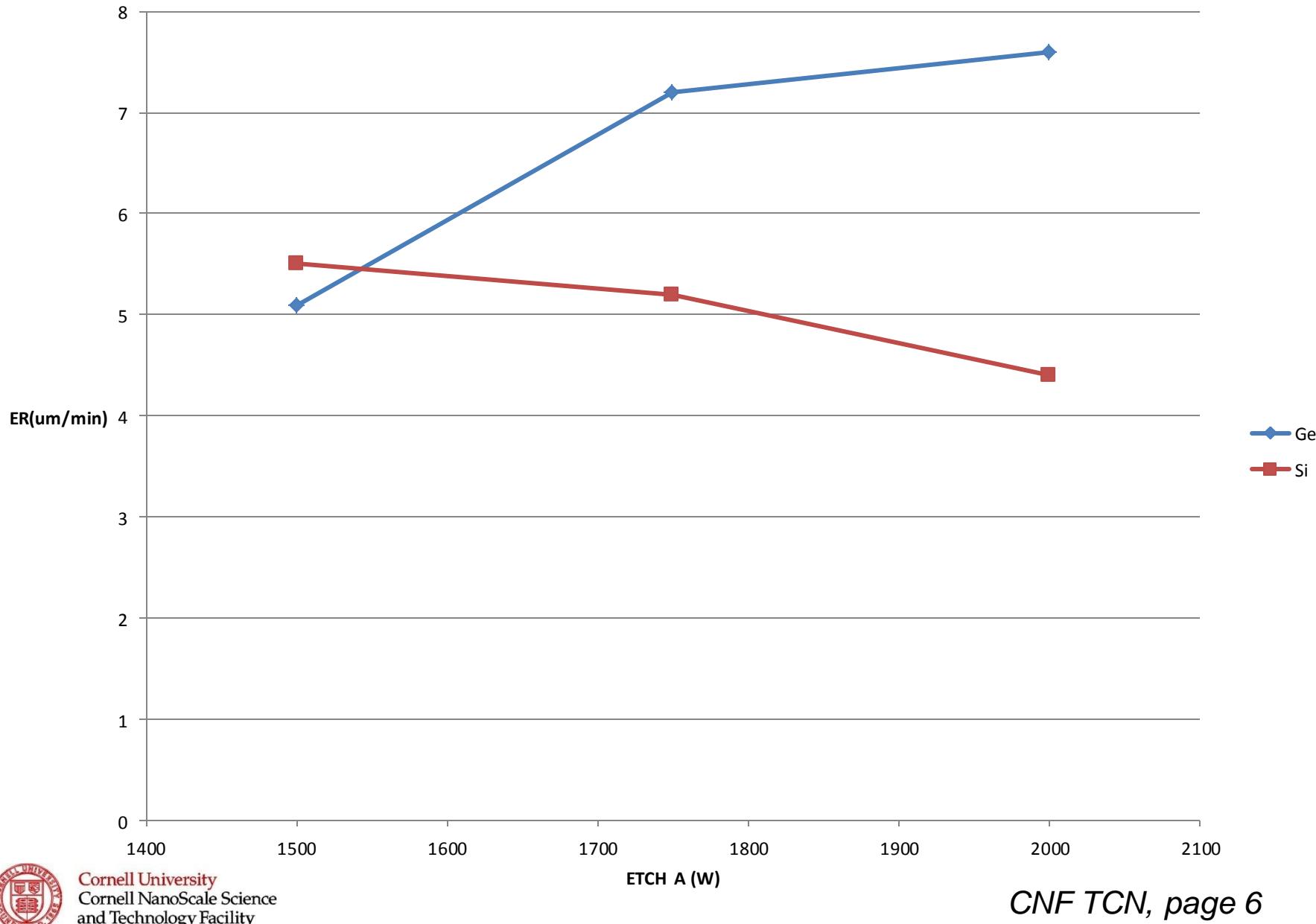
RUN	DEP.W	EAW	EBW	VPP	Ge	Ge	PR-ER	Ge	Si-ER	Si-ER
					um/min	um/min	nm/min	40um	40um	4um
1	1500	1500	2000	375	4.8	2.6	53	91	5.3	3.8
2	1500	1750	2250	400	6.5	3.4	86	76	5.4	3.8
3	1500	2000	2500	425	9.6	5.5	127	76	4.7	3.3
4	1750	1500	2500	400	6.1	3.3	72	85	5.5	3.9
5	1750	1750	2000	425	7.2	3.4	101	71	5.1	3.5
6	1750	2000	2250	375	6.8	3	105	65	4	3.1
7	2000	1500	2250	425	4.4	3.7	70	63	5.8	4
8	2000	1750	2500	375	7.9	4	88	90	5	3.5
9	2000	2000	2000	400	6.3	2.7	115	55	4.5	3.7



