# Estimating Milling Time

Milling rate depends on:

- Beam Current
- Volume to be milled
- A material-unique constant (volume/dose, ‘V/d’):

$$t_{\mathrm{mill}}[\mathrm{min}] = \frac{\left({}^{1min}/_{60s}\right) * V[\mu m^3]}{\left({}^{V}/_{d}\right)\left[{}^{\mu m^3}/_{nC}\right] * I[nA]} \approx \frac{(\boldsymbol{depth}[\boldsymbol{\mu m}])^{\mathbf{3}}}{\mathbf{73} * \left({}^{\boldsymbol{V}}/_{\boldsymbol{d}}\right) * \boldsymbol{I}[\boldsymbol{nA}]}$$

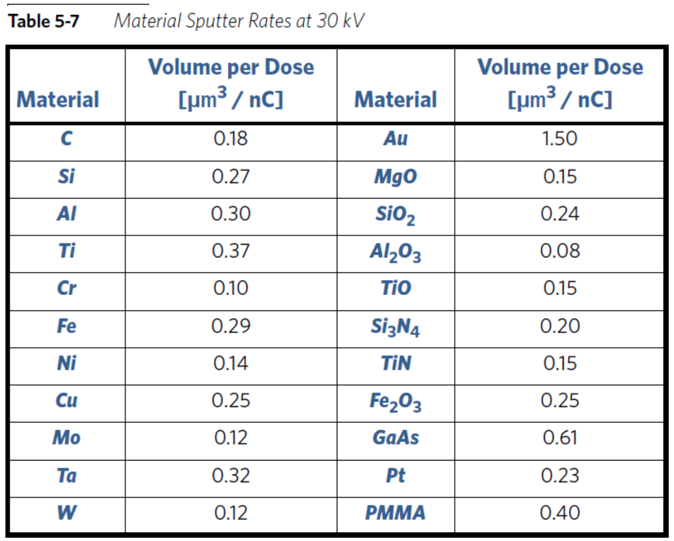


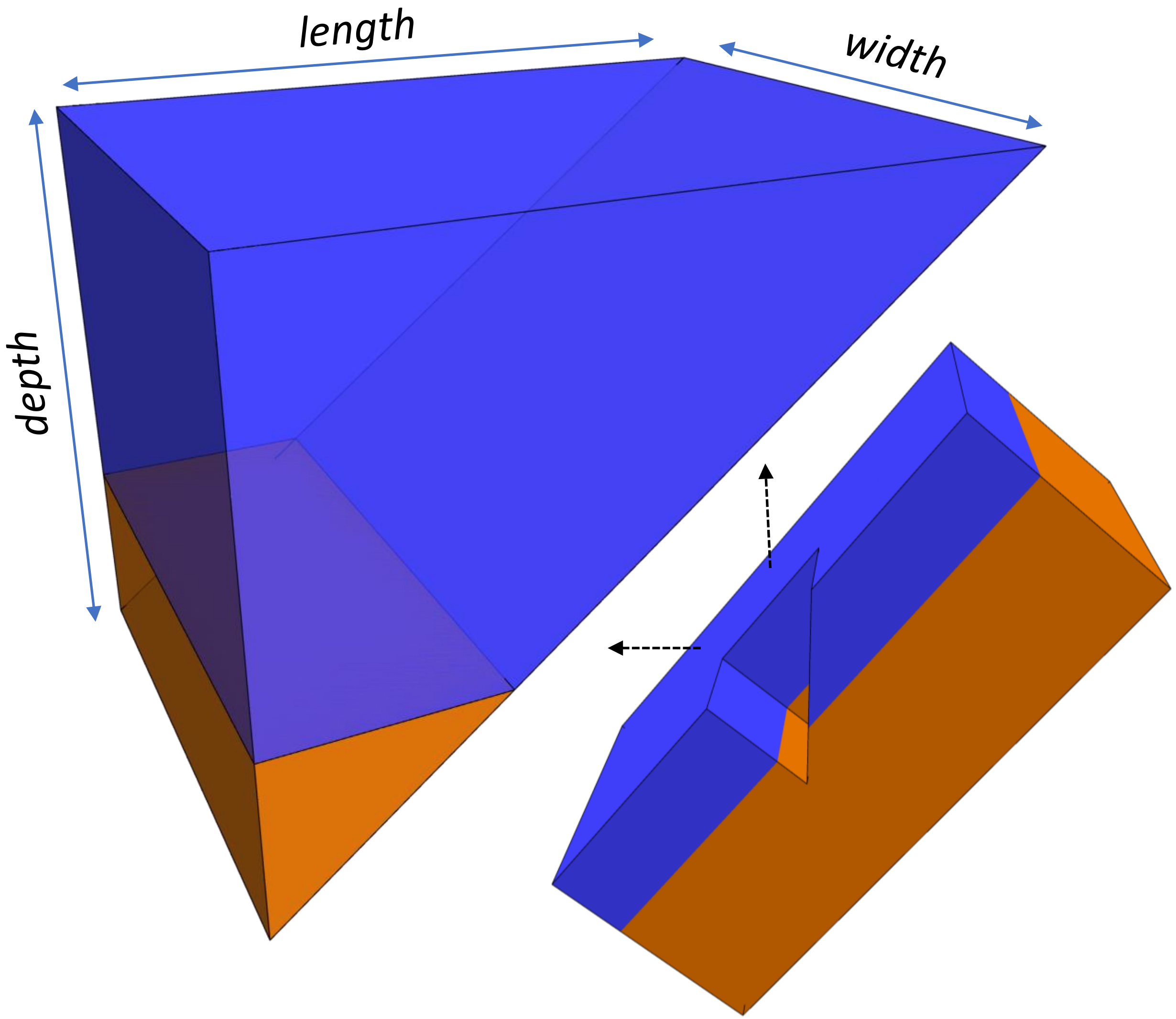
**Table 5-7** *Material Sputter Rates at 30 kV*

