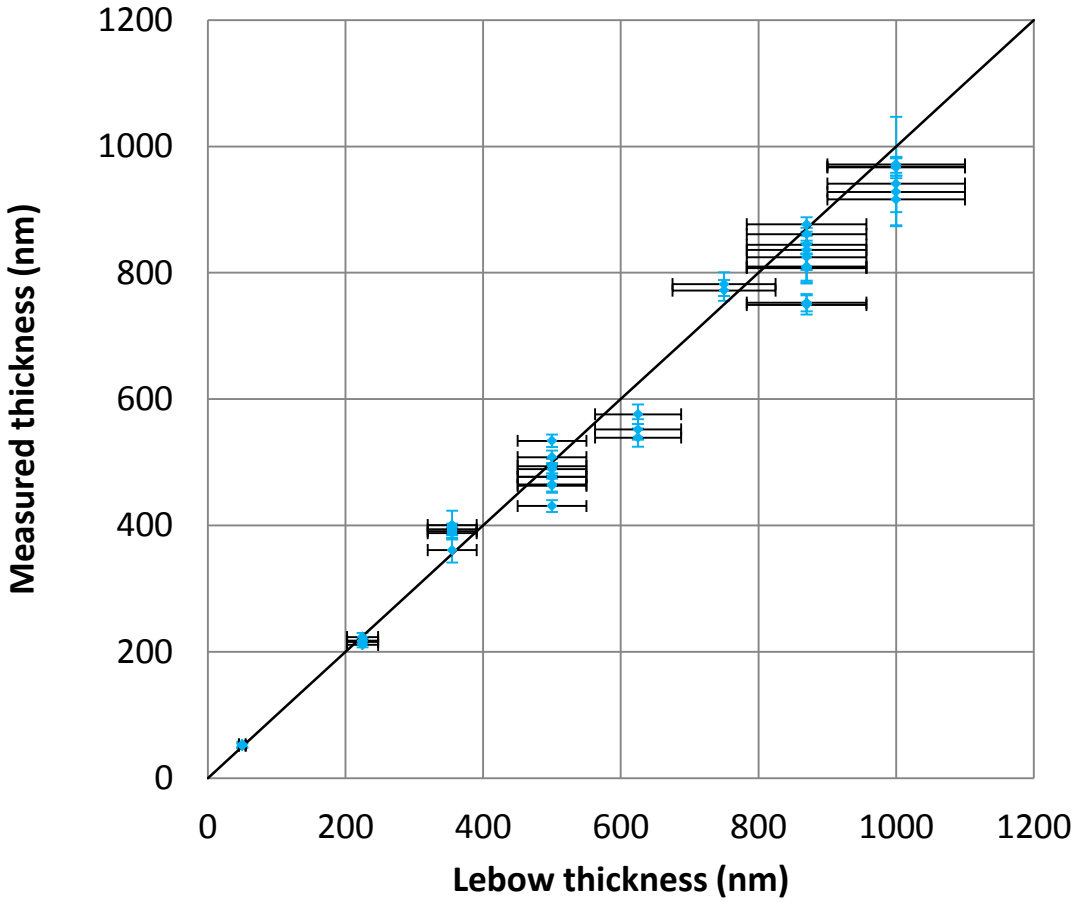
Foil thickness measurements more uncertainties captured

29July2015

Old slide: First pass at data error bars

Foil	Lebow (nm)
5385B	1000
3057C	870
5134B	750
7028B	625
5275C	500
5613A	350
7029B	225
6809B	50



Sources of uncertainty in measurement

1. Inherent limitations of the sample preparation and measurement in the FESEM
   a. FESEM resolution: 1.2 nm machine specifications
   b. Image tilt
   c. Uncertainty in magnification/working distance
2. Limitations on analyzing the image
   a. Pixel resolution: ± 4 pixels estimated, varies from ± 2.5 – 40 nm depending on scale
   b. Reproducibility between different analyses of same image
   c. Differences between images that should be the same
   d. Differences between images that should be similar (tilt, translation)
3. Errors or problems introduced in the preparation of the samples
   a. Sample mounting flatness, uniformity
   b. Any deformation during cleaving? Did it snap nicely or pull?
4. Uncertainties that have to be bounded by Lebow specifications
   a. Uniformity across entire sample: quote <= 2%
   b. Uniformity between samples within a batch: quote <= 5%

