AutoEdge: Precise and Accurate Xray Measurement with Compact Equipment

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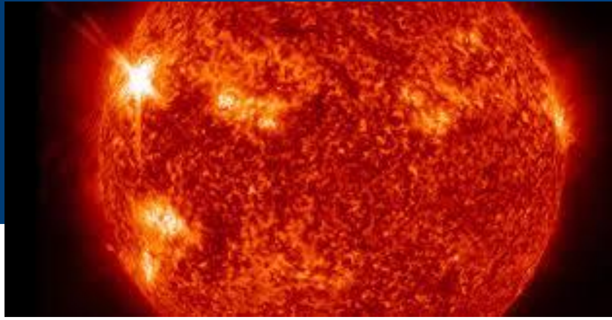
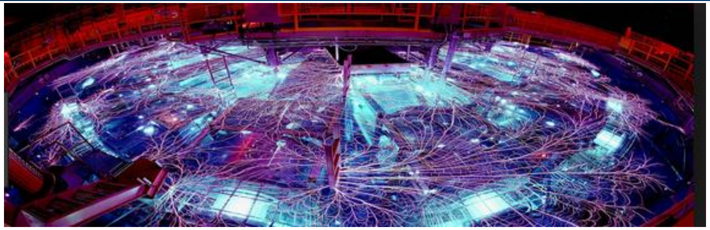
High precision targets and metrology are central to HED experiments



Plasma Universe

Know heaven from earth

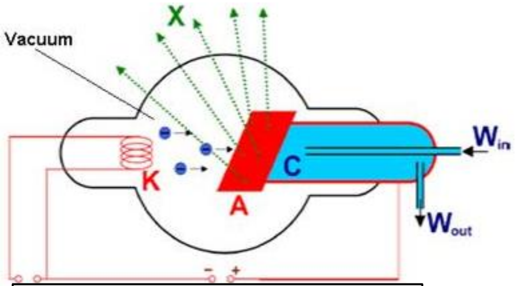


HEDLA Experiment

Enable shots

Target Fab.

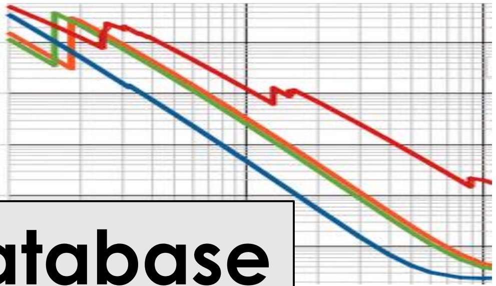
Know target-to-be-shot to 2% accuracy



Metrology

Verify database to 1%

Enable non-destructive measurement



X-ray Database

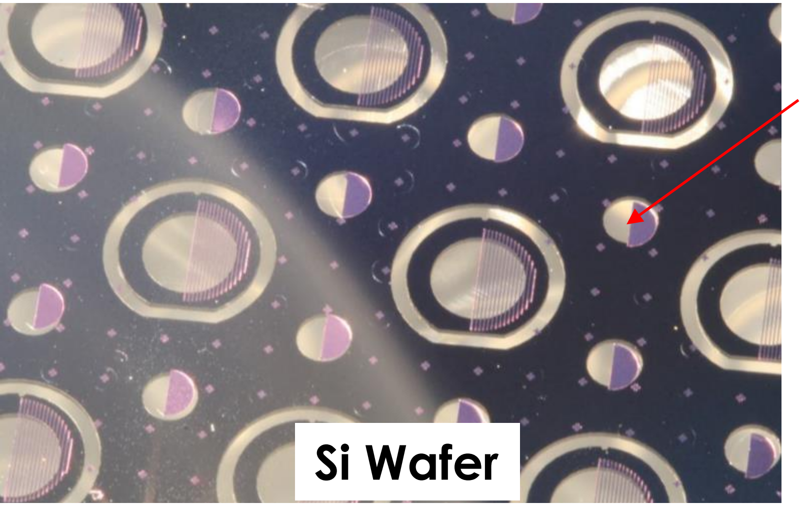
Enable other applications

Bringing target fab and metrology into the semiconductor era

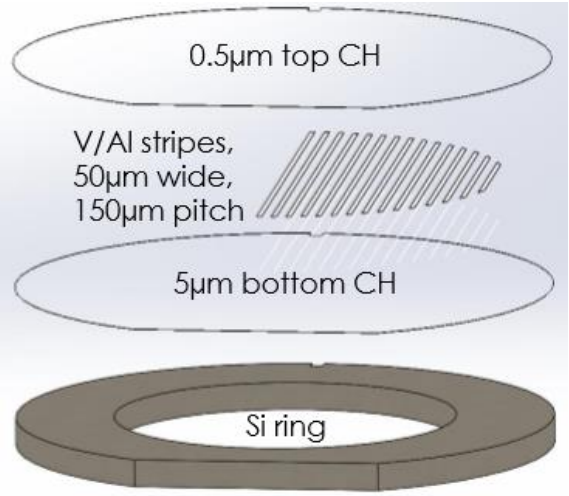
- **New target fab approach**
  - Photolithography
- **New metrology equipment**
  - AutoEdge
- **How to prove precision to 1%?**
  - Photon statistics
- **How to prove accuracy to 1%?**
  - X-ray database refinement

Photolithography-based fabrication produces complex plasma-transport targets, impossible by contact mask

- **Line pattern for inter-diffusion of high Z/Low Z**



Built-in probes
“Mini-Opacity”