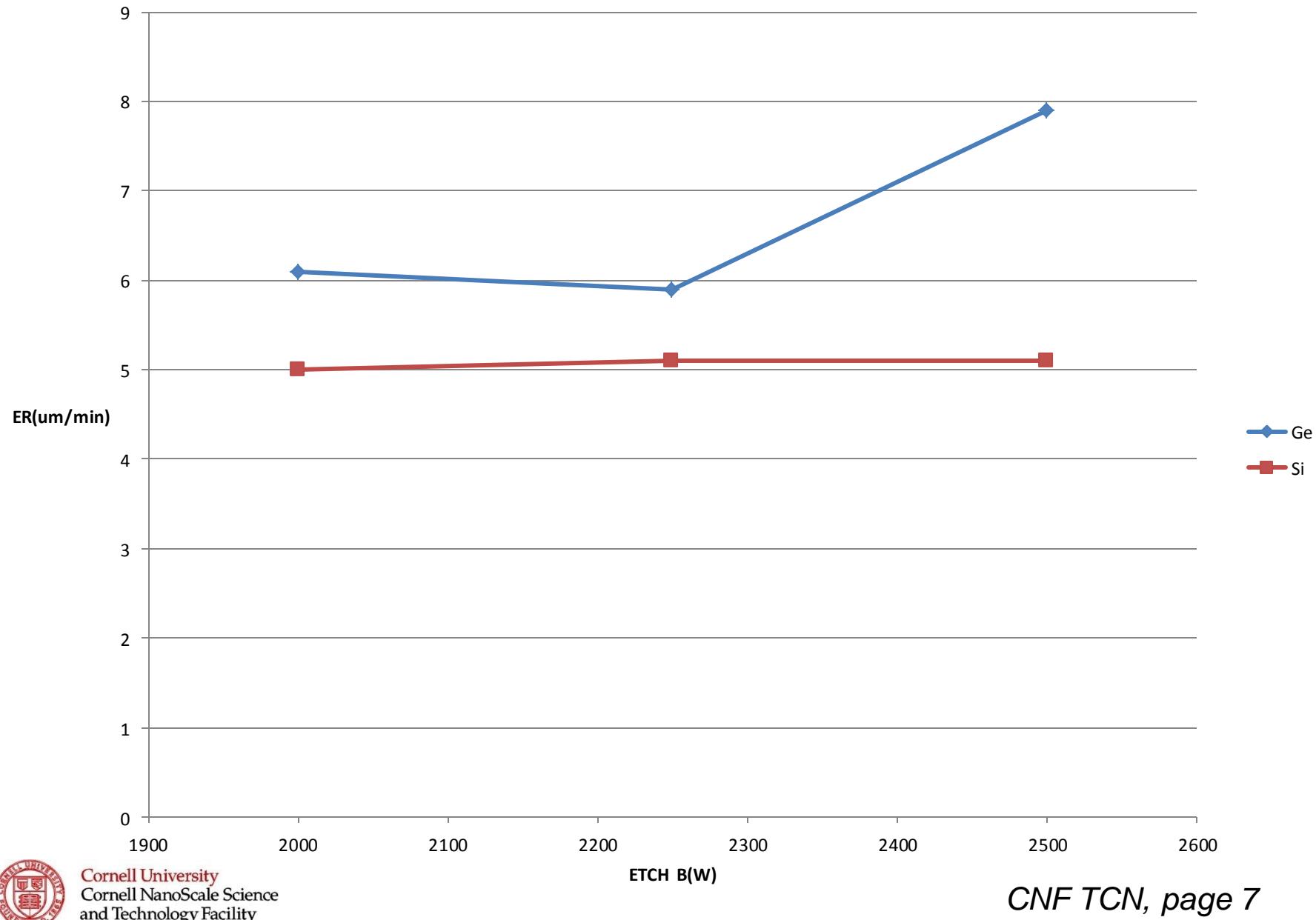
## DRIE-DOE-DEP W-40u



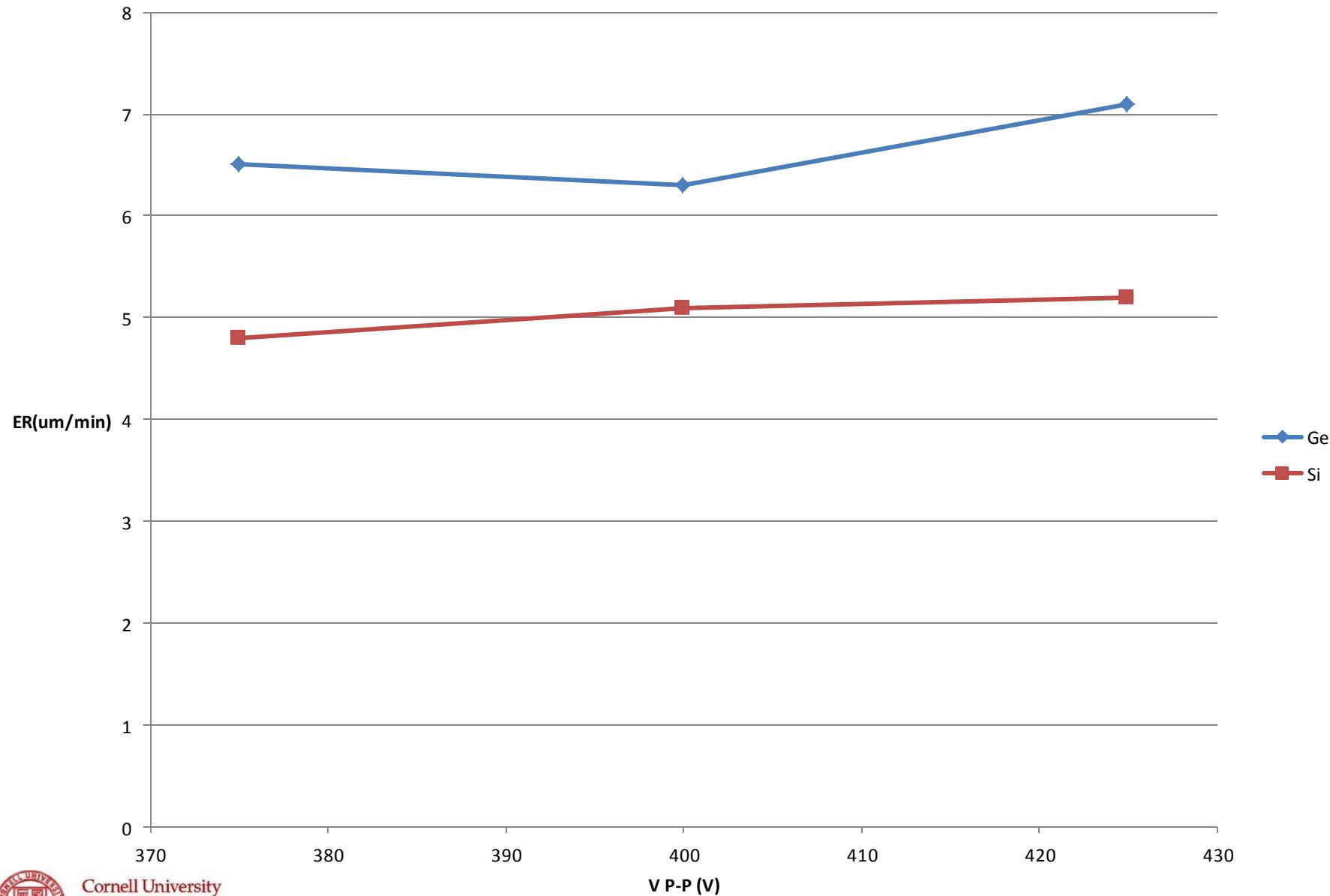
## DRIE-DOE-ETCH A W-40u



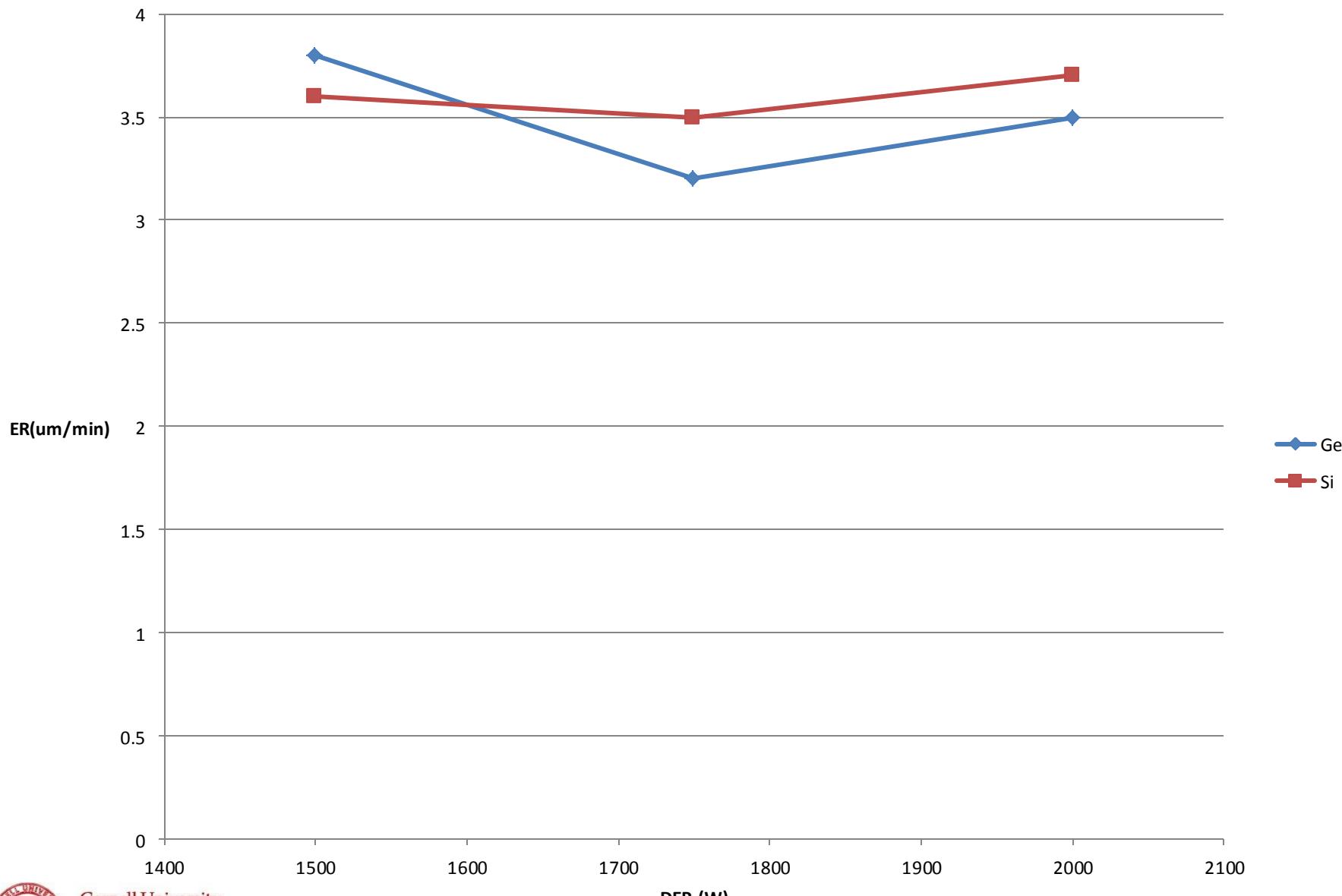
## DRIE-DOE-EBW-40u



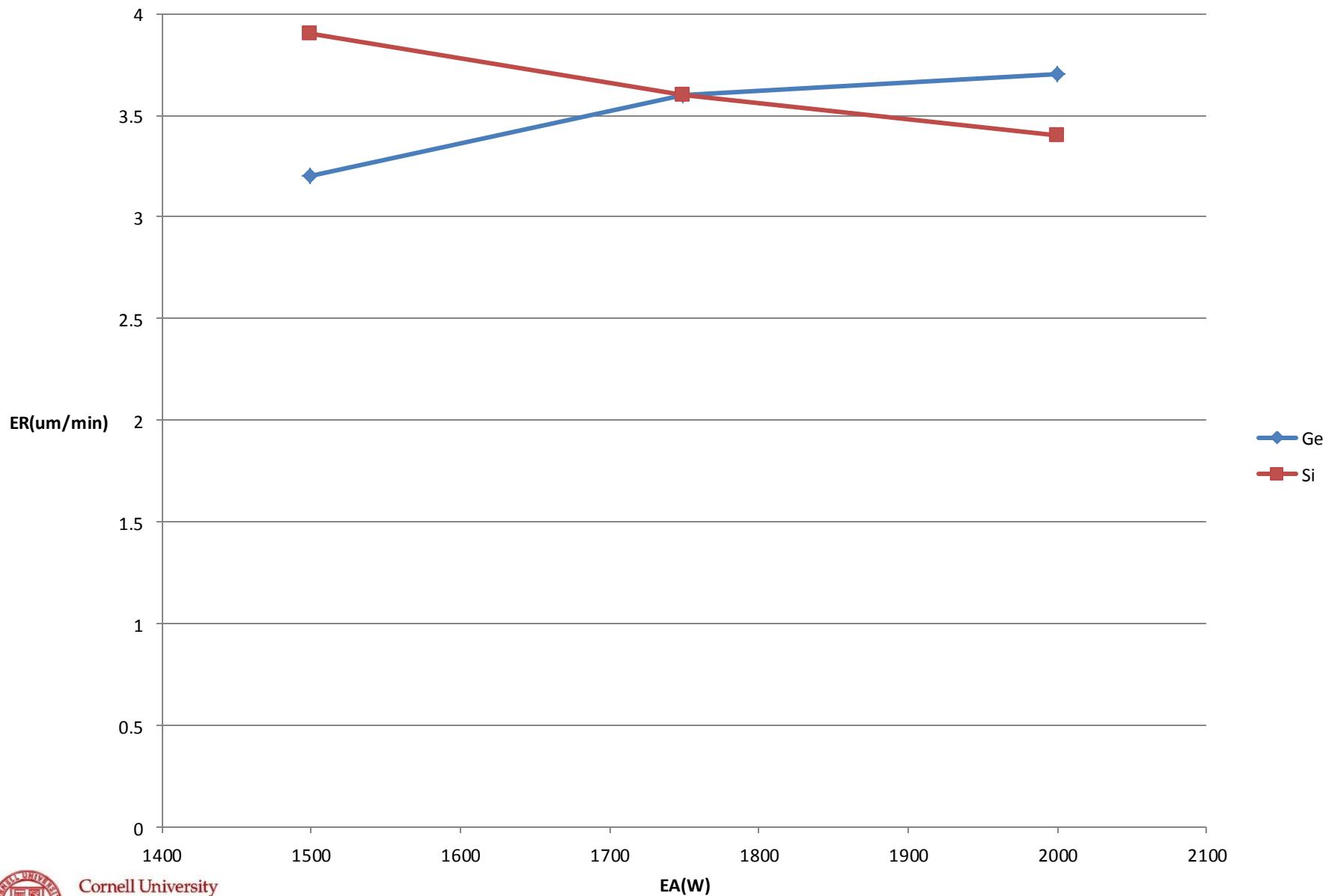
## DRIE-DOE-VP-P 40u



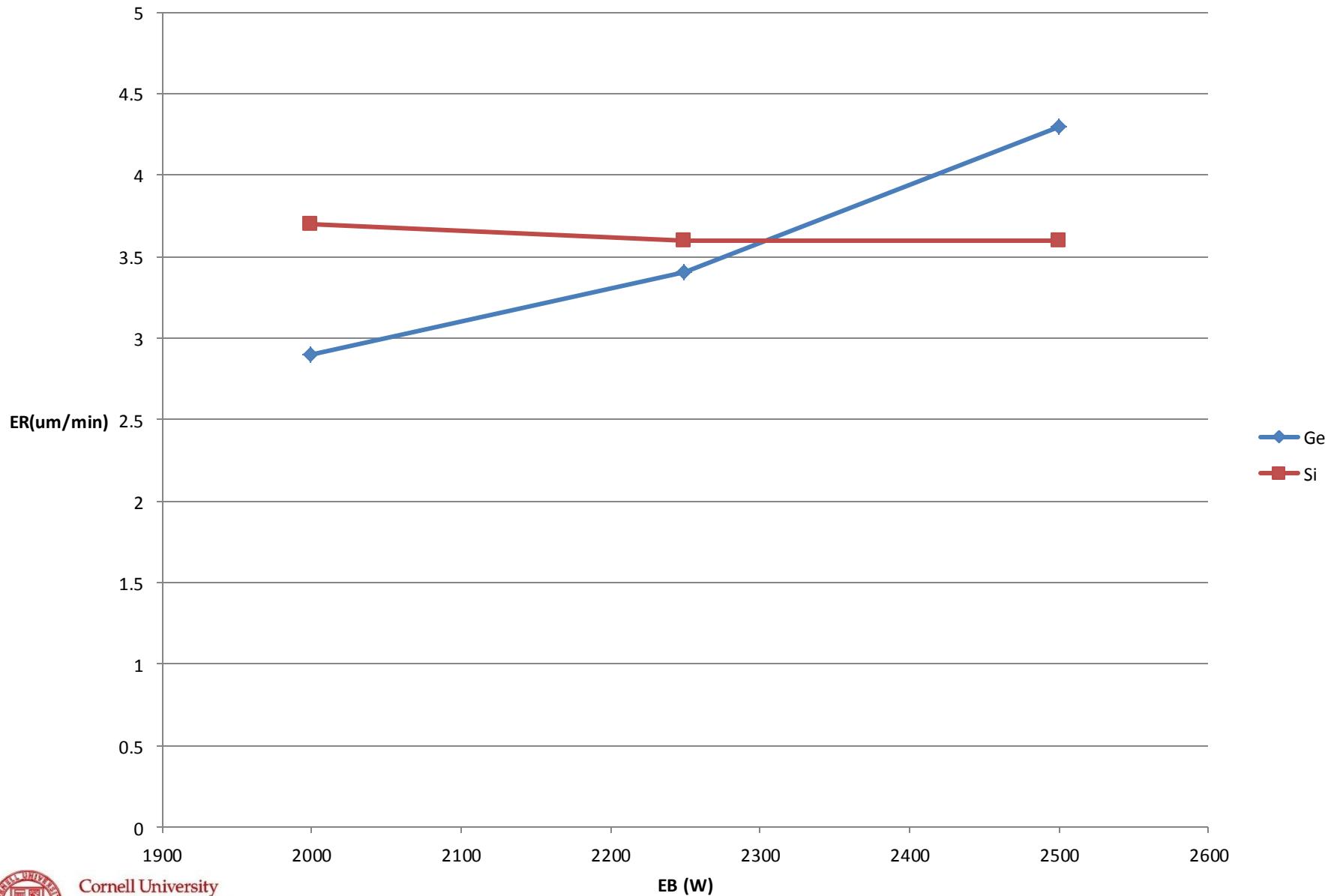
## DRIE-DOE-DEP W-4um



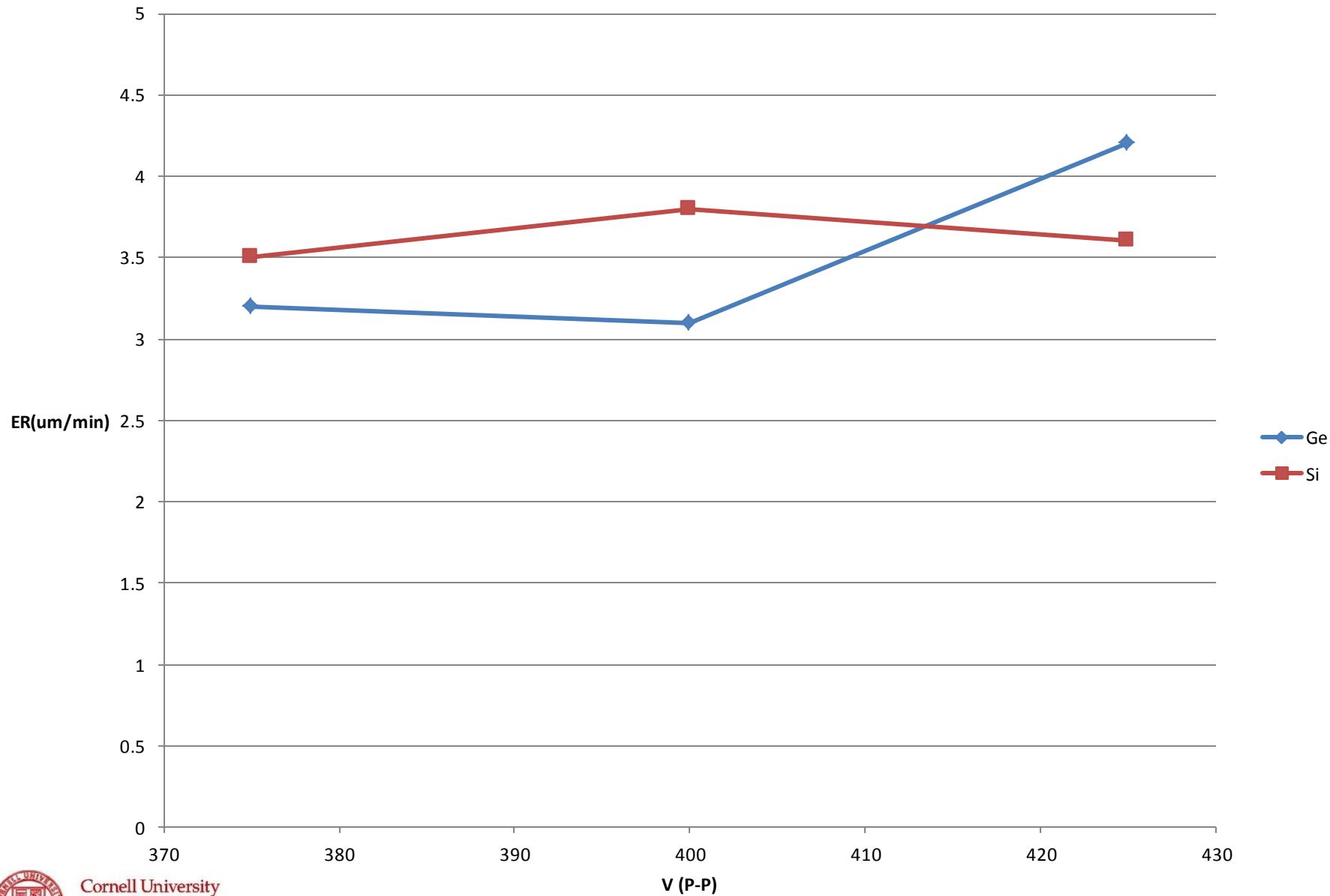
