A decade of EUV resist outgas testing – Lessons learned

C. Tarrio, S. B. Hill, R. F. Berg, T. B. Lucatorto
NIST, Gaithersburg, MD, USA

Outline

A little history

Recent round-robin witness-sample testing results

Critical issues

How RR results have been improved

A little history

Early work:

Earliest lifetime testing was done to aid development of oxidation-resistant cap layers

Outgassing testing done to qualify resists for ADT

Measure and analyze resist outgassing

Then perform "accelerated" testing by admitting molecules observed in the outgas

A little history

Outgas measurement:

Original outgassing intercomparison (K. R. Dean, EUVLS 2007)

Eight laboratories, several methods, 4 orders of magnitude disagreement

NIST developed a new two-step method

Subsequent intercomparison in 2009, agreement within about 30% among 3-4 labs.

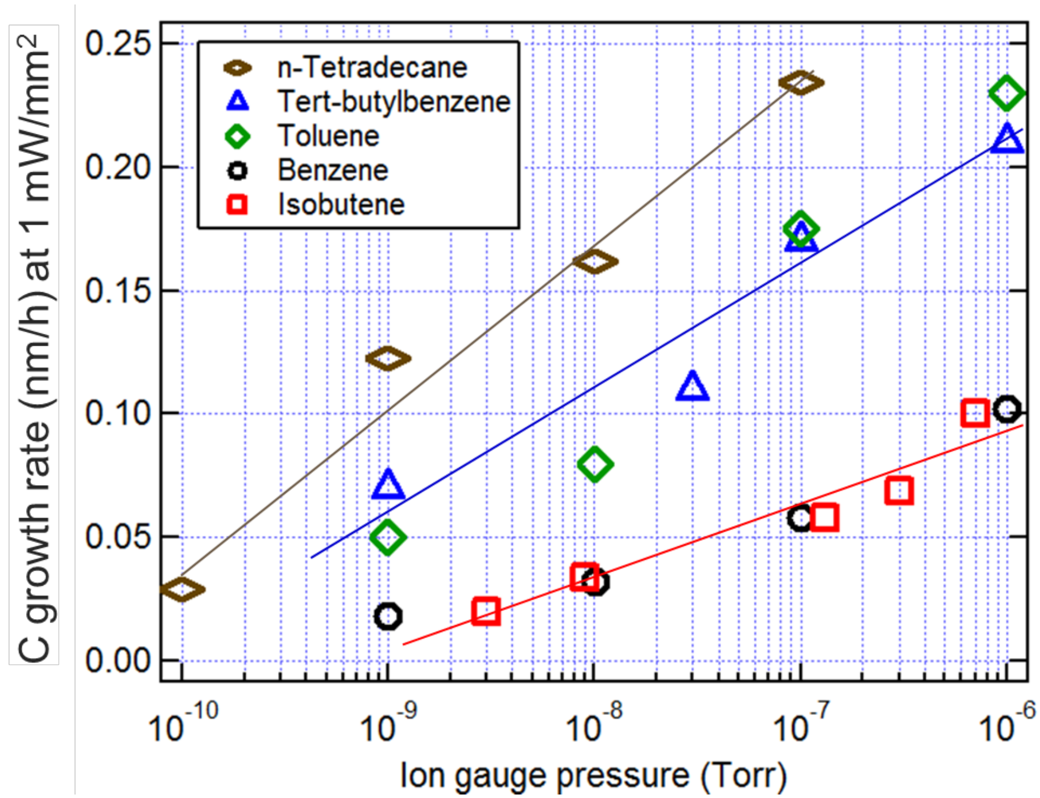
A little history

Accelerated testing feasible?