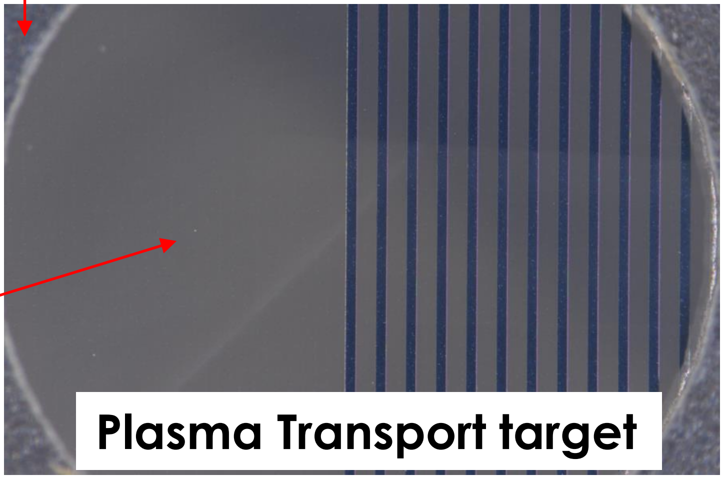


No glue

Si

Perfectly Flat

CH

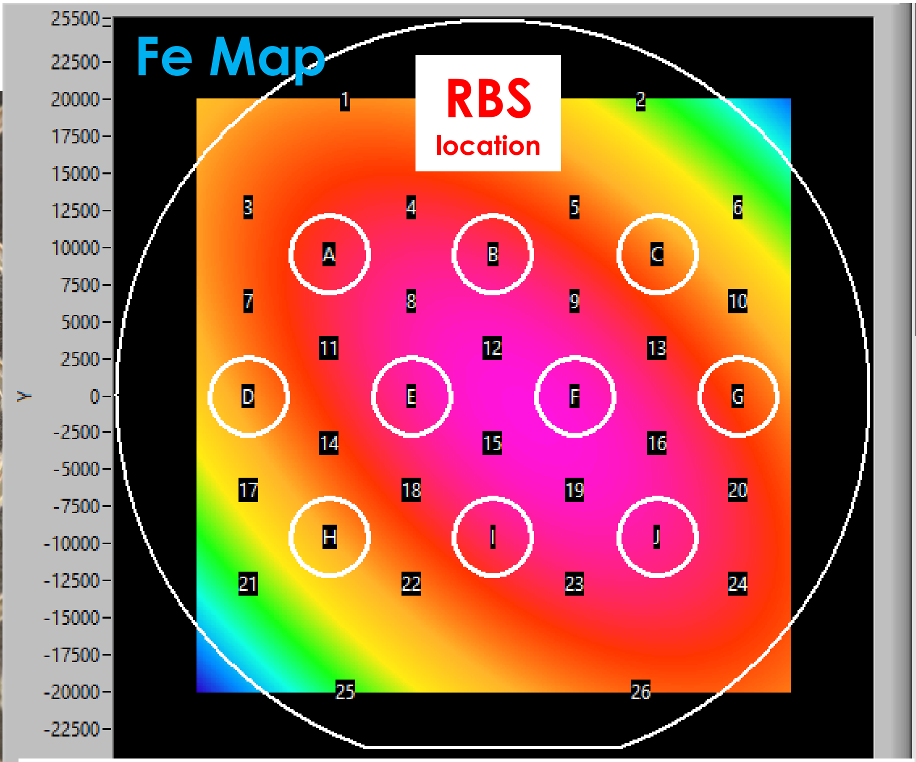


Free-standing ZAPP/Opacity targets enable quantification of actual targets rather than witness

- **Xray measures both "cold opacity" and areal density**
  - Baselining the anomalous "hot opacity" increase

"Solar opacity" problem

ZAPP/Opacity targets

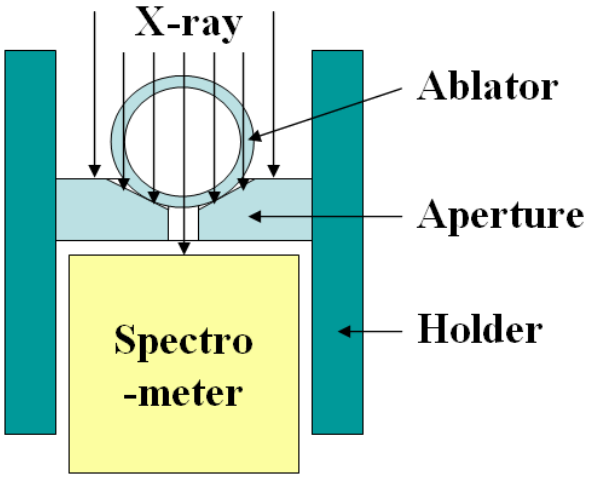


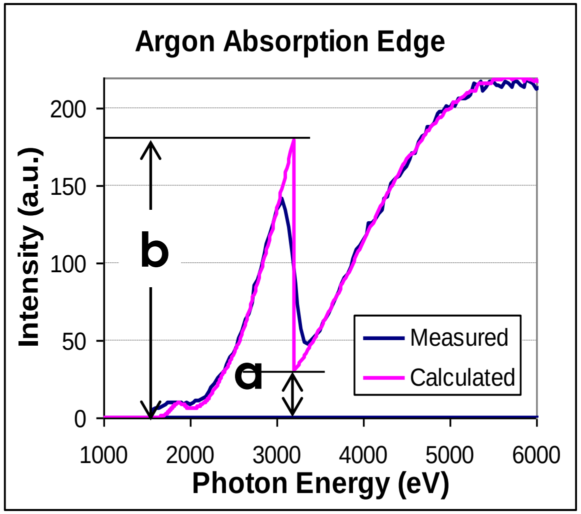
Fe Average 0.287um, ±3% Max-Min

New wine in old bottle: X-ray absorption spectroscopy is most relevant, can quantify metal foil areal density

- **Old technique: Non-destructive, first principle**

No calibration standard needed





"Why not XRF?"