## DRIE DOE EA W-4μm



## DRIE DOE EB W-4um

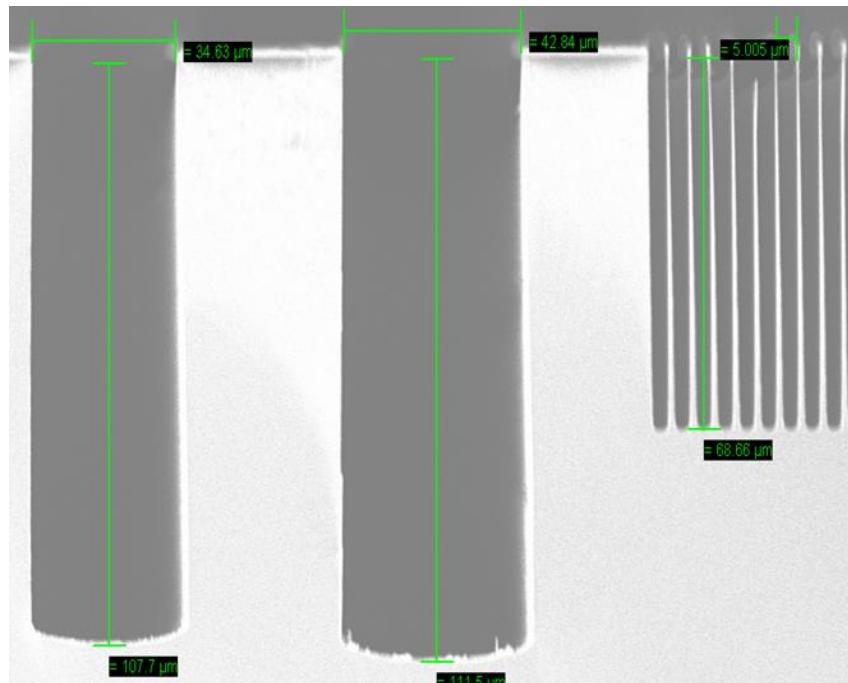


## DRIE DOE V(P-P)4um



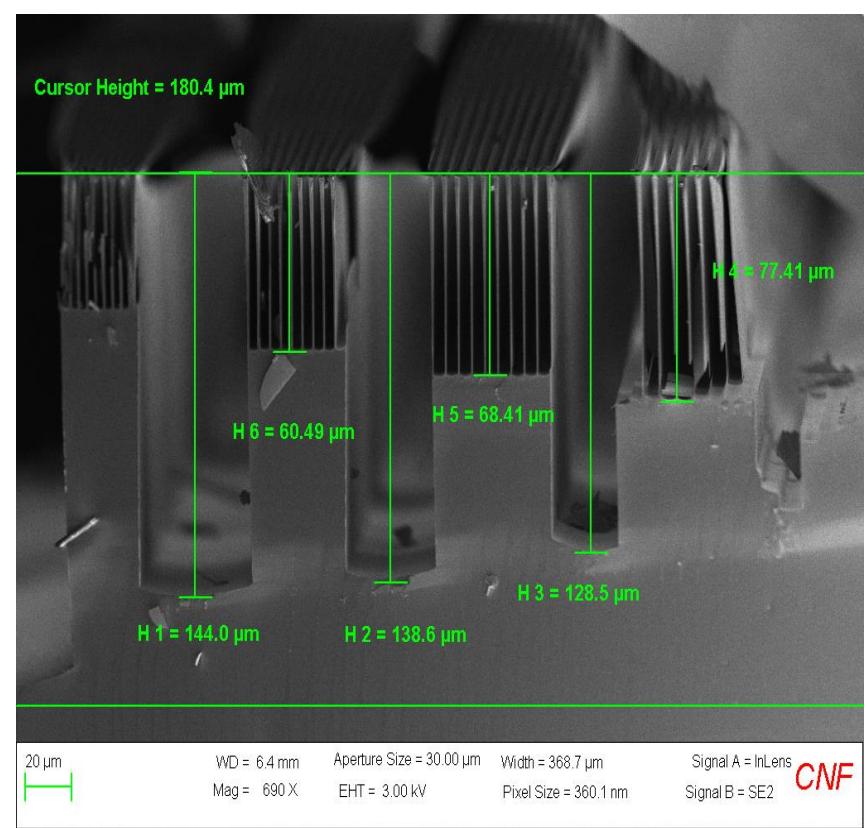
## Si vs. Ge DRIE

**Silicon-R5 PR: 40um gap → 115um, 5.1u/min  
4um gap → 69um, 3.5u/min, AR=17:1**



20  $\mu\text{m}$       EHT = 1.50 kV      Signal A = InLens  
WD = 4.0 mm      Photo No. = 11003      Date :24 Aug 2015  
Time :14:09:14      ZEISS

**Ge:R5 PR:40um gap → 144um, 7.2u/min  
4um gap → 60um, 3.4u/min, AR=15:1**



20  $\mu\text{m}$       WD = 6.4 mm      Aperture Size = 30.00  $\mu\text{m}$       Width = 368.7  $\mu\text{m}$   
Mag = 690 X      EHT = 3.00 kV      Pixel Size = 360.1 nm      Signal A = InLens  
Signal B = SE2      CNF