Large, low-VP molecules probably responsible for most damage

Sub-linear (quasi-log) scaling of carbon growth rate with pressure

Linear pressure scaling only observed for “mass limited” growth

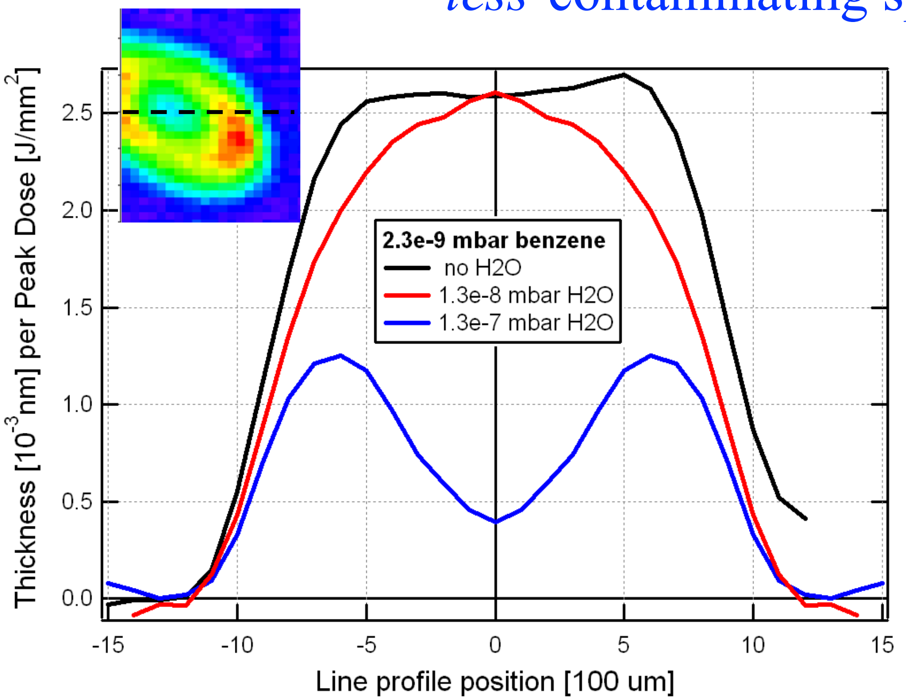


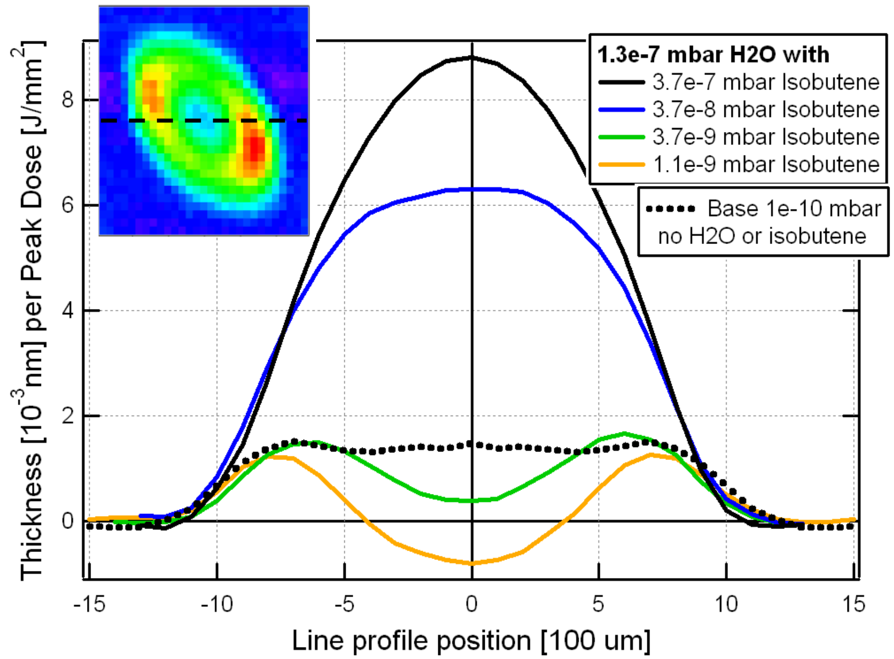
Hill et al., SPIE 2010

A little history

Effect of water admixture on contamination:

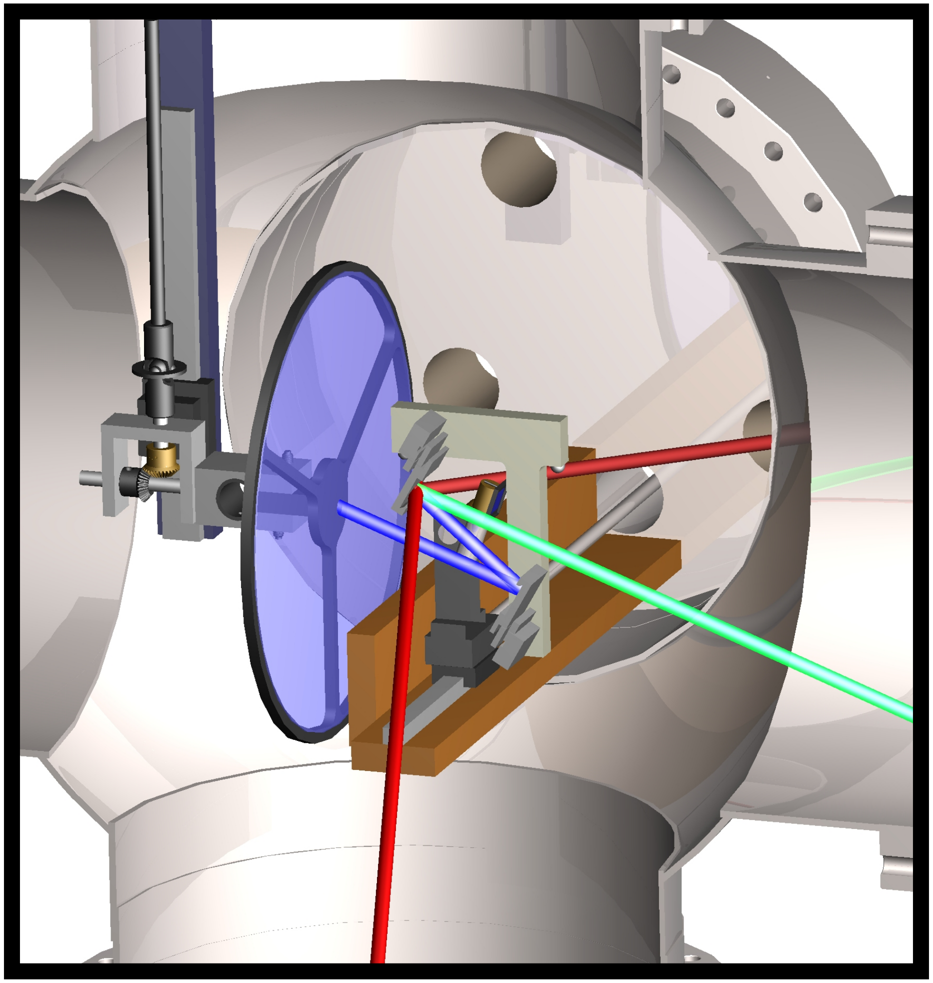
less-contaminating species (benzene, isobutene)





- Water has strong effect on benzene & isobutene contamination at low pressures
- Complex shape across Gaussian EUV intensity distribution of exposure beam is consistent with intensity scaling that is linear for cleaning but saturated for carbon growth.