| Material | Volume per Dose [$\mu m^3$ / nC] | Material | Volume per Dose [$\mu m^3$ / nC] |
|---|---|---|---|
| *C* | 0.18 | *Au* | 1.50 |
| *Si* | 0.27 | *MgO* | 0.15 |
| *Al* | 0.30 | *$SiO_2$* | 0.24 |
| *Ti* | 0.37 | *$Al_2O_3$* | 0.08 |
| *Cr* | 0.10 | *TiO* | 0.15 |
| *Fe* | 0.29 | *$Si_3N_4$* | 0.20 |
| *Ni* | 0.14 | *TiN* | 0.15 |
| *Cu* | 0.25 | *$Fe_2O_3$* | 0.25 |
| *Mo* | 0.12 | *GaAs* | 0.61 |
| *Ta* | 0.32 | *Pt* | 0.23 |
| *W* | 0.12 | *PMMA* | 0.40 |

## Volume rules of thumb

Cross-section milling generates a wedge (min. volume to expose face to $e^-$ beam): $V_{\mathrm{mill}} = 1/2\ l*w*d$

- $w \approx l$
- $l \geq d*\tan(52)$
- $V_{\mathrm{mill}} \approx 0.82\ d^3$



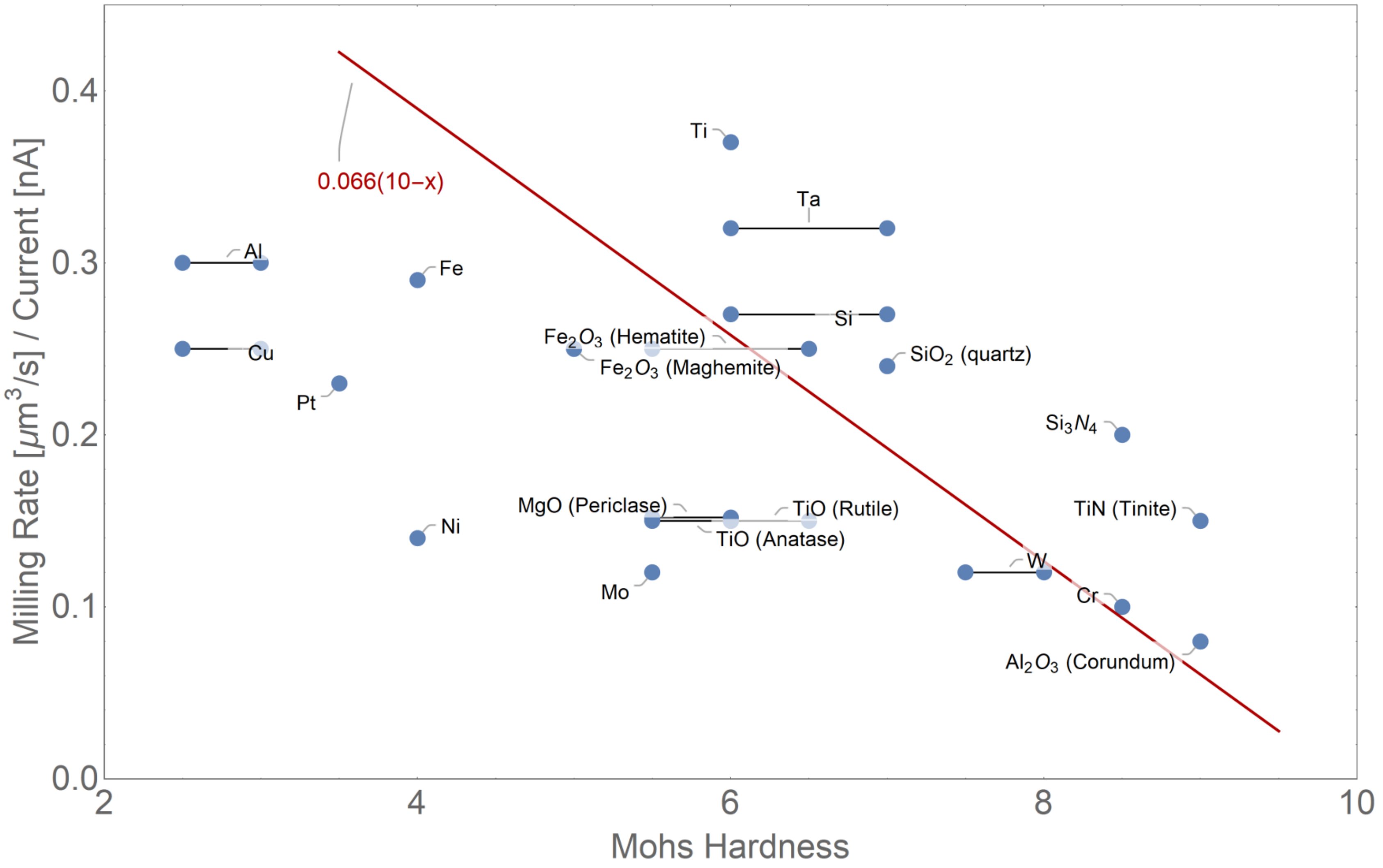
## Example calculations for various materials and depths