⇨ Mass ∝ *Log* (a/b)

- **New ingredient: New instrument to cross-check, discriminate and refine x-ray databases**

"A strong-yet-unfulfilled need in HED"

New "AutoEdge" instrument pushes the precision and accuracy limits in x-ray absorption metrology

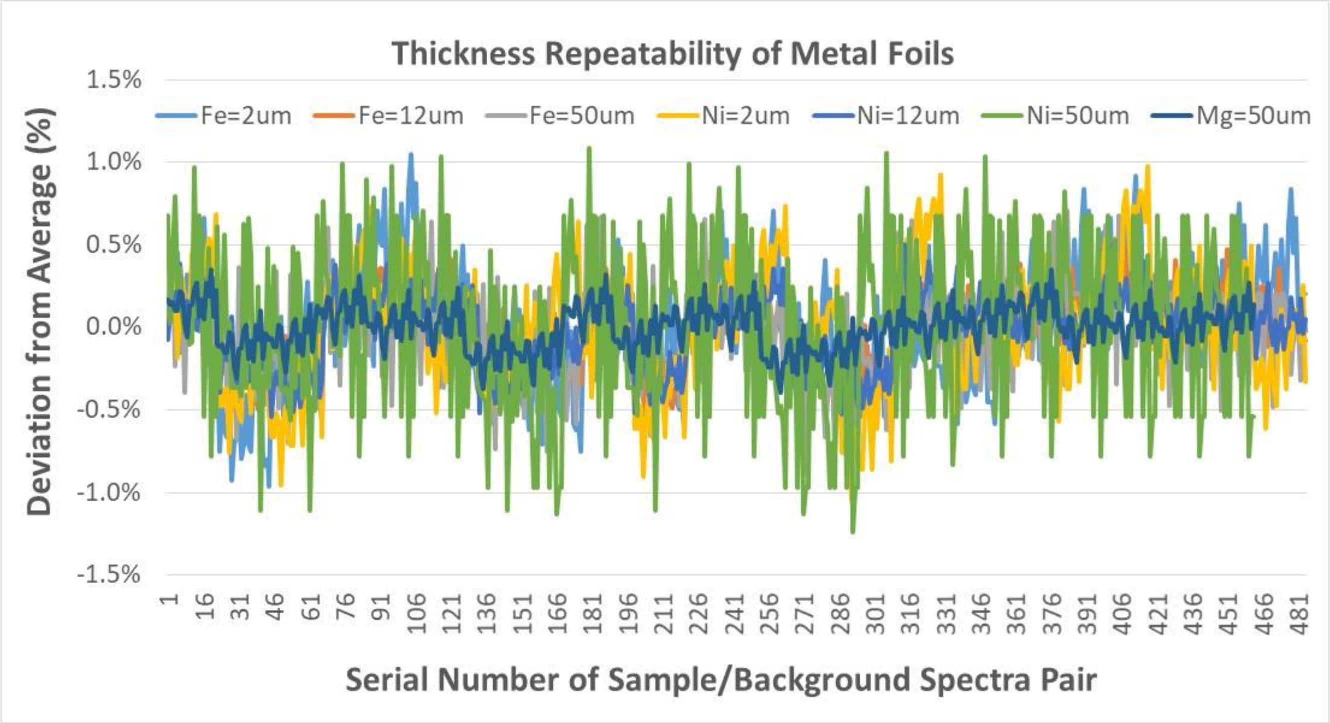
- **New tool**
  - Mo tube
  - Silicon Drift Detector
- **Three goals**
  - Metrology automation
  - Accuracy within 2%
  - Refine x-ray database

- **Automation enables "Big data" approach**
  - Use spectrum ensemble to probe instrument behaviors
  - Precision set by noise, mitigated by counting time
  - Accuracy set by database, calibrated gravimetrically

30 minutes spectra on 2+μm metal foils measures thickness to within 0.5% (1-σ) precision

- **Thickness repeatability empirically determined**

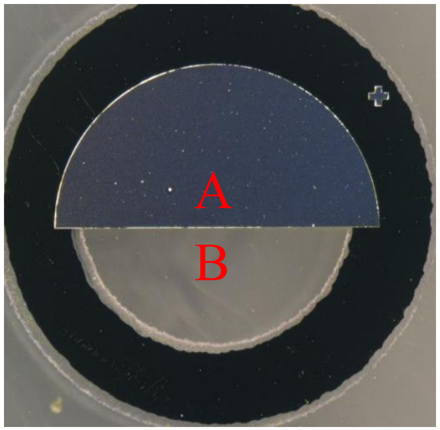
	Fe	Fe	Fe	Ni	Ni	Ni	Mg
Average (um)	2.331	12.375	52.090	2.072	12.185	50.658	45.517
StDev (um)	0.008	0.027	0.143	0.008	0.027	0.252	0.062
StDev (%)	0.36%	0.22%	0.27%	0.37%	0.22%	0.50%	0.14%