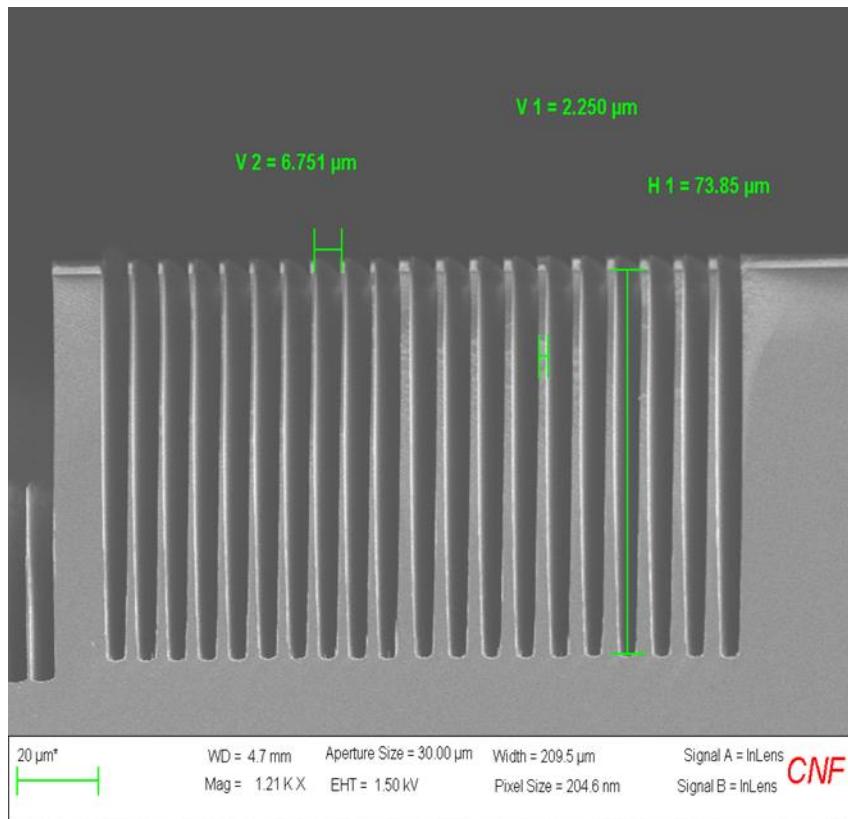


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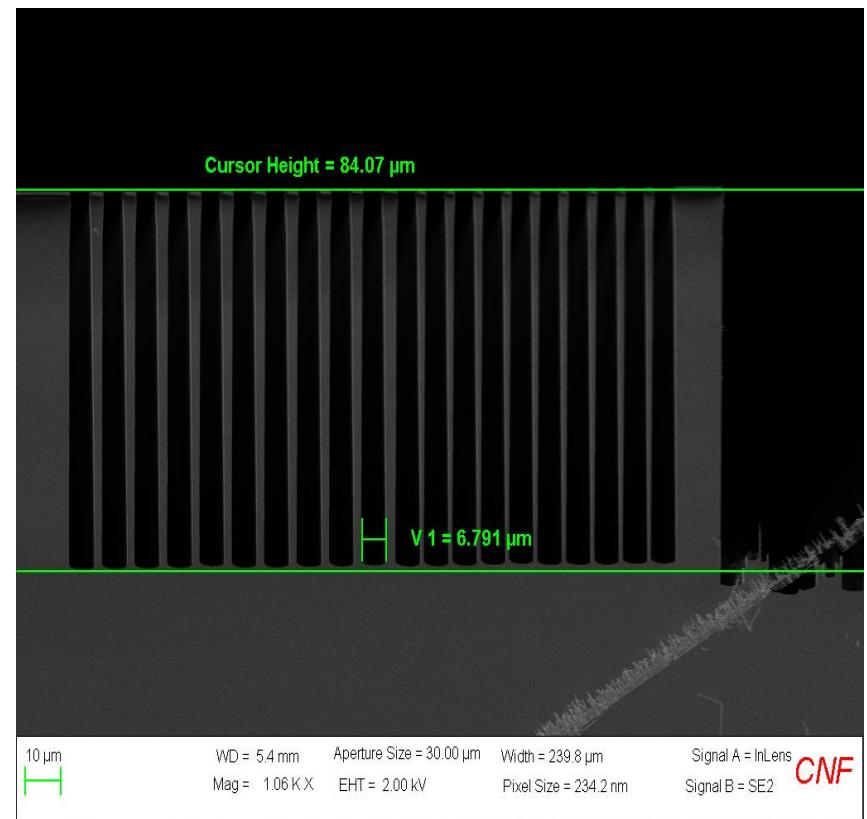
**CNF TCN, page 13**