| Z | (V/d) | q [$\mu m^3$/s] | $t_{\mathrm{mill}}$ [min] | time (d=5μm) | time t(d=20μm) | time (d=100μm) |
|---|---|---|---|---|---|---|
| Au | 1.50 | 97.5 | $d^3/7135$ | 1 s | 1 min | 2.5 hr |
| Al | 0.30 | 19.5 | $d^3/1427$ | 5 s | 5.5 min | 12 hr |
| $Al_2O_3$ | 0.08 | 5.2 | $d^3/381$ | 20 s | 21 min | 44 hr |

# Estimating Milling Time

The listed sputter rates have a roughly ~linear dependence on the hardness. So, for materials not listed, but which have known hardnesses, the sputtering time can be estimated by:

$$t_{\text{mill}}[\text{min}] \approx \frac{(depth[\mu m])^3}{4.83 * (10 - Mohs) \; * I[nA]}$$



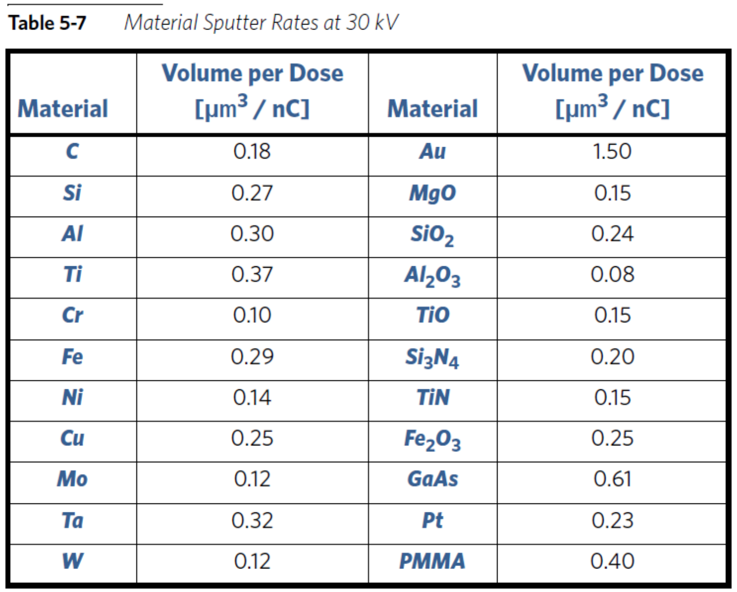


**Table 5-7** *Material Sputter Rates at 30 kV*

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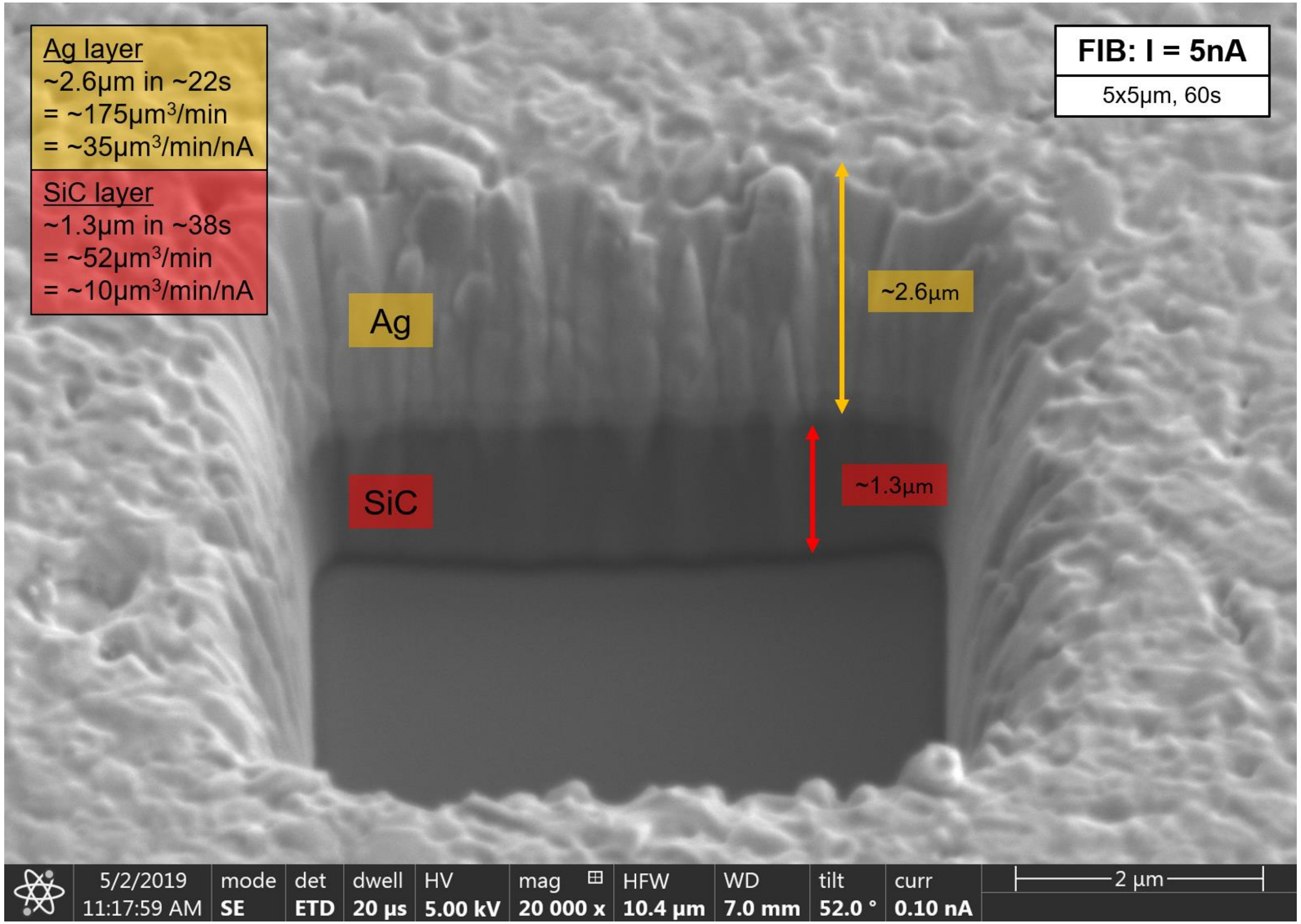
| ***Ti*** | 0.37 | ***Al₂O₃*** | 0.08 |
| ***Cr*** | 0.10 | ***TiO*** | 0.15 |
| ***Fe*** | 0.29 | ***Si₃N₄*** | 0.20 |
| ***Ni*** | 0.14 | ***TiN*** | 0.15 |
| ***Cu*** | 0.25 | ***Fe₂O₃*** | 0.25 |
| ***Mo*** | 0.12 | ***GaAs*** | 0.61 |
| ***Ta*** | 0.32 | ***Pt*** | 0.23 |
| ***W*** | 0.12 | ***PMMA*** | 0.40 |

# Estimating Milling Time

For unknown materials (or for a more precise value), a short preliminary test can determine milling rate:

- Mill a small square (~5x5µm) in a test region for 60s
- Measure the depth achieved
- (V/d)[µm$^3$/nA/min] = 25*depth[µm]/I[nA]

- ○ *In the example to the right, using the Moh's value for Ag (2.5-3) yields a very similar milling rate compared to what we see experimentally (~31 vs ~35 µm$^3$/min/nA)*
- ○ *Conversely, the predicted rate for SiC (Moh's 9-9.5) is significantly lower than what we actually see (~3 vs 10µm$^3$/min/nA)*