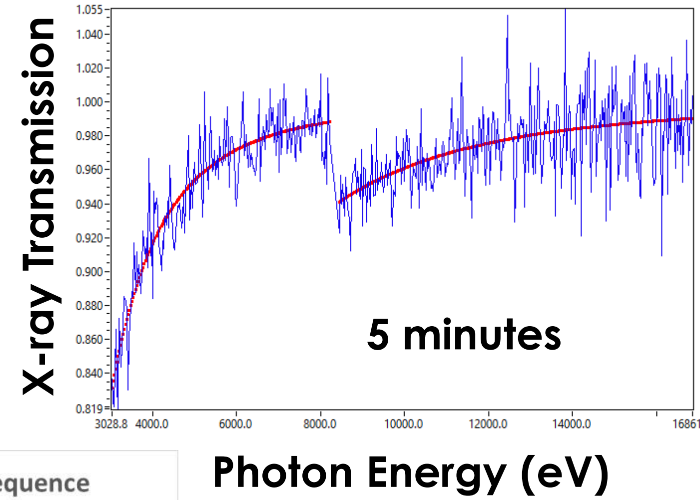


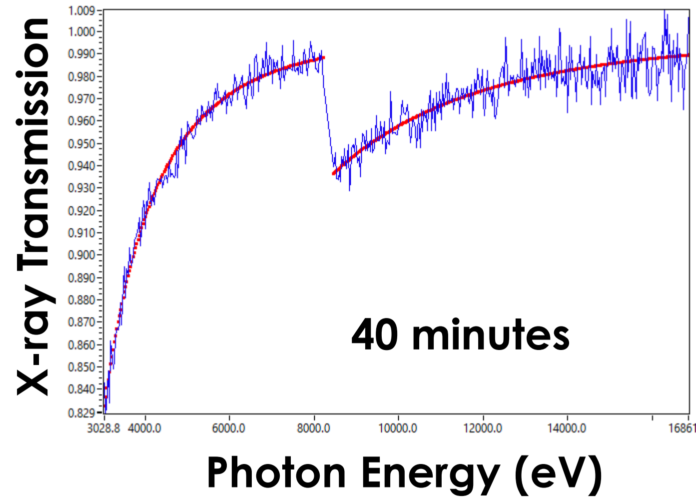
Applicable to NIF diagnostic filter foils

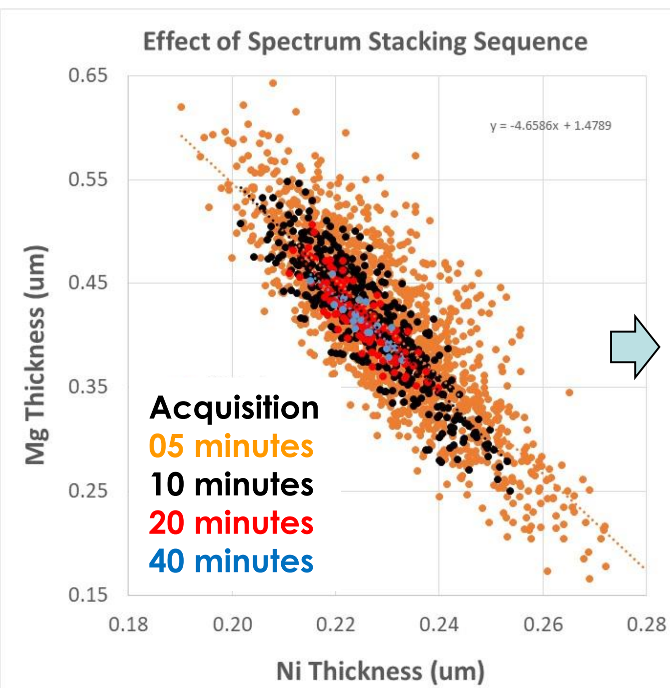
Precision set by photon-counting noise, empirically studied through spectral ensemble

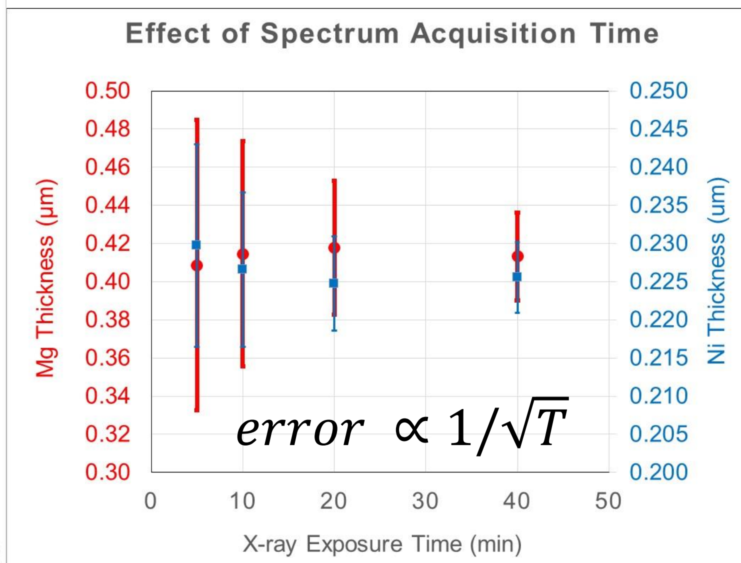
- **Opacity18A, Type EEE: 0.23 µm Ni/0.45 µm Mg**