Boldface items included previously

FESEM measurement uncertainties

1b:

- Tilt (pitch) of ±5° introduced – none of the images appear to have pitch greater than ±5°
- For a tilt of ±5°, we'd expect to measure 99.6% of the actual thickness of the foil.
- 0.4% uncertainty added to all for possible misalignments in tilt

1c:

- Tilting can change the working distance of the edge of the foil.
- Calculated for sample stage 25 mm, hinged at back edge. Change in working distance no more than 0.1 mm for tilts of ±5°, or ~1% of ~10 mm working distance
- Tilt induced working distance uncertainty of 1% added

1d:

- Working distance knob specifies working distance to 0.1 mm. This adjusts focus
- Out of focus images can be about 1 "click" of the focus knob off.
- This accounted for by 0.1 mm/working distance for each image ~1%

Image analysis uncertainties

2a:

- Line length assumed to be no better than ±2 pixels at each end,
- Pixel – nm conversion for each image used
- **Note – this has been assumed constant across images with different magnifications and still needs to be addressed**

2b:

- The same image was analyzed 2-3 times typically.
- Each measurement has an uncertainty
- Percent uncertainty for each measurement were used, average percent uncertainty of the weighted mean of the measurements is quoted here to get one number for each foil

2c:

- Some of the foils have multiple images of the same area at nominally the same tilt and location: perhaps focus or magnification was changed, but these should yield the same value since it is the same foil.
- The standard deviation of data sets in nominally identically conditions used here (smaller set of data than in 2d).

2d:

- Some of the foils have images made of different spots: different samples (center, edge) or translations along one sample.
- The standard deviation of all the data sets at different locations is used to get this uncertainty

Sample prep and Lebow consistency

3a: Sample mounting flatness and uniformity need to be considered and assigned an uncertainty. Not sure how to quantify this

3b: if we are systematically stretching or pulling the foil when we try to cleave the gold along with the silicon substrate, we should assign a value to this: it will only make them thinner, and we see a trend toward all the thicker foils measuring thinner than the Lebow quote. This systematic could affect the fit of the line.

4a: Lebow quotes the non-uniformity across each foil at less than 2%. If we are getting non-uniformities in 2d greater than 2%, it is likely our technique rather than the foils and we need to reconcile these numbers.

4b: Lebow only guarantees that sibling foils are identical to less than 5%. We could have cases where this could be our leading cause, and if we find elastic rates that deviate significantly from the FESEM measurements, this could be a factor.

Error contributions

All measurements in nm

foil	Lebow (nm)	Meas (nm)	1a: FE-SEM res.	1b: tilt 0.4% mea thick	1c: working distance due to tilt	1d: working distance or focus – 0.1 mm/ WD	2a: pixel res.	2b: re-analy. same image	2c: diff btwn similar images	2d: varia. btwn diff configs	3: ??? stretch, foil mnt issues	4a: lebow foil uniform 2%	4b: Lebow batch uniform. 5%
5385	1000	**943.7**	1.2	3.7	9.2	8.5	40.0	31.0	29.0	6.5		20.0	50.0
3057	870	**836.8**	1.2	3.3	8.3	8.3	8.0	13.8	7.1	5.6		17.4	43.5
5134	750	**774.6**	1.2	3.1	7.7	6.9	10.0	13.2	9.1	9.1		15.0	37.5
7028	625	**561.2**	1.2	2.2	5.6	4.6	8.0	12.6	8.0	8.0		12.5	31.3
5275	500	**487.6**	1.2	2.0	4.9	4.3	8.0	8.4	3.4	2.9		10.0	25.0
5613	355	**389.4**	1.2	1.6	3.9	3.4	8.0	6.6	4.5	4.5		7.1	17.8
7029	225	**215.2**	1.2	0.9	2.2	1.9	2.6	2.7	1.9	1.9		4.5	11.3
6809	50	**52.0**	1.2	0.2	0.5	0.4	2.6	3.2	2.3	2.3		1.0	2.5