## Si vs. Ge DRIE

**Silicon R8 PR: 6.7um gap → 74um, 3.7u/min  
AR=11:1**

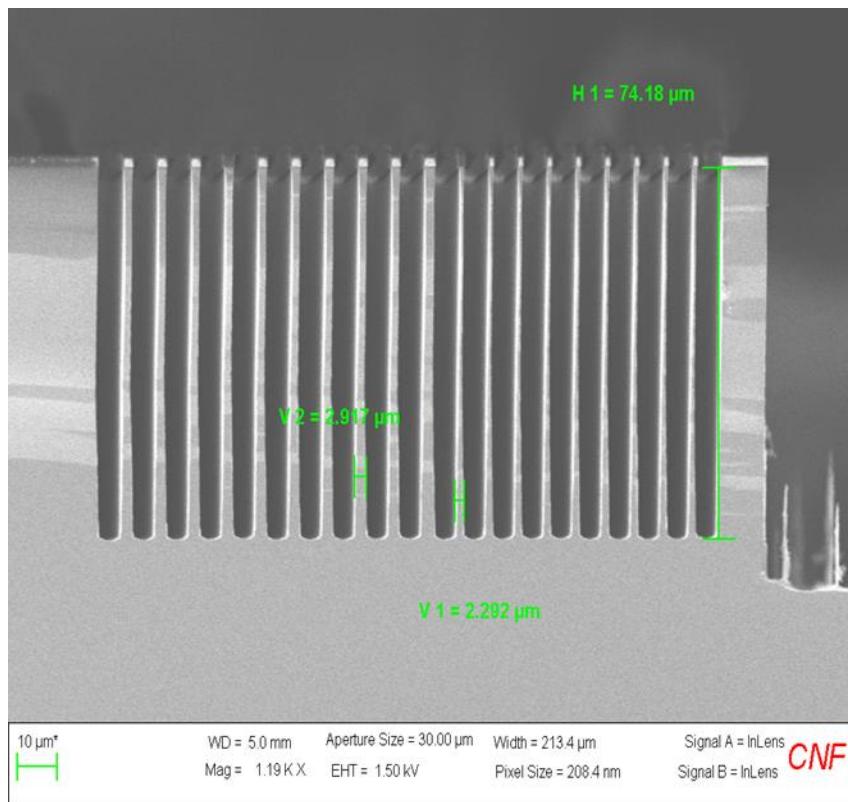


**Ge R8 PR: 6.7um gap → 84um, 4.2um/min  
AR=12:1**

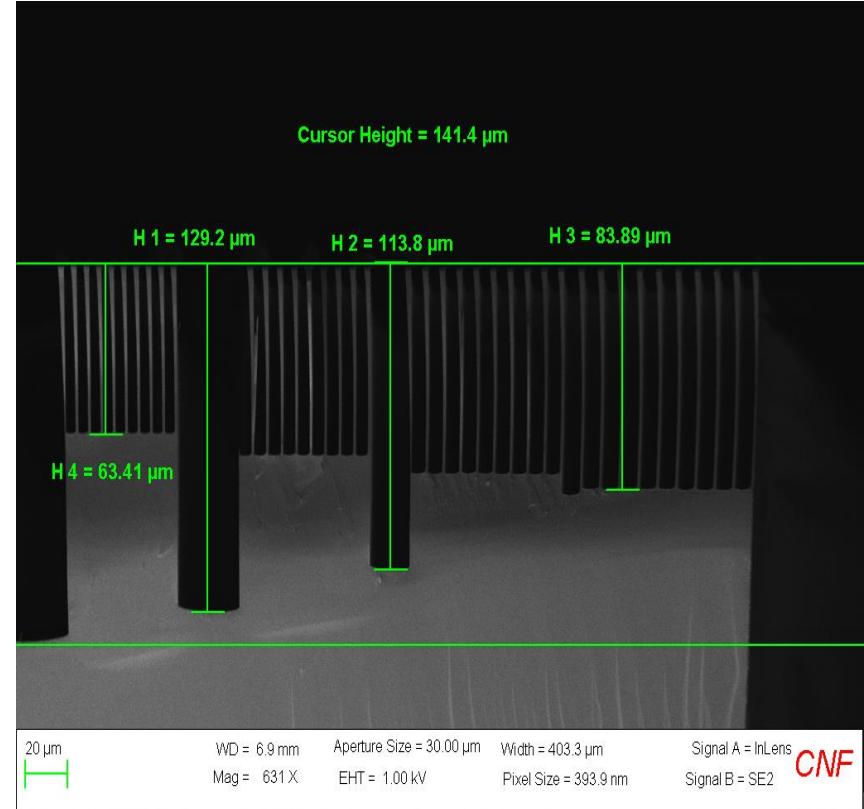


## Si vs. Ge DRIE

Si R9 PR: 5um gap → 74um, 3.7u/min  
AR=15:1

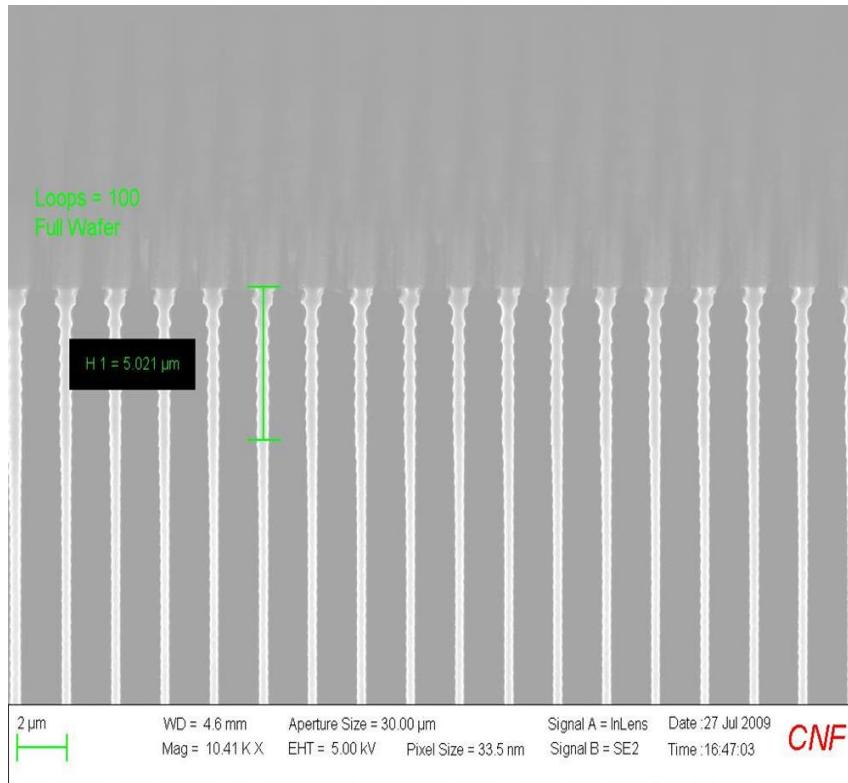


Ge R9 PR: 5um gap → 67um, 3.4u/min,  
AR=13.5:1

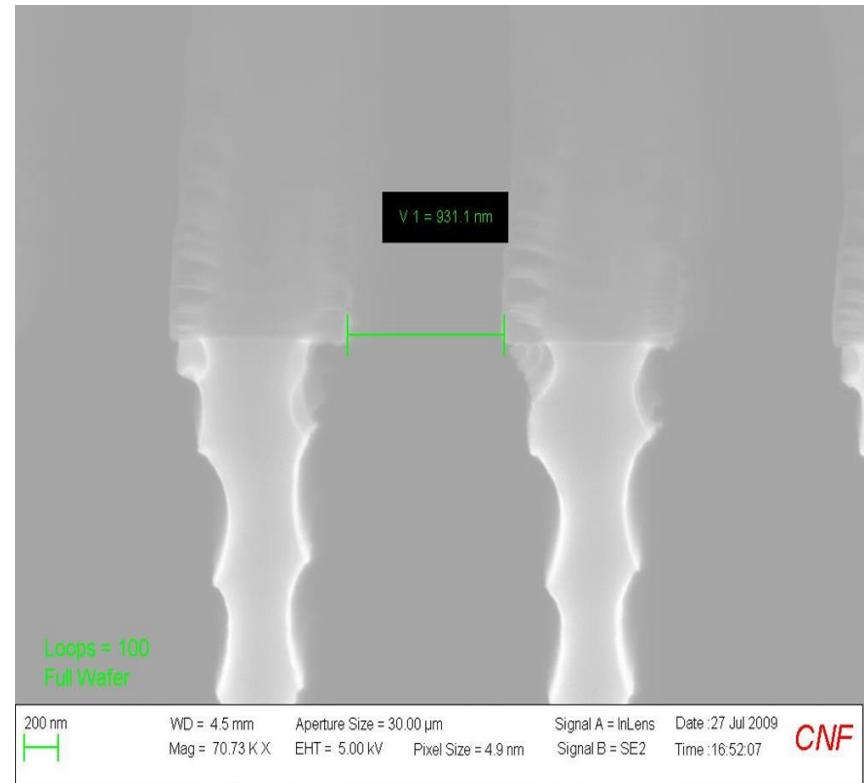


# Plasmatherm Versaline Silicon DRIE

Si DRIE-IAT-AS200-PR mask  
1um patterned on a 2um pitch



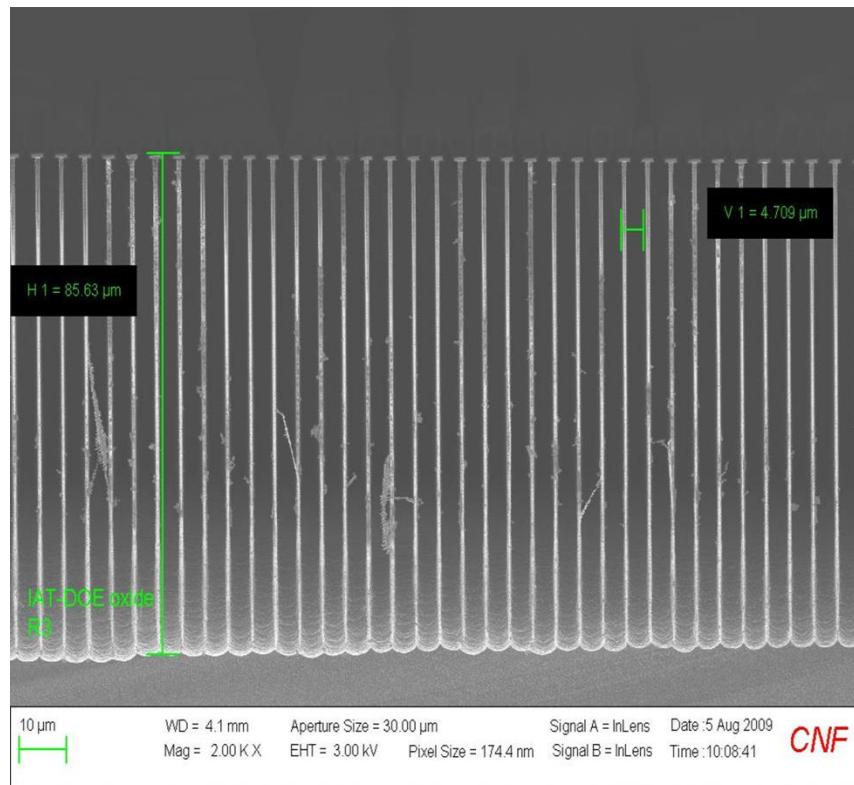
Si DRIE-IAT-AS200-PR mask  
1um patterned→300nm etched lines