20 minute spectrum measures Ni to 3%, Mg to 8% 1-σ noise

Double Ni content halves the error bar

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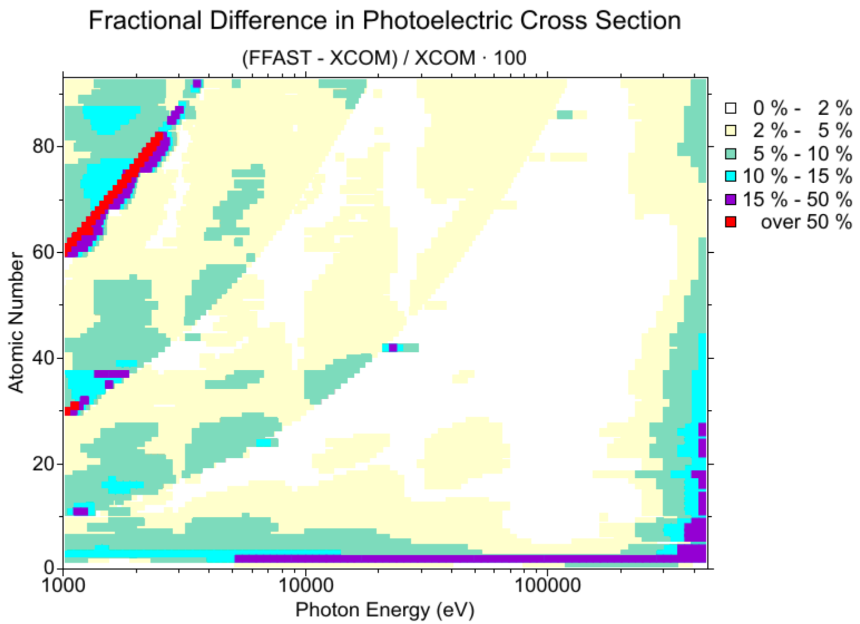
Compiled five “standard” x-ray databases into one program to enable benchmarking and calibration

- **Rude awakening: 90 sec that shatters “trusted” data**

Name	Z	Energy	Purpose & Source
NIST XCOM	1-100	1k-100G	Absorption https://physics.nist.gov/PhysRefData/Xcom/html/xcom1.html
NIST XFFAST	1-92	1-433k	Diffraction https://physics.nist.gov/PhysRefData/FFast/html/form.html
LBNL Henkie	1-92	30-30k	Optics http://henke.lbl.gov/optical_constants/pert_form.html
SNL	1-100	10-1M+	HED 1988 Report, “Analytical Approximations for X-Ray Cross Sections”
LLNL	1…..94	1k-1M	HED 1969 Report, “Compilation of X-Ray Cross Sections”

- **Old data not so great**
  - Source data from 1930-1970s, before microelectronics
- **New data not forthcoming**
  - Shutdown of Brookhaven beamline left the US HED program in the dark: No more synchrotron access

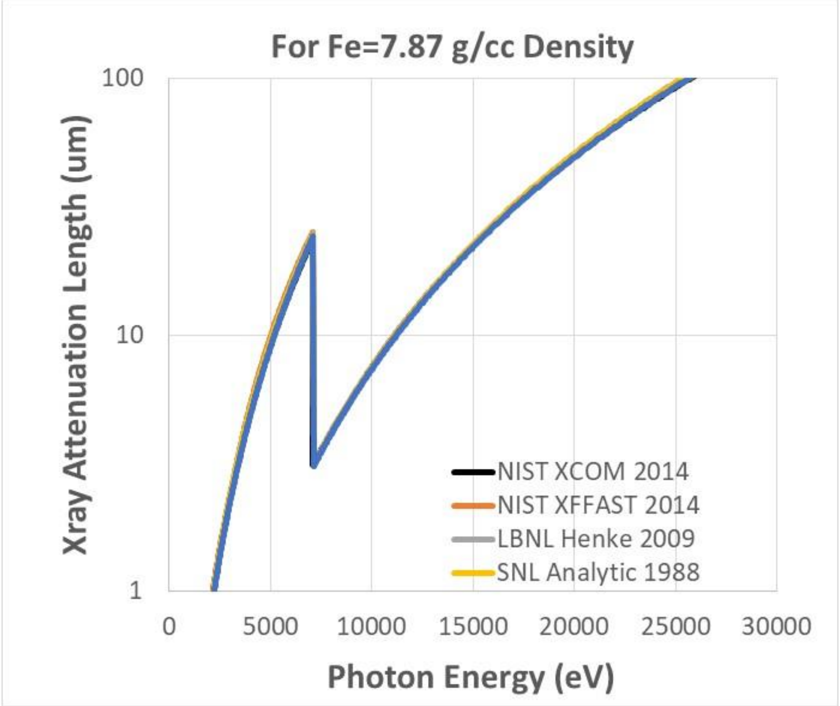
NIST treats XCOM-XFFAST as limit of knowledge on opacity