2007(!): ASML proposes witness-sample testing



1) Measure resist E_0

2) Expose wafer to E_0 in 1 hour

3) Measure carbon growth (CG) with spectroscopic ellipsometry

4) Clean CG with atomic H

5) Measure residuals with XPS

Witness-sample testing

Early work done by TNO and ASML

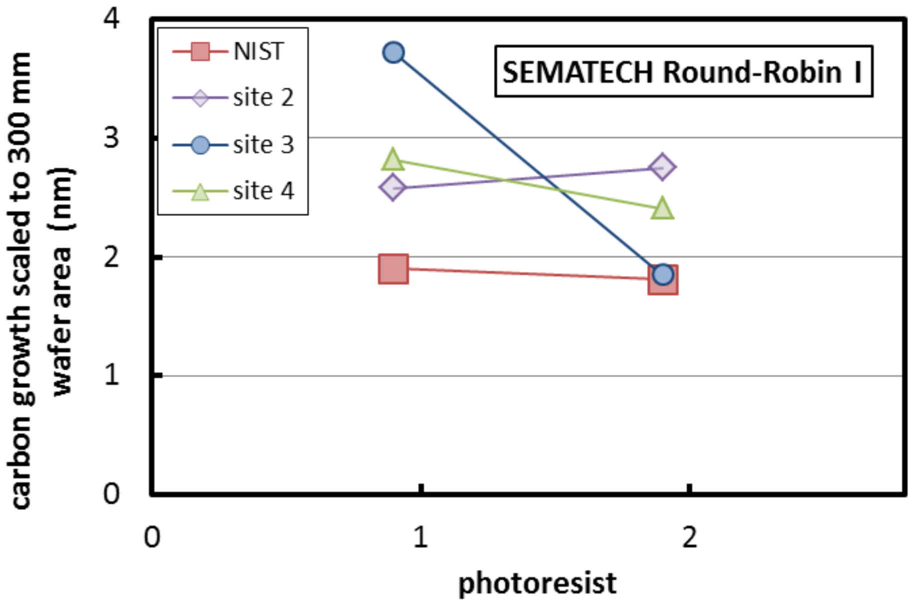
NIST commissioned the first publically available facility certified by ASML in early 2011

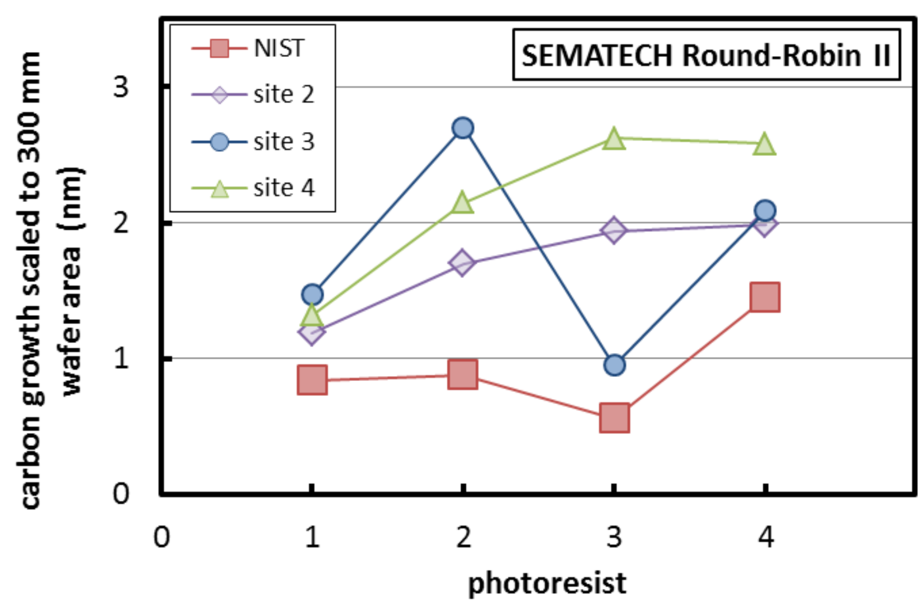
NIST is the only all-EUV facility

Each site tests several initial resists. Scale factor has been chosen for each site to scale its results to NIST

Sematech outgas testing Round Robins

Organized by Karen Petrillo and Jaewoong Sohn, Sematech





Only sites 2 and 4 showed similar trends in Round Robin II

NIST values consistently lower than others in both Round Robin I & II

Potential systematic effects in CG measurements

Chamber geometry: Chamber shape, size, and pumping speed certainly affect carbon growth. This is included in the site scale factor, but could be resist dependent. In a limited set of resists, we've demonstrated that CG is inversely proportional to pumping speed, but again, this could be resist-dependent.

Ambiguity in interpreting SE measurements: Although different laboratories use different methods to analyze data, those should all normalize out. Variations in the thickness profiles across the resists in different laboratories was consistent – degree of saturation, etc.

Temperature: NIST climate control was not able to keep up with some VERY cold weather. We found a large effect of temperature on some resists and corrected data for this effect. This may introduce errors because facility scale factors assume there is no temperature dependence.

Interpreting E0 measurements (esp. in e-beam systems): Large dependence on dose has been observed in one resist. This is inconsistent with previous measurements.

Potential systematic effects in CG measurements

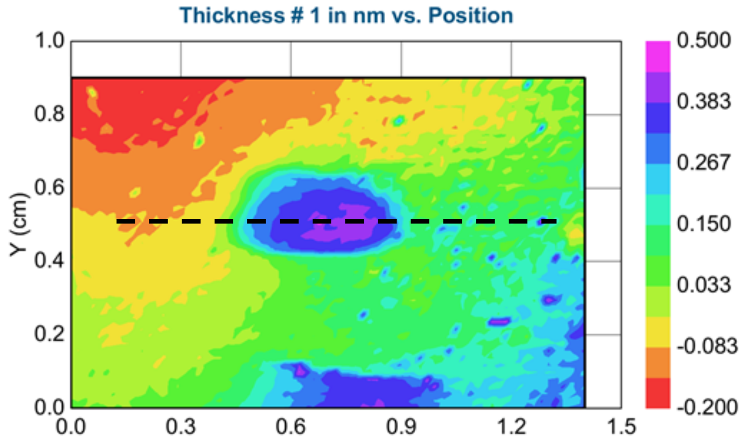
Chamber geometry: Chamber shape, size, and pumping speed certainly affect carbon growth. This is included in the site scale factor, but could be resist dependent. In a limited set of resists, we've demonstrated that CG is inversely proportional to pumping speed, but again, this could be resist-dependent.