# Plasmatherm Versaline Silicon DRIE

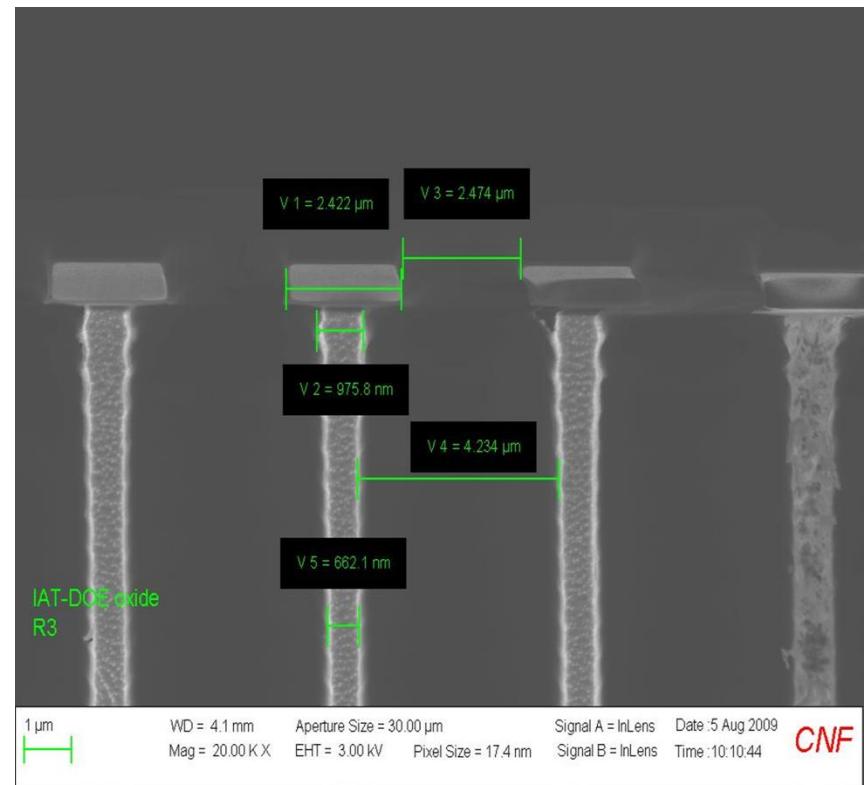
Si DRIE-SiO<sub>2</sub> mask

2.5um patterned lines, 86um deep, AR>34:1



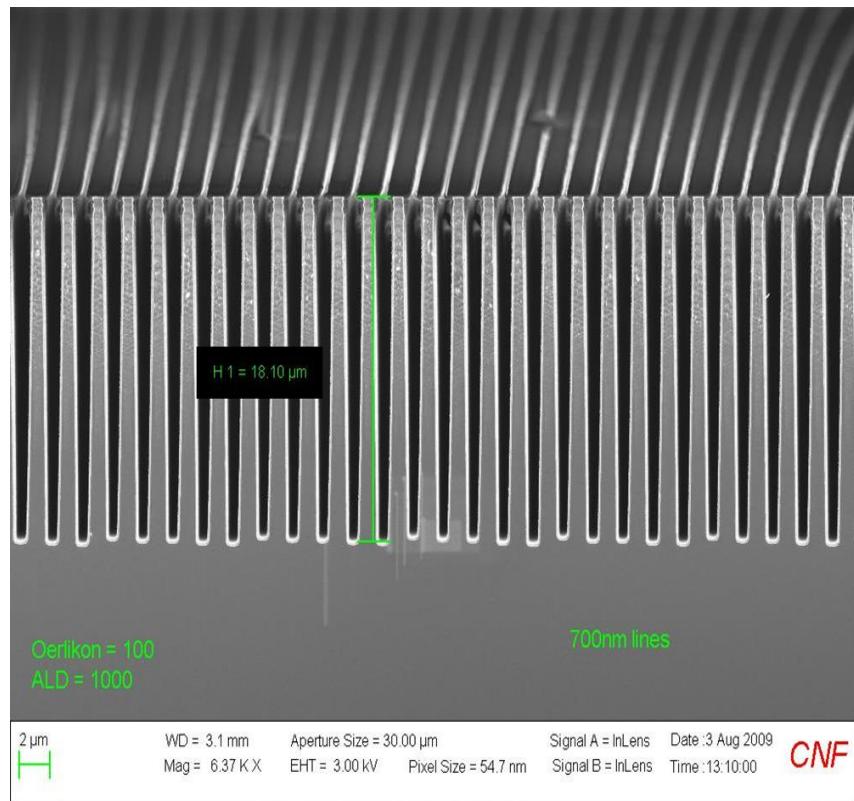
Si DRIE-SiO<sub>2</sub> mask-IAT

Actual etched linewidth=660nm

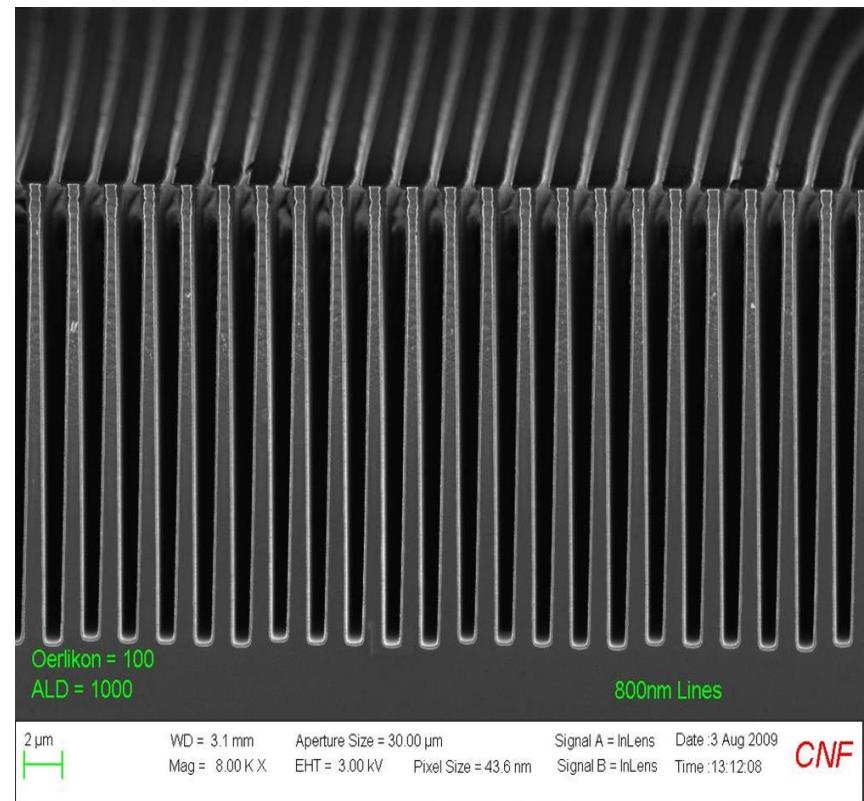


# **Plasmatherm Versaline Silicon DRIE**

**Si-700nm lines, 18um deep, 26:1 AR, 2.2u/min  
ALD Al<sub>2</sub>O<sub>3</sub> mask-15nm**

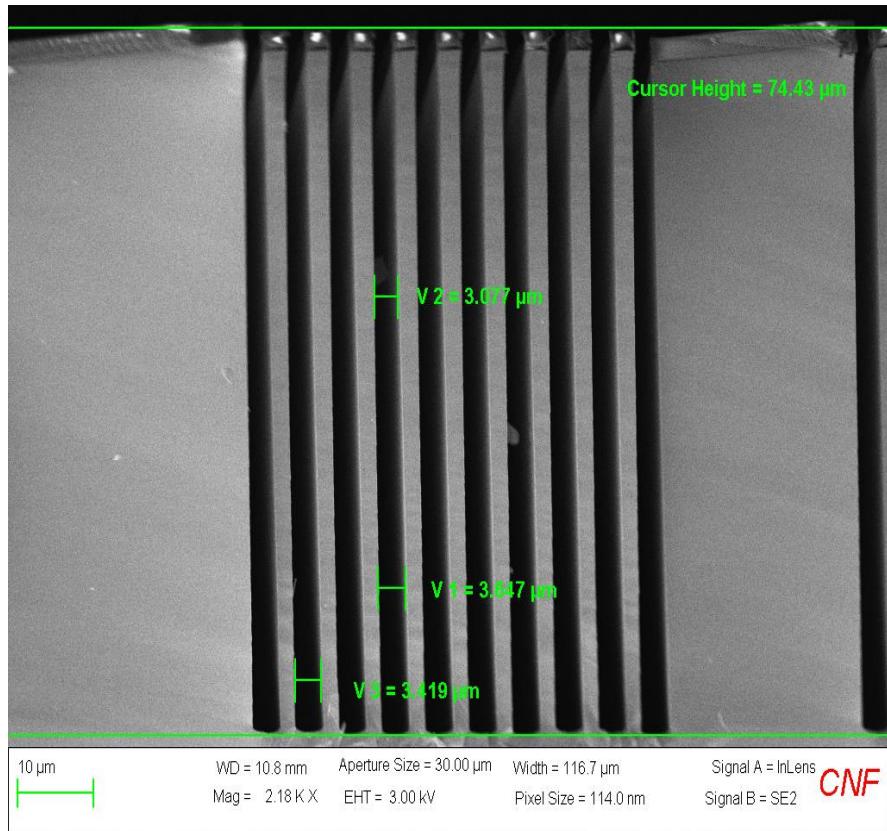


**Si-800nm lines, 18um deep, 23:1 AR, 2.2u/min  
ALD Al<sub>2</sub>O<sub>3</sub> mask-15nm**

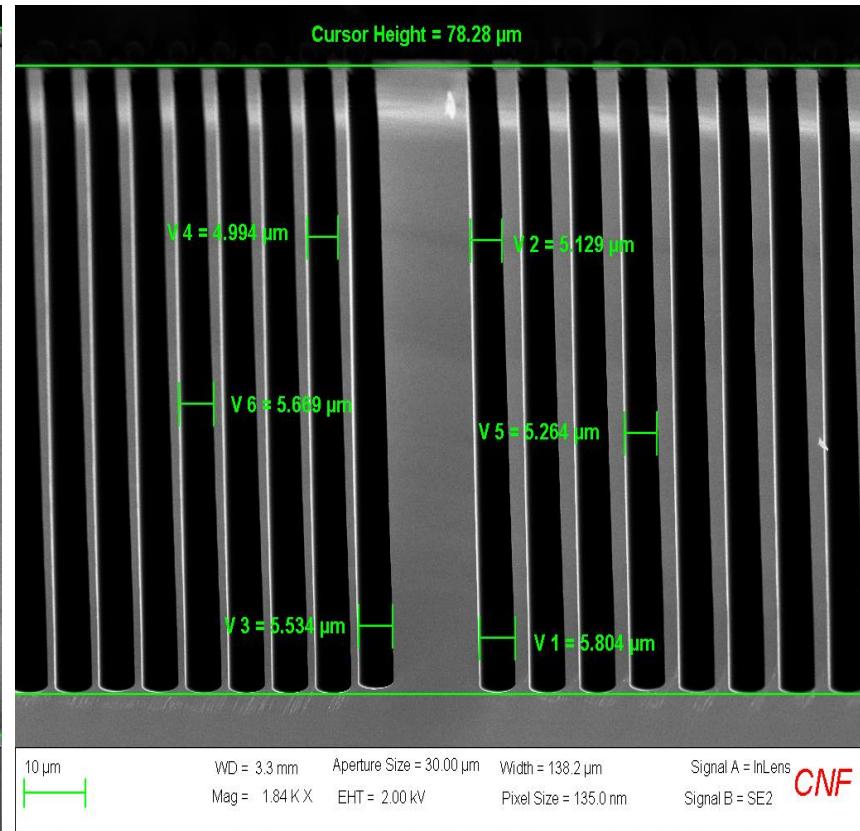


# Plasmatherm Versaline DRIE Germanium

Ge DRIE: PR mask-GKR-ASML  
R7-IAT DOE: 3.7um/min, 25:1 AR

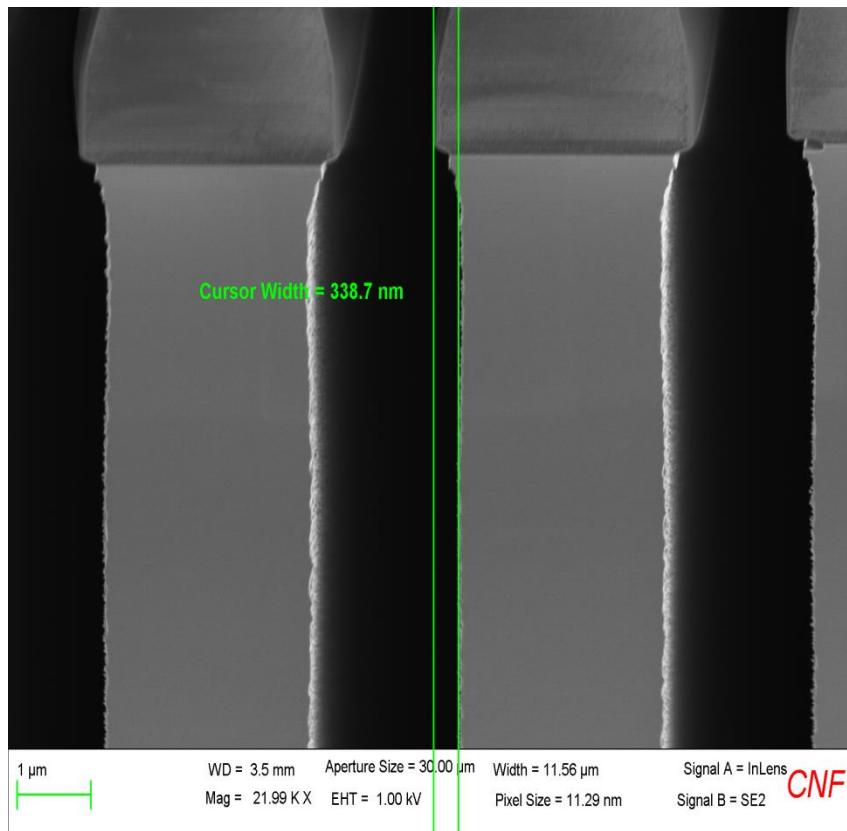


Ge DRIE: SiO<sub>2</sub> mask  
R5-IAT DOE: 3.9um/min, 16:1 AR

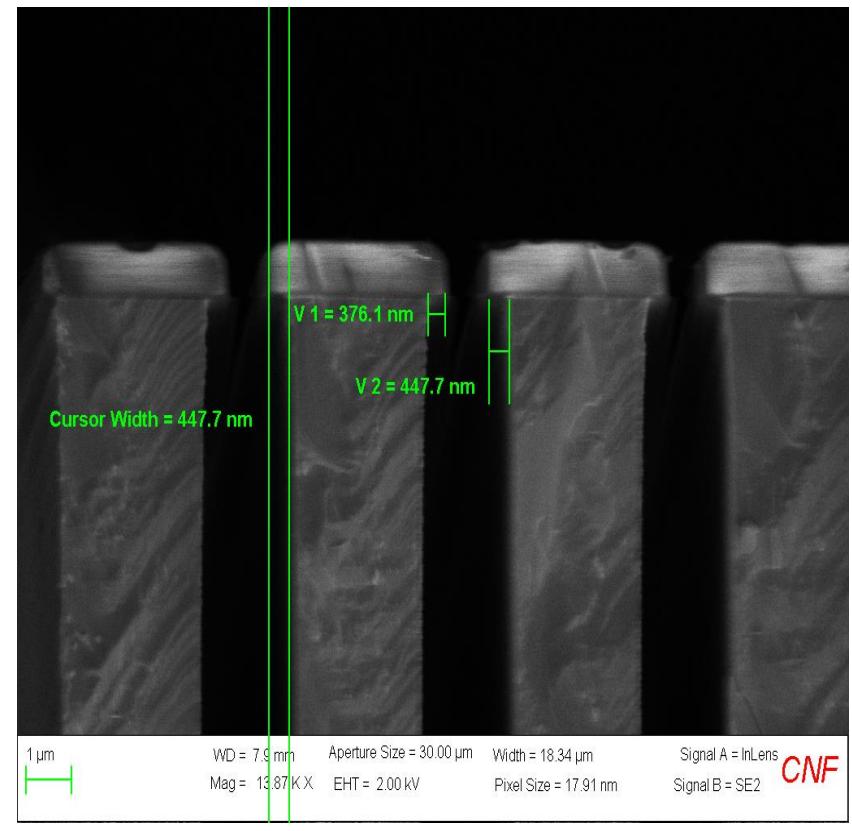


# **Plasmatherm Versaline Ge DRIE**

**Ge DRIE-R4-PR mask(GKR-ASML)**

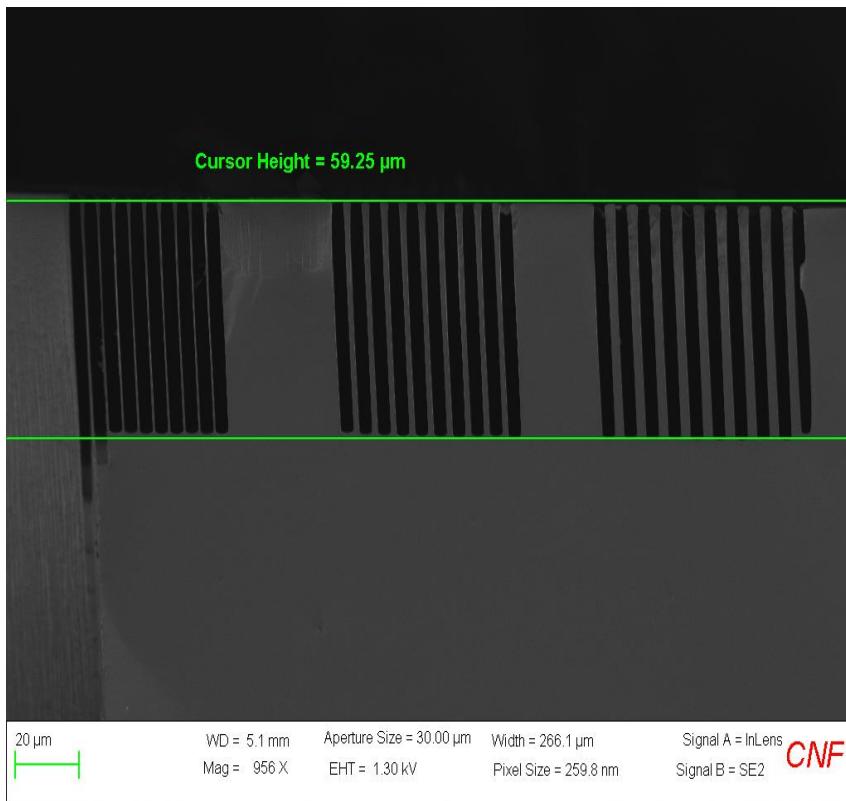


**Ge DRIE-R3-SiO<sub>2</sub> mask**

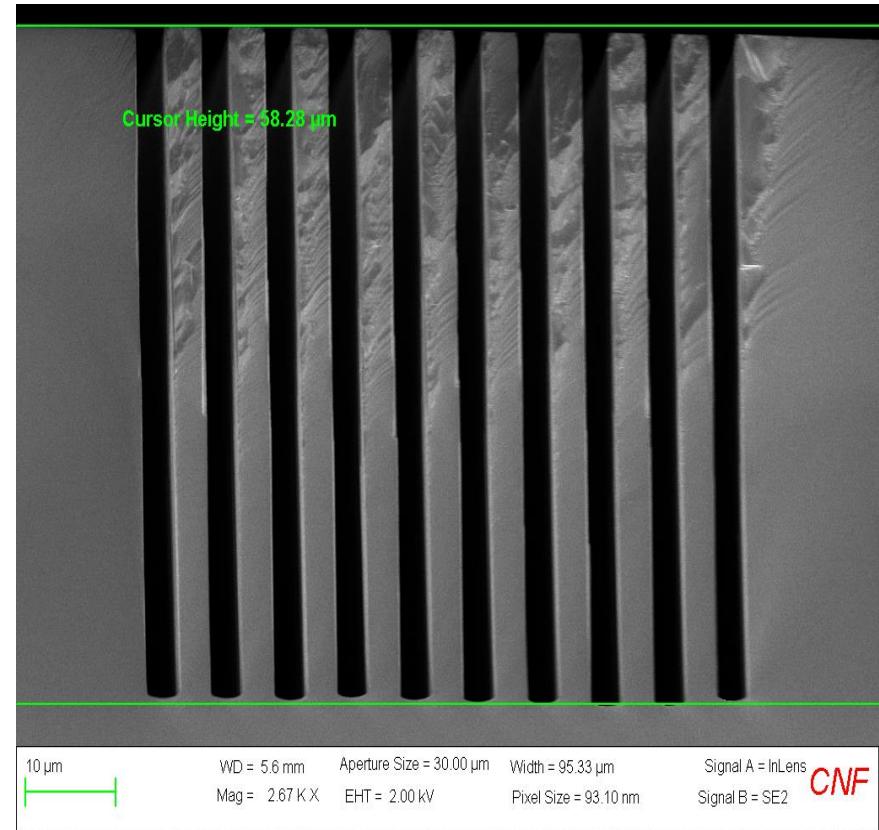


# **Plasmatherm Versaline Ge DRIE**

**Ge DRIE-Al<sub>2</sub>O<sub>3</sub> mask (70nm)-R2  
Minimal RIE lag**



**Ge-R1-Al<sub>2</sub>O<sub>3</sub> mask: 3.5u gaps, 17:1 AR,  
3u/min**



## Conclusions

- Etch rates of Ge exceed Si for large features and aspect ratios < 13:1
- Etch rates much closer for higher aspect ratios (> 13:1) with Si having somewhat higher ERs.
- Ions play a more significant role in high aspect features enhancing Si ERs.
- Thinner reactive etch layer on Ge and its higher reactivity leads to generally higher ERs.
- Lower Ge thermal conductivity yields higher surface mobility, F substitution of O, & desorption.
- Increased heating during the Ge etch also leads to thinner surface polymer, less tapering..
- Higher oxygen concentration at the Ge interface can also mitigate polymer deposition.
- Thinner and more permeable sidewall inhibitor on the Ge perhaps leads to reduced scalloping and a higher sticking coefficient of atomic F may also contribute to sidewall smoothing.