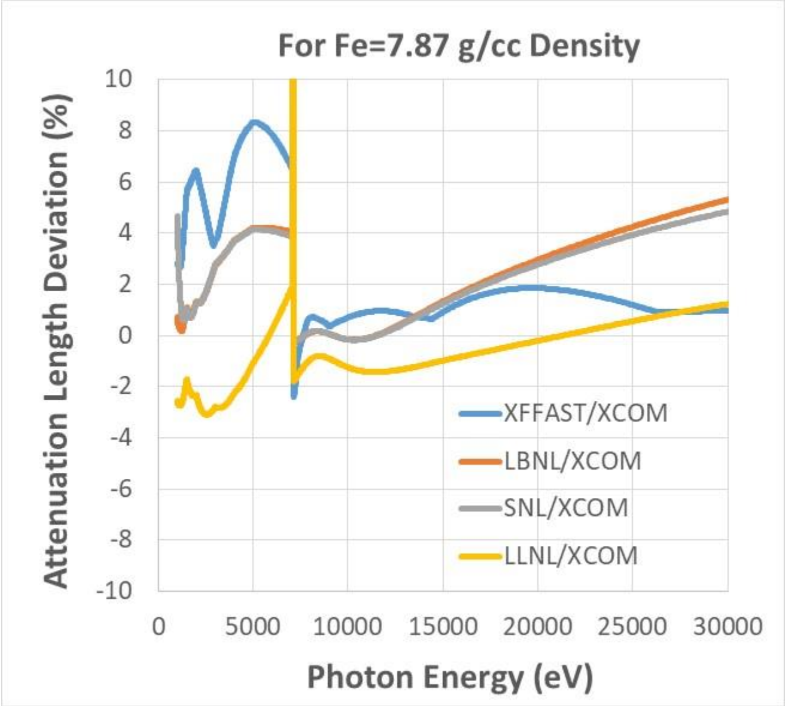
- **Green is 5-10% uncertainty**

https://physics.nist.gov/PhysRefData/XrayNoteB.html

- **Fe is uncertain to 8%**



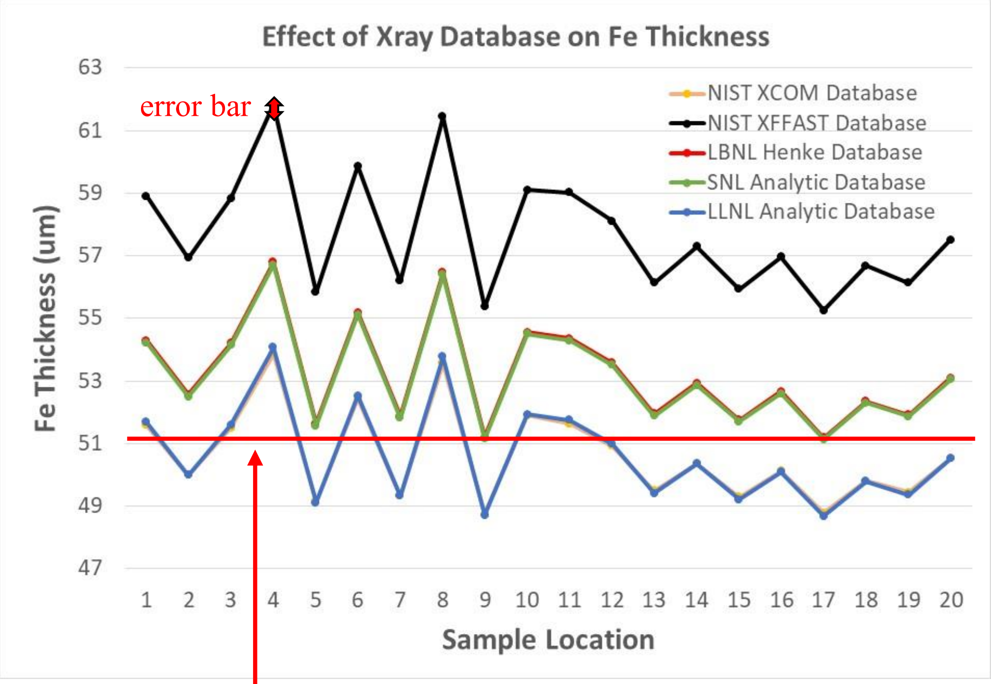
Look closer



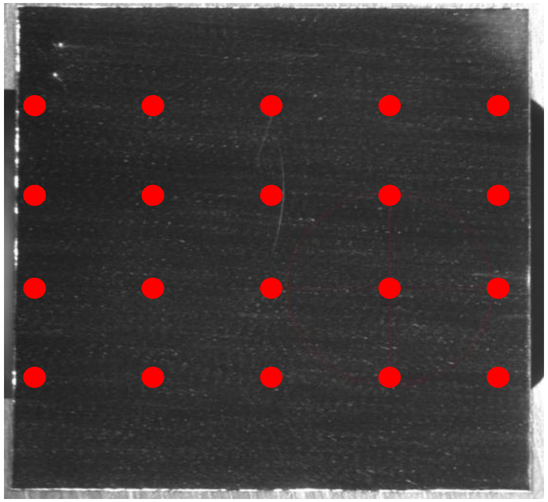
For Opacity and Diffusion Experiments: Ni, Mg, V, Al are not any better

Automated areal scan enables benchmarking against gravimetric thickness on imperfect foils

Fe Thickness Calibration	Micron	Deviation (%)
Gravimetric (0.1um 1-σ)	51.11	0%
NIST XCOM	50.62	-1%
NIST XFFAST	57.66	13%
LBNL Henkie	53.23	4%
SNL Analytic	53.16	4%
LLNL Analytic	50.64	-1%
Average	**53.06**	**4%**