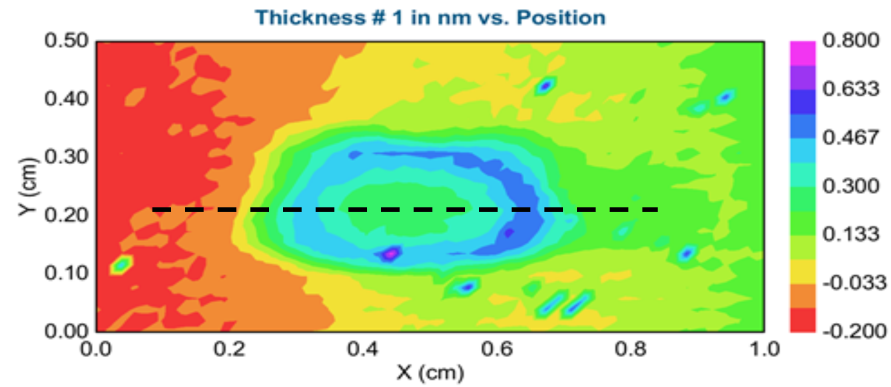
Ambiguity in interpreting SE measurements: Although different laboratories use different methods, those should all normalize out. Thickness profile in different laboratories was consistent – degree of saturation, etc.

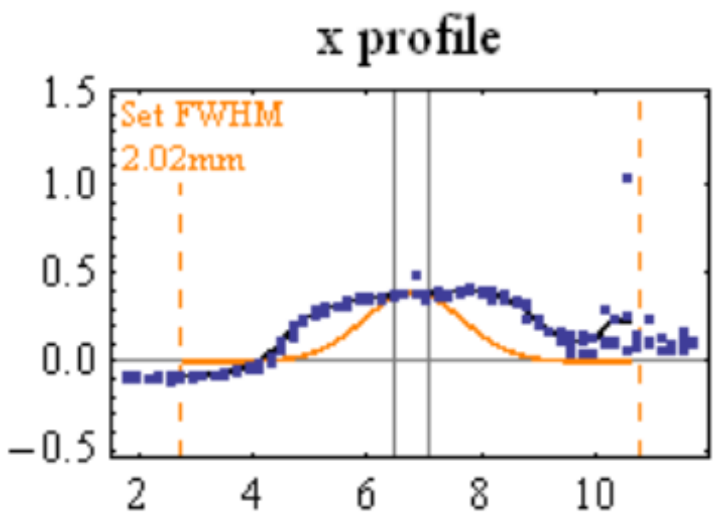
Temperature: NIST climate control was not able to keep up with some VERY cold weather. We found a large effect of temperature on some resists and corrected data for this effect. This may add uncertainty in the scale factor between laboratories that is temperature/resist dependent.

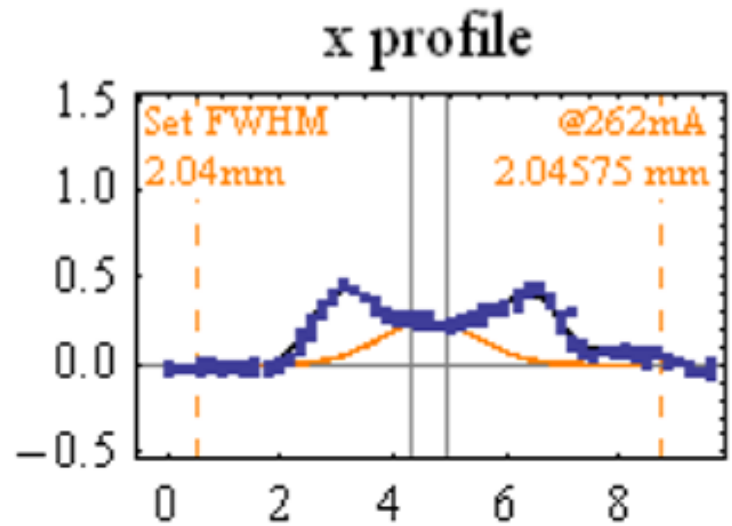
Interpreting E0 measurements (esp. in e-beam systems): Large dependence on dose has been observed in one resist. This is inconsistent with previous measurements.

CG profiles – thickness measured in center for all runs
Different runs may exhibit different degrees of saturation









