# Gold foil thickness measurement Tech Note

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## Sample preparation

Gold foil thickness was measured using a field emission scanning electron microscope (FESEM) technique. A gold foil that was manufactured in the same batch as the target foils, referred to as the “sibling” foil, was mounted to a silicon substrate. For the nominally 50 nm foils, static electricity was sufficient to adhere the foil to the substrate. For the thicker foils, a commercial carbon suspension in alcohol, Aerodag™, was used as a conductive adhesive between the foil and the silicon crystal. A drop of Aerodag was typically put on either the substrate or foil and the foil placed on the substrate. In some of the early foils, the foil was set on the substrate then the aerodag applied at the edge of the foil, which yielded some evident carbon flakes over the foil. The samples were then cleaved by applying pressure to the edge of the silicon substrate with a curved blade, cleaving the silicon and separating the gold foil to expose a thickness cross section for SEM imaging.

## Measurement

A Hitachi s-4700 FESEM model using an electron energy of 15.0 kV was used image the gold foil edges. Magnifications between 10k and 150k were used depending on the foil thickness. The working distance was varied until the image was in focus, and varied between 10 and 14 mm. Images were typically made at a single location for each sample prepared. For two of the samples, to test uniformity across a small area of the foil, the sample was translated and 3 or 4 spots were measured along the edge of a sample. Additionally, for two foils, two FESEM samples were prepared from a single target foil, one near the center and one near the edge, and both were analyzed. Finally, the tilt (pitch) dependence of the mounting in the FESEM was studied for one foil.

## Image analysis

The software program “ImageJ[[1]](#endnote-1)” was used to determine the foil thickness from the FESEM images. For each image, the measurement gradation line was used to set the scale between nm and pixels, and measurements of the distance between the top and bottom of the foil were made using the built in measurement feature of the software. Depending on the quality of the image, the enhancement features of the software, including “edge find” and “sharpen”, as well as rotation correction were used to assist in the process of determining the edge of the foil in the image. A systematic study was also performed to determine the effect of sample tilt, intentionally varying the angle of the sample holder in the FESEM by angles of -1.7 through +2.5 degrees and measuring the variation due to that change.

## Error sources and error analysis

#### Random (Statistical) Uncertainties

The random uncertainty in the measurements can be either estimated from trying to approximate and sum the sources of random thickness uncertainty, such as tilt, focus, ImageJ distance uncertainty. However, repeated measurements of images that are nominally identical yields a more accurate measurement of our random uncertainty. For example, with foil 3057 (nominally 870 nm), the estimates on uncertainties due to tilt, focus, and line analysis are 8, 4.2 and 8.4 nm respectively, which would be added in quadrature to determine the random uncertainty of 12.3 nm. Using the variation between measuring several different images of the nominally identical spot, the random uncertainty is only 7.1 nm, which we will use as a more accurate measure of random uncertainty in the measurements. Experimentally measured random uncertainties in the data are shown in Table 1 line 3.

#### Systematic Uncertainties

Systematic uncertainties in the foil measurements include inherent limitations of the FESEM machine, the uncertainty in image analysis which is estimated through the variation in thickness measured on the same image in multiple analyses, and finally the specification from Lebow that the sibling foils may vary as much as 5% within a batch.

The inherent resolution of the FESEM is 1.2 nm, and this uncertainty is the first systematic uncertainty considered in row 5 of Table 1.

Repeated analysis of a particular image gives a systematic uncertainty for the measurement that is shown in row 6 of Table 1.

The target foils used in the Mott study were manufactured in the same batch as the samples mounted for FESEM measurements, but the manufacturer guarantees only that these sibling foils are consistent with the target foils to 5%. This comprises the largest source of uncertainty in the target foil measurement at 5%, listed in Row 7 of Table 1.

#### Additional uncertainties

Uncertainties that have not been quantified are any difference between the thickness of the foil as mounted and any difference introduced by the mounting and cleaving process. This could be significant, but is a parameter that can’t be well measured. Additional extrapolation with rate rather than measured target thickness is used to help account for any systematic discrepancies in the foil mounting, cleaving, imaging and measuring process.

## Results

The summary of the measurements of the foils are listed in Table 1. The target foils are each labelled with a 4-digit batch identification, and “sibling” foils from the same batch are distinguished by suffixes from A-D. One of the foils, 50 nm foil 6845, did not have a sibling foil available for analysis. Two of the target foils, ladder positions 8 and 14, were both siblings of the same measured foil, 5613A.

Table : Summary of gold foil thicknesses measurements for “siblings” of the Mott target foils measured with FESEM technique. Random and systematic sources of uncertainty in these measurements are shown in rows 3-8, and final uncertainty in the thickness measurements is shown in line 9.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Au\_5385\_B | Au\_3057\_C | Au\_5134\_B | Au\_7028\_B | Au\_5275\_C | Au\_5613\_D | Au\_7029\_B | Au\_6809\_B |
| *Nominal Thickness (nm)* | *1000* | *870* | *750* | *625* | *500* | *355* | *225* | *50* |
| Thickness (all data, nm) | **943.7** | **836.8** | **774.6** | **561.2** | **482.0** | **389.4** | **215.2** | **52.0** |
| random: nominally identical  | 29.0 | 7.1 | 9.1 | 8.0 | 9.7 | 4.5 | 1.9 | 2.3 |
| Systematic |  |  |  |  |  |  |  |  |
| * FESEM resolution
 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.20 | 1.2 |
| * same image reanalysis
 | 22.6 | 12.4 | 13.3 | 10.2 | 9.7 | 9.2 | 3.80 | 2.9 |
| * Lebow sibling 5%
 | 47.2 | 41.8 | 38.7 | 28.1 | 24.1 | 19.5 | 10.80 | 2.6 |
| Systematic total | 52.4 | 43.6 | 40.9 | 29.9 | 26.0 | 21.6 | 11.51 | 4.1 |
| dT (nm) | **59.8** | **44.2** | **41.9** | **31.0** | **27.7** | **22.1** | **11.7** | **4.7** |

1. ImageJ software can be found at https://imagej.nih.gov/ij/index.html [↑](#endnote-ref-1)