Gravimetric average: 51.11 μm



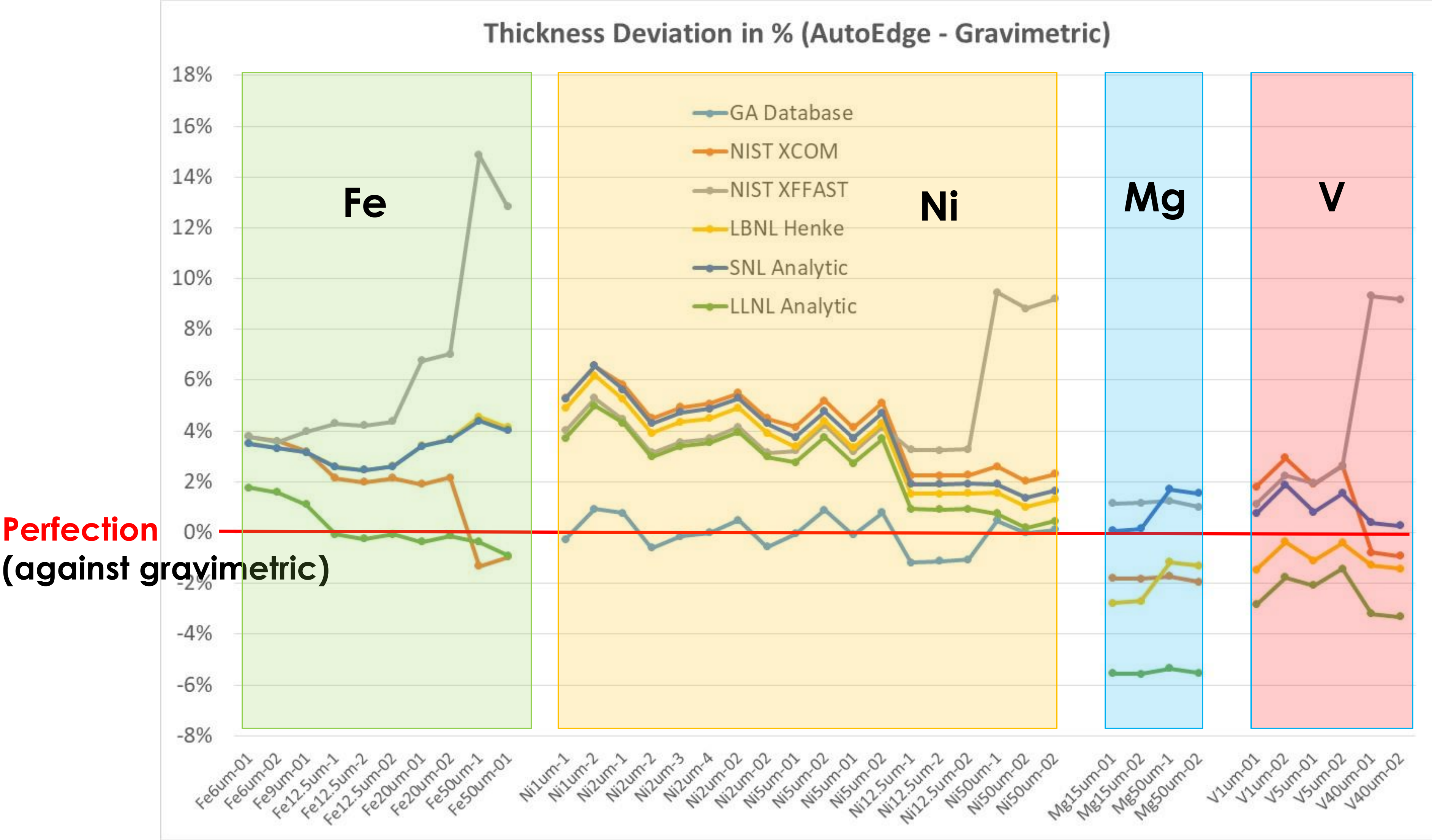
Scan a 1" x 1" Fe foil

Gravimetric uncertainty: ±0.1 μm

X-ray sampling uncertainty: ±0.4 μm

Check x-ray database to 1% accuracy

“GA database” corrects areal density measurement to ~1% accuracy, about 5x reduction in error



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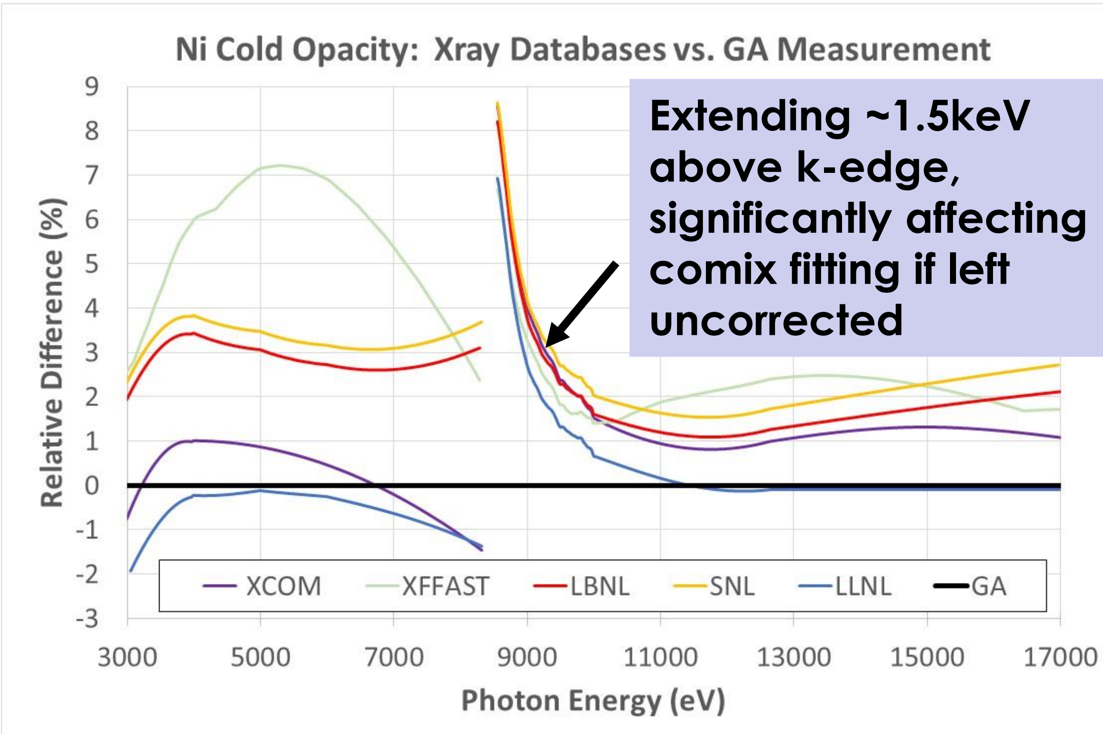
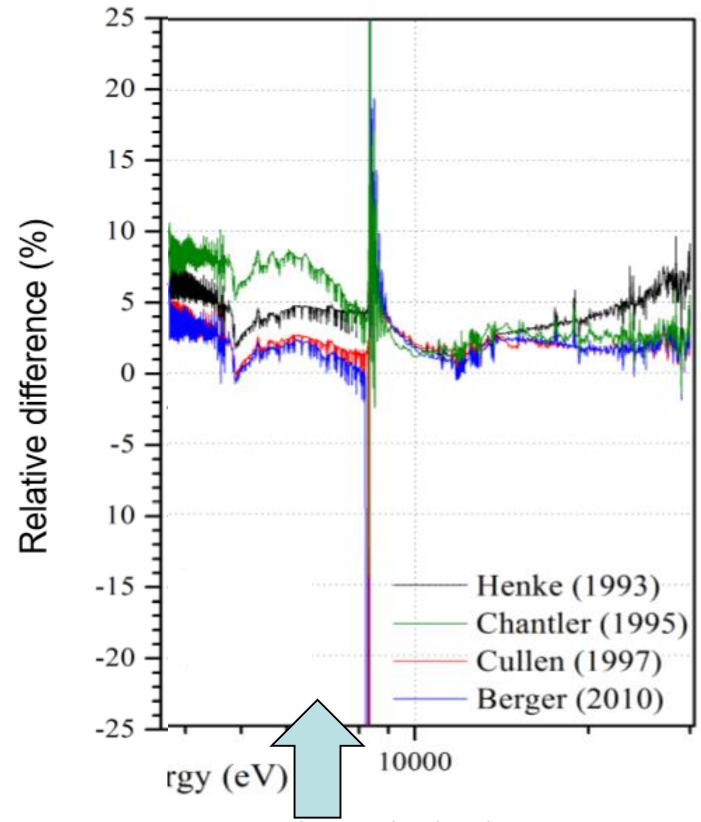
Ni opacity data from GA agrees to CEA-PTB synchrotron data to ~1% in common energy range of 3-17keV