same carbon growth, very different profiles

Potential systematic effects in CG measurements

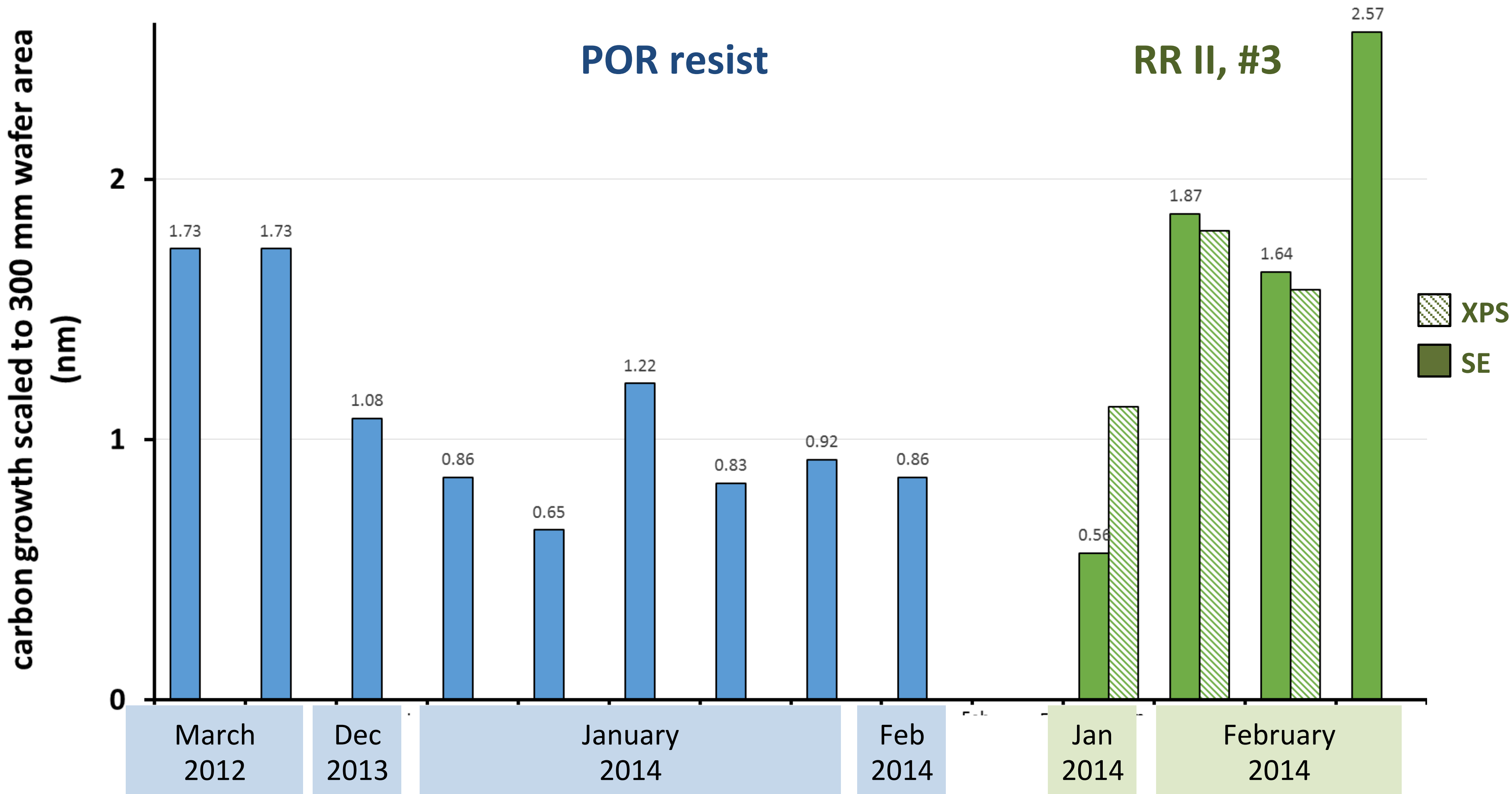
Chamber geometry: Chamber shape, size, and pumping speed certainly affect carbon growth. This is included in the site scale factor, but could be resist dependent. In a limited set of resists, we've demonstrated that CG is inversely proportional to pumping speed, but again, this could be resist-dependent.

Ambiguity in interpreting SE measurements: Although different laboratories use different methods, those should all normalize out. Thickness profile in different laboratories was consistent – degree of saturation, etc.

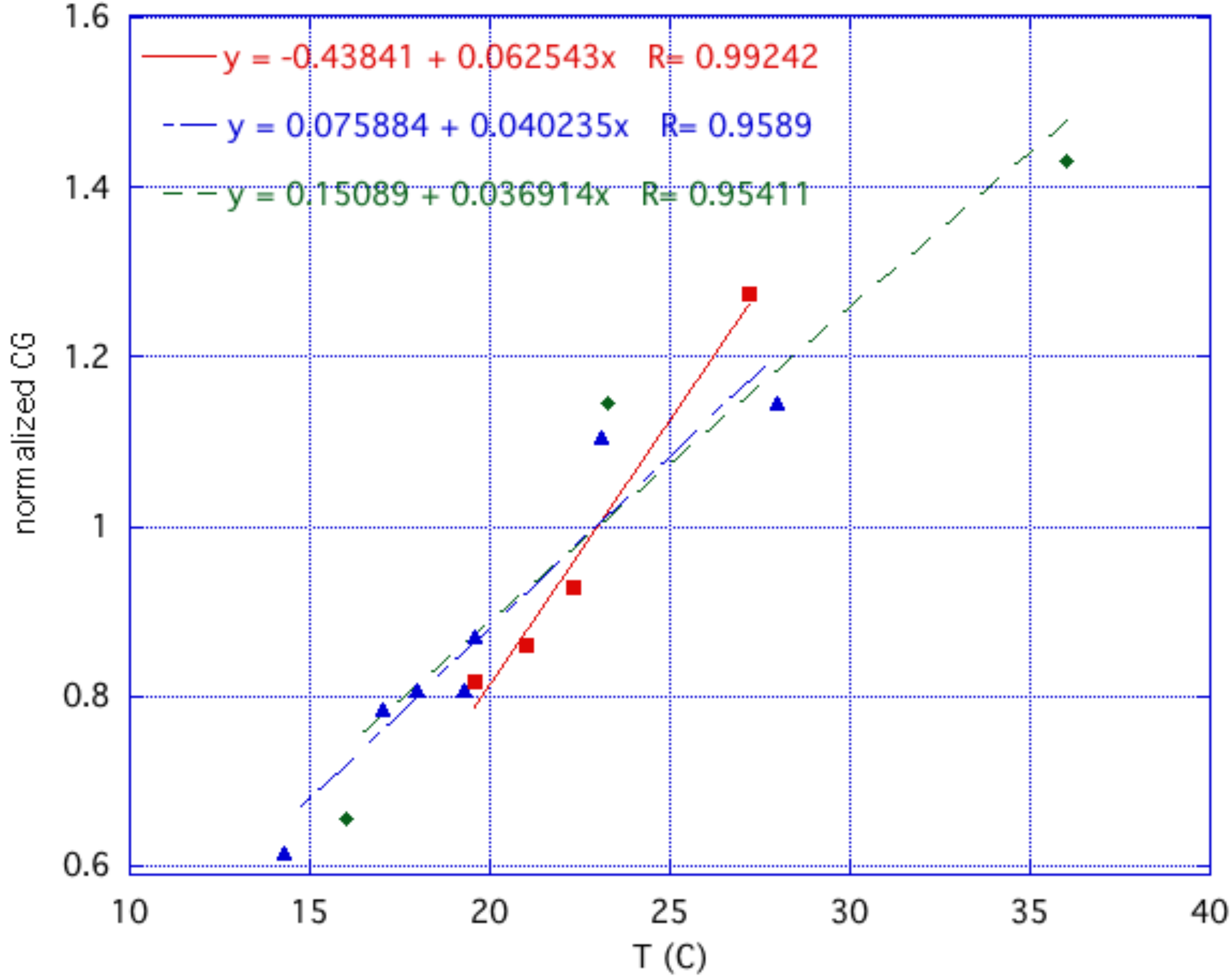
Temperature: NIST climate control was not able to keep up with some VERY cold weather. We found a large effect of temperature on some resists and corrected data for this effect. This may add uncertainty in the scale factor between laboratories that is temperature/resist dependent.