FESEM uncertainties

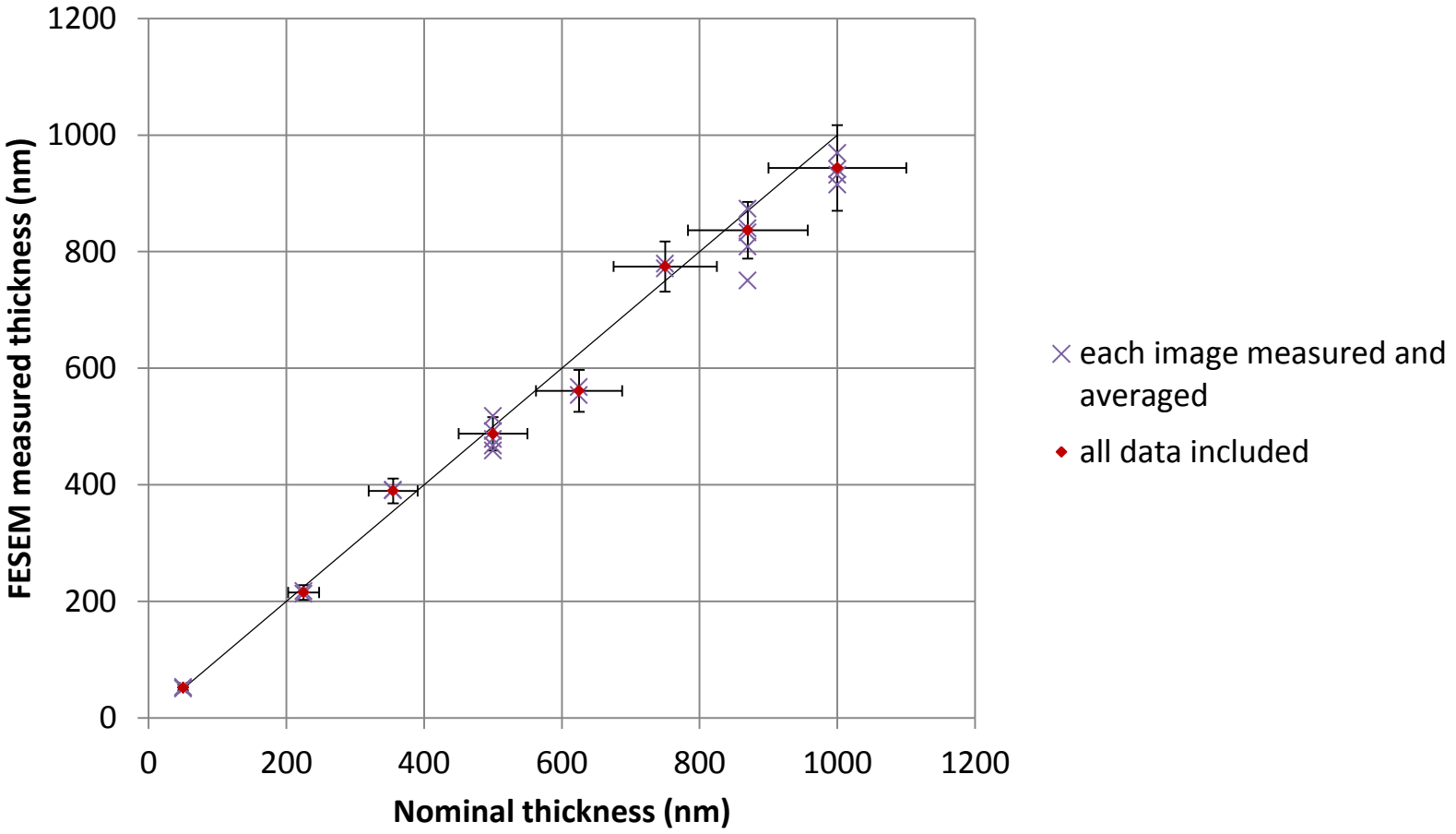
Image analysis uncertainties

Quoted batch and sibling uniformity

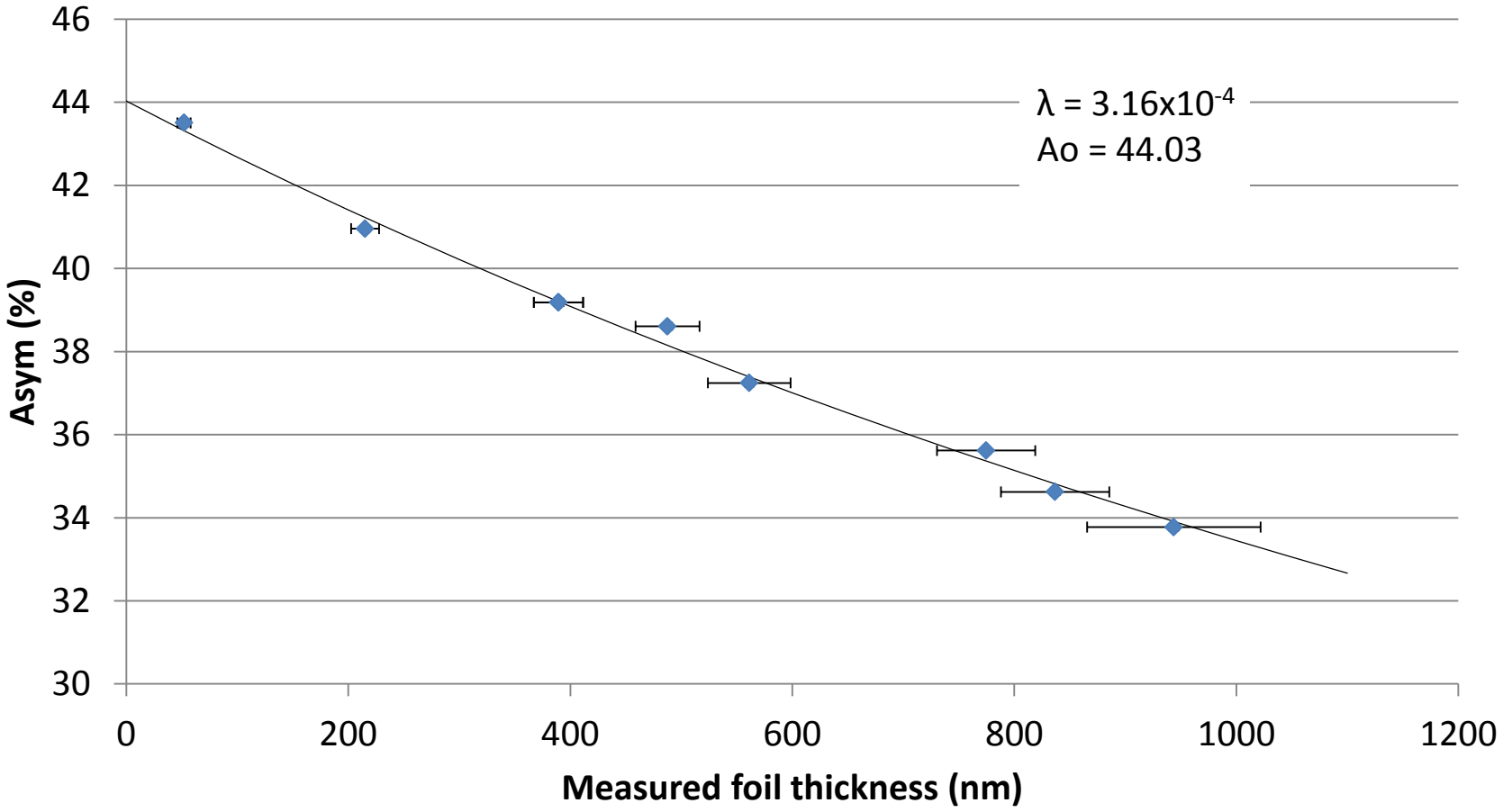
Combining uncertainties

Target ladder position	foil	Meas (nm)	FESEM (all from section 1)	image anayl (all from section 2)	Lebow (from section 4: larger only)	Total uncertainty (nm)
15	5385	**943.7**	13.1	58.7	50.0	**78.2**
3	3057	**836.8**	12.3	18.3	43.5	**48.8**
4	5134	**774.6**	10.9	21.0	37.5	**44.3**
2	7028	**561.2**	7.7	18.7	31.3	**37.2**
5	5275	**487.6**	6.9	12.5	25.0	**28.8**
8, 14	5613	**389.4**	5.5	12.1	17.8	**22.2**
1	7029	**215.2**	3.2	4.6	11.3	**12.6**
13	6809	**52.0**	1.4	5.3	2.5	**6.0**