Both suggest earlier databases have >5% error, especially above K edge



GA Data for Ni

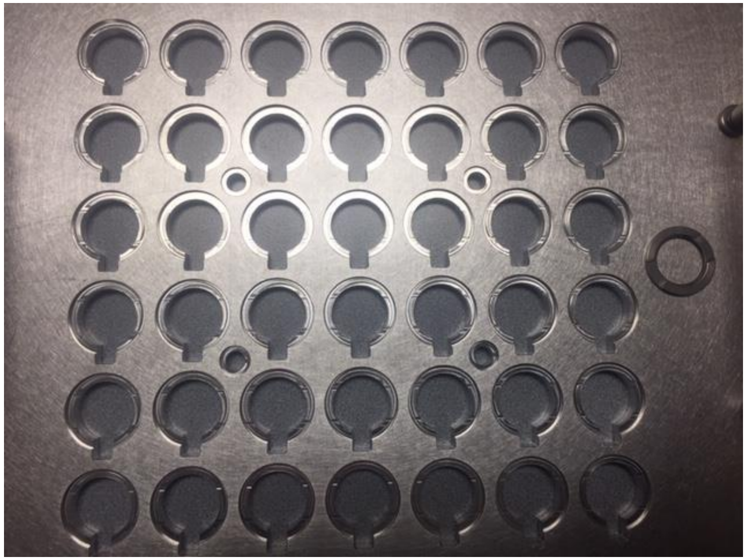


From Dr. Marie-Christine Lepy 2018 DXC presentation

Joined "International Initiative on X-ray Fundamental Parameters" to participate in standard-setting activities

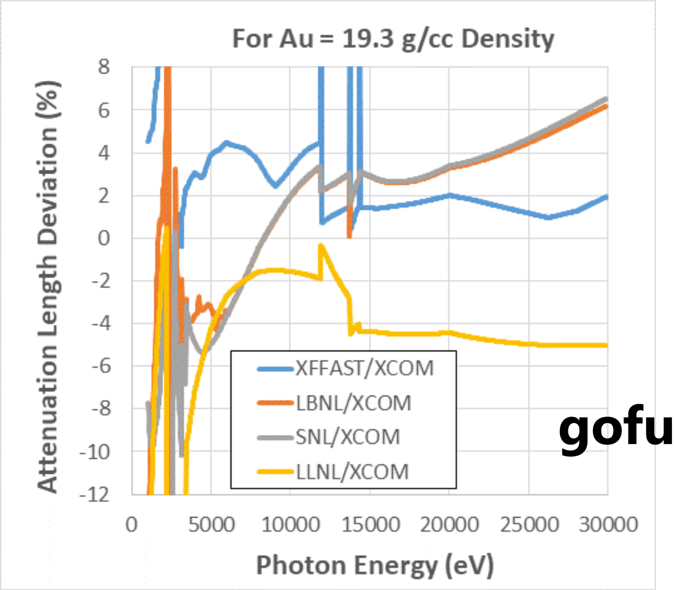
Precision metrology enables precision target fab, Portable instrument shows promise in opacity revision

- **Photolithography => complex and rep-rate targets**
- **AutoEdge => 1% precision, measuring actual targets**
  - Systematic calibration of Comix, Dante filter, Ross Pair
- **GA database => 1% accuracy via "element" projects**



Ready to go: Calibrate 500 Dante filters in 12 batches (annual NIF consumption)

Gold is not golden



gofundme

GENERAL ATOMICS