Interpreting E0 measurements (esp. in e-beam systems): Large dependence on dose has been observed in one resist. This is inconsistent with previous measurements.

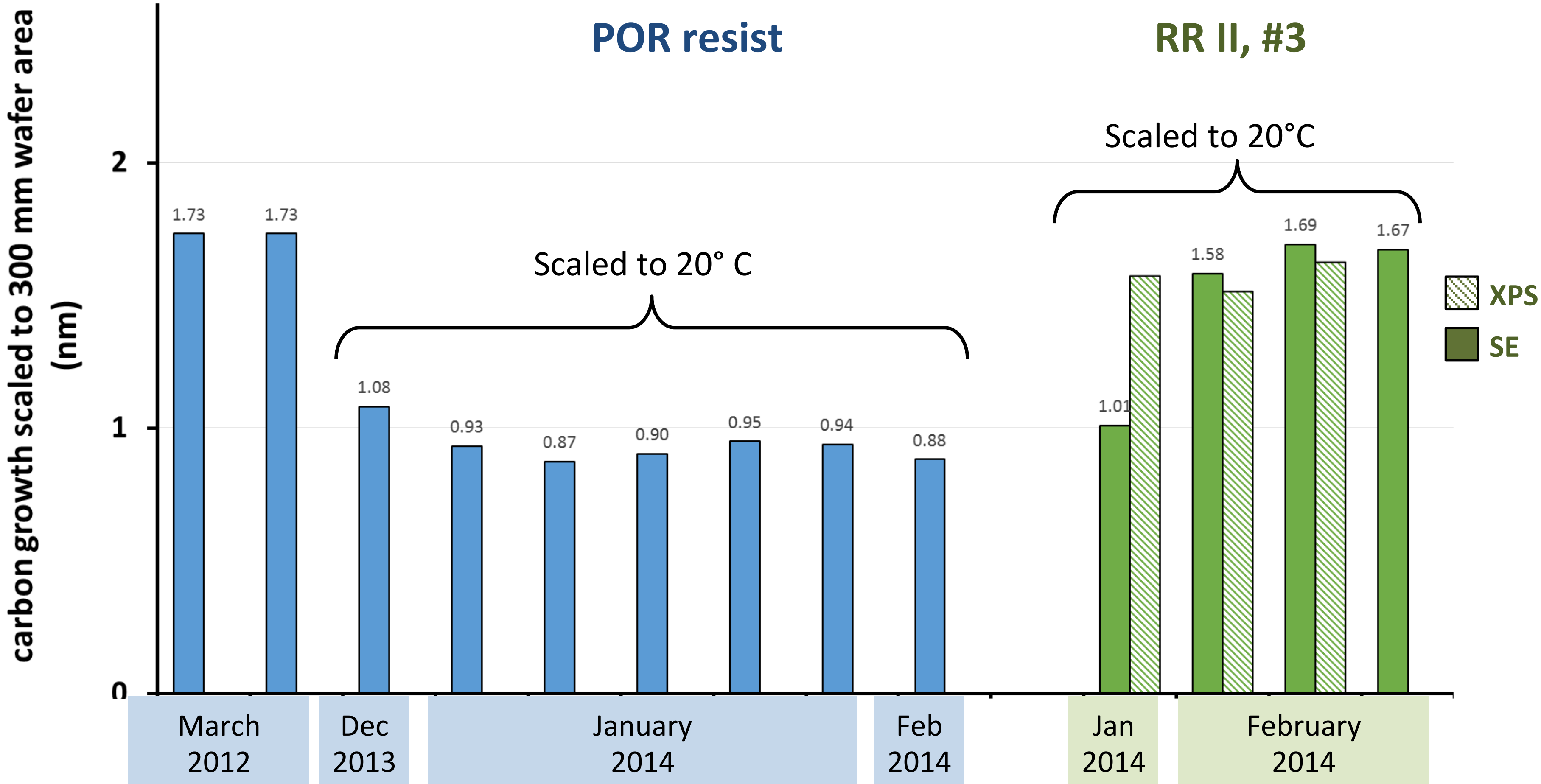
Poor repeatability of original data



temperature dependence of CG



Correcting for ±3° C variation improves repeatability



Temperature control can be extremely important for some resists

Feedback control of chamber temperature being implemented at NIST

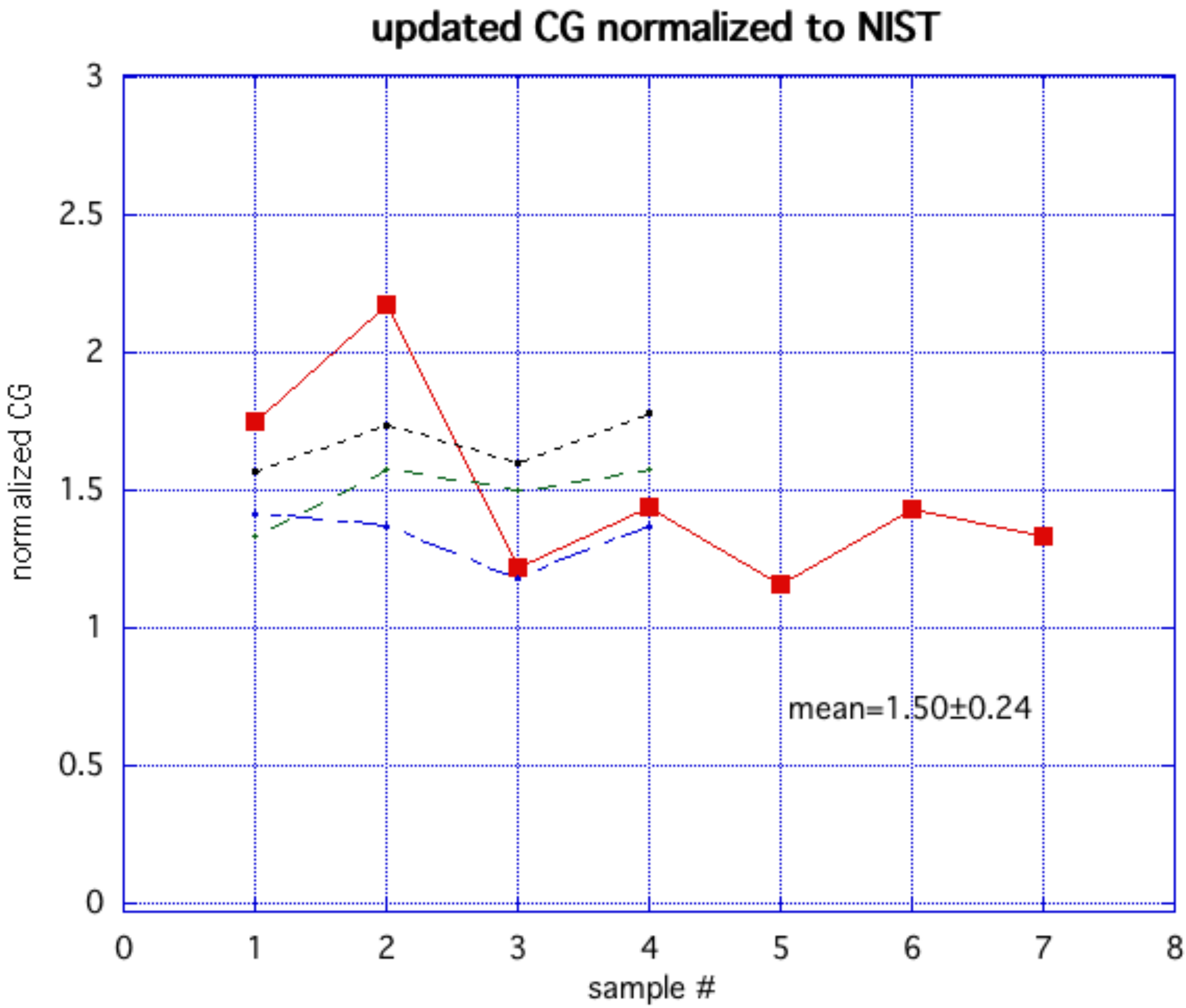
Potential systematic effects in CG measurements