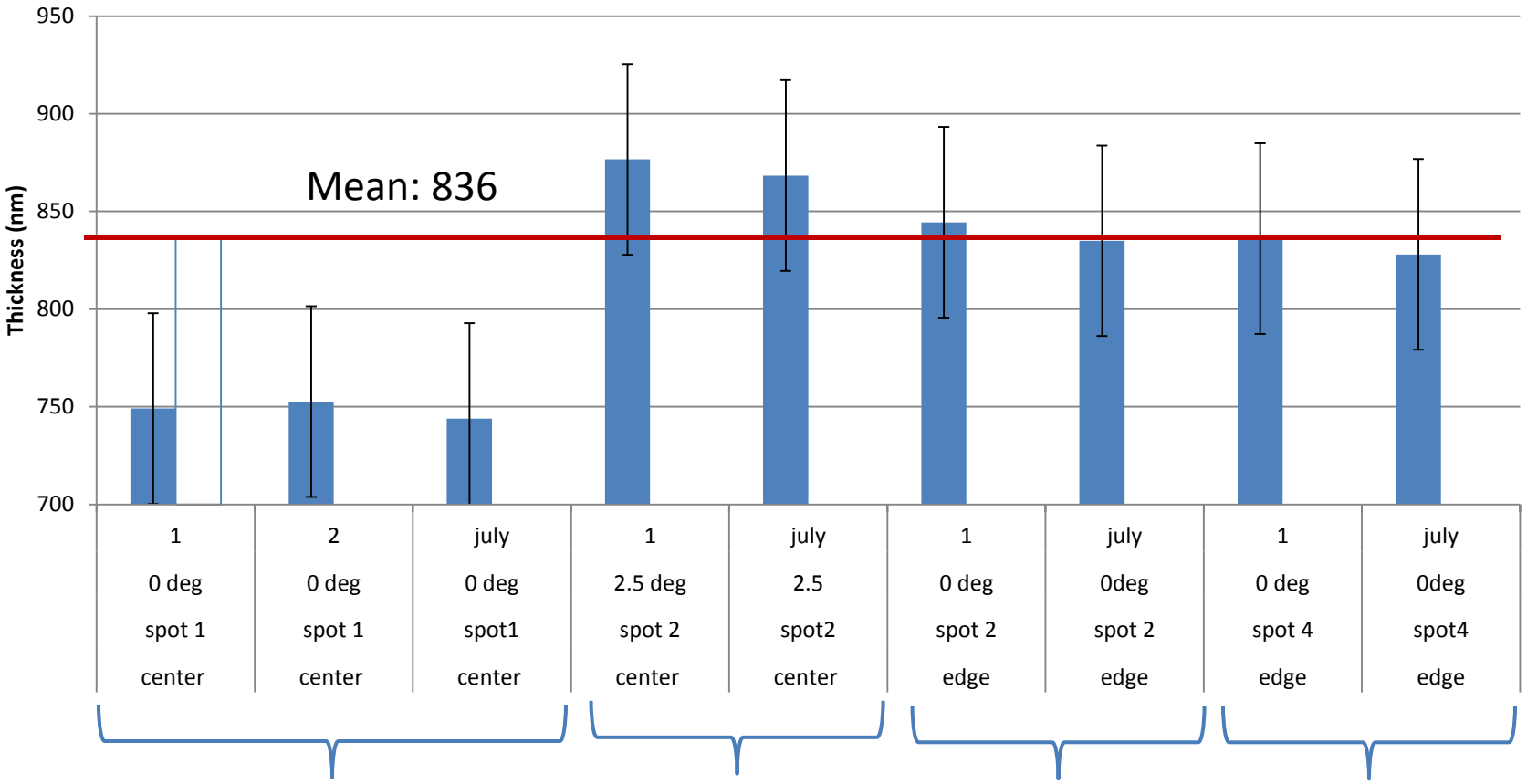
Incorporating more sources of uncertainty



Incorporating more sources of uncertainty



Foil “870 nm” looked at again



Multiple analyses of the same image are grouped