Chamber geometry: Chamber shape, size, and pumping speed certainly affect carbon growth. This is included in the site scale factor, but could be resist dependent. In a limited set of resists, we've demonstrated that CG is inversely proportional to pumping speed, but again, this could be resist-dependent.

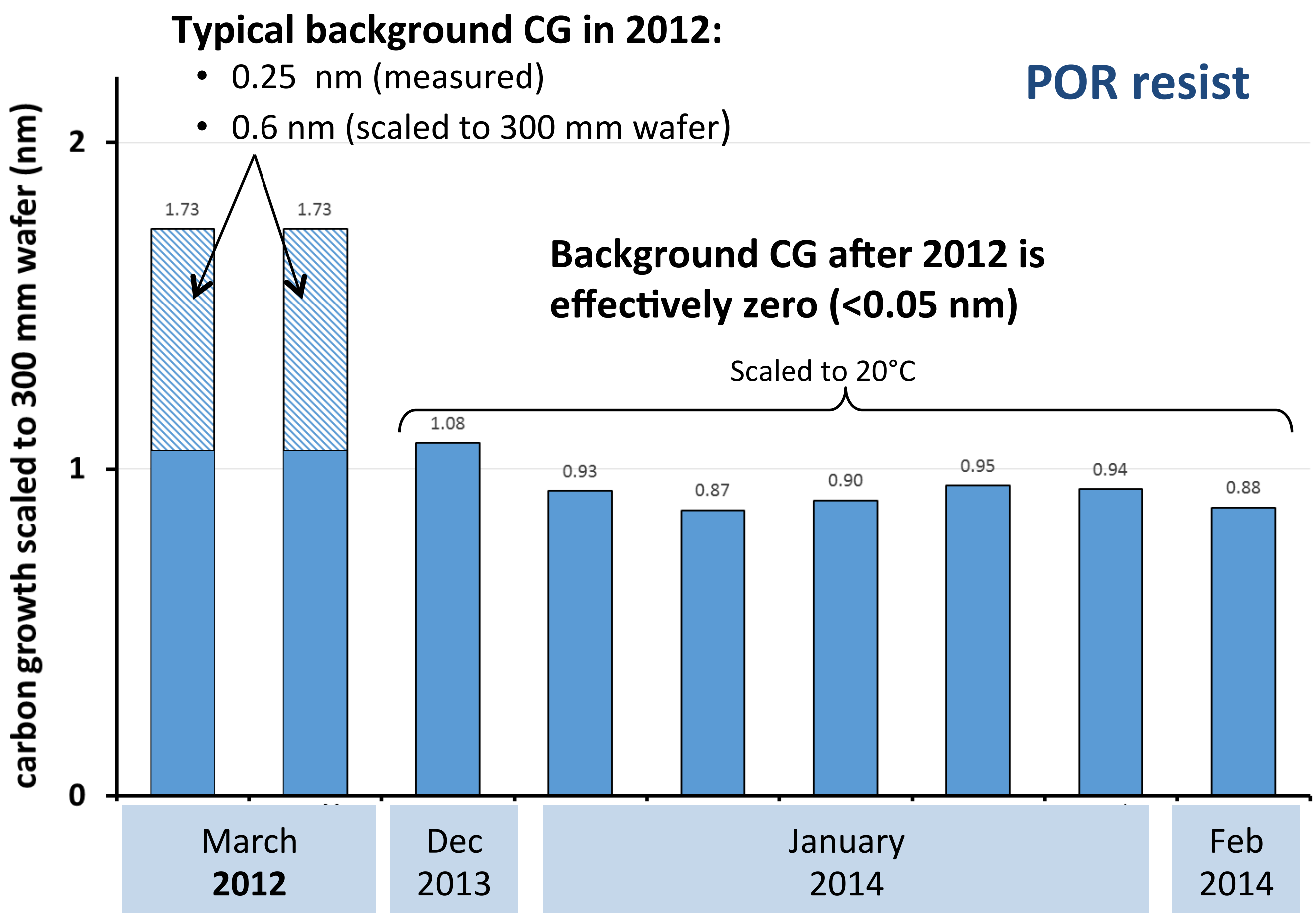
Ambiguity in interpreting SE measurements: Although different laboratories use different methods, those should all normalize out. Thickness profile in different laboratories was consistent – degree of saturation, etc.

Temperature: NIST climate control was not able to keep up with some VERY cold weather. We found a large effect of temperature on some resists and corrected data for this effect. This may add uncertainty in the scale factor between laboratories that is temperature/resist dependent.

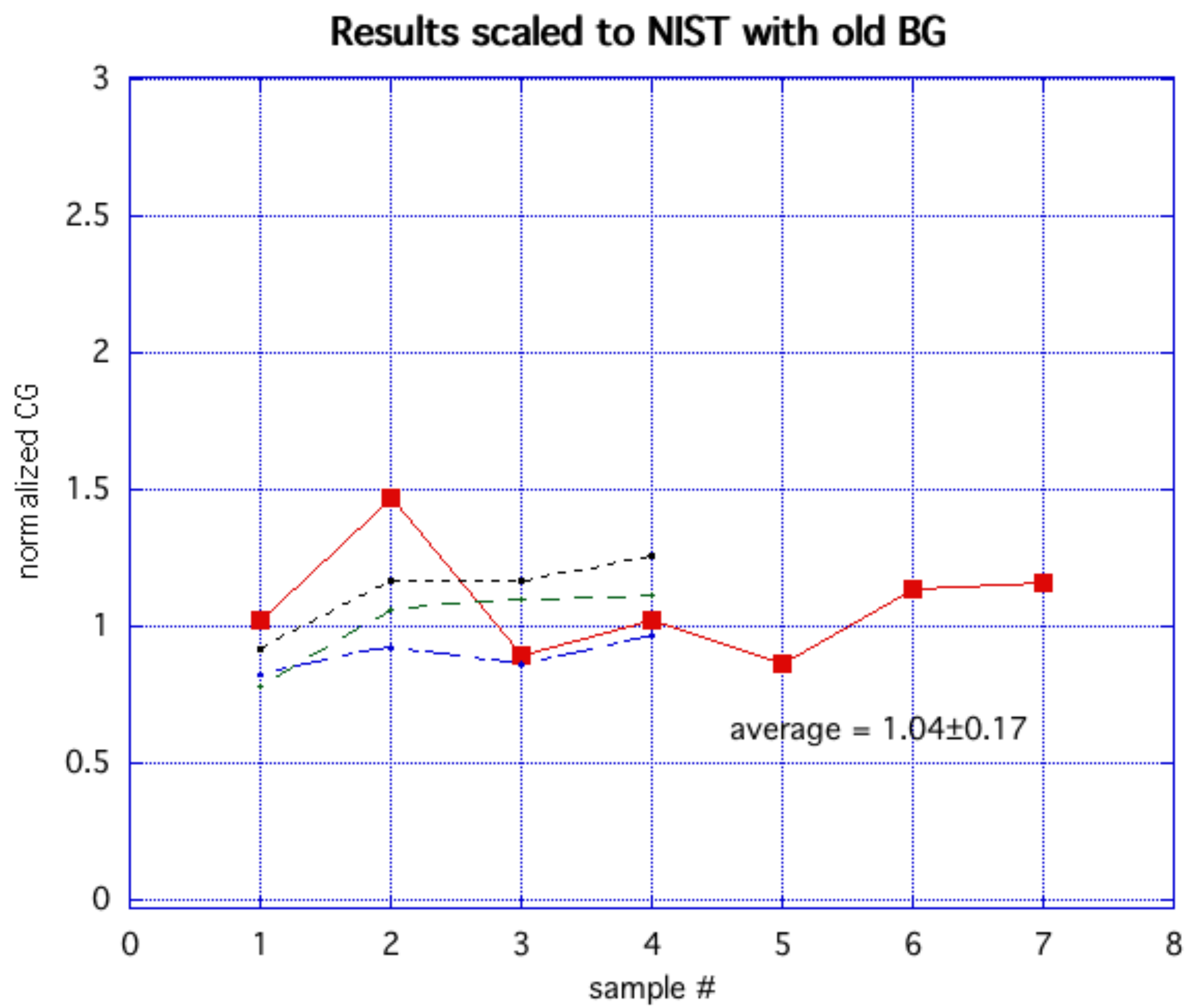
Interpreting E0 measurements (esp. in e-beam systems): Large dependence on dose has been observed in one resist. This is inconsistent with previous measurements.


updated CG normalized to NIST
normalized CG
sample #
mean=1.50±0.24
0
0.5
1
1.5
2
2.5
3
0
1
2
3
4
5
6
7
8

Improved cleanliness of NIST chamber



Correlation factors used by other sites to obtain "NIST equivalent" CG thicknesses are based on 2012 data with higher background contribution.



Results scaled to NIST with old BG
normalized CG
sample #
average = 1.04±0.17
0
0.5
1
1.5
2
2.5
3
0
1
2
3
4
5
6
7
8

Summary

When fully analyzed, the data from the recent round robin agree remarkably well

NIST is implementing temperature control of exposure chamber

A third round-robin that will test resists with a wider range or carbon growths is being considered

Acknowledgments

Round Robin participants:

EIDEC:	S. Inoue, E. Shiobara
imec:	I. Pollentier
CNSE:	G. Denbeaux
SEMATECH:	K. Petrillo, J. Sohn
ASML:	N. Harned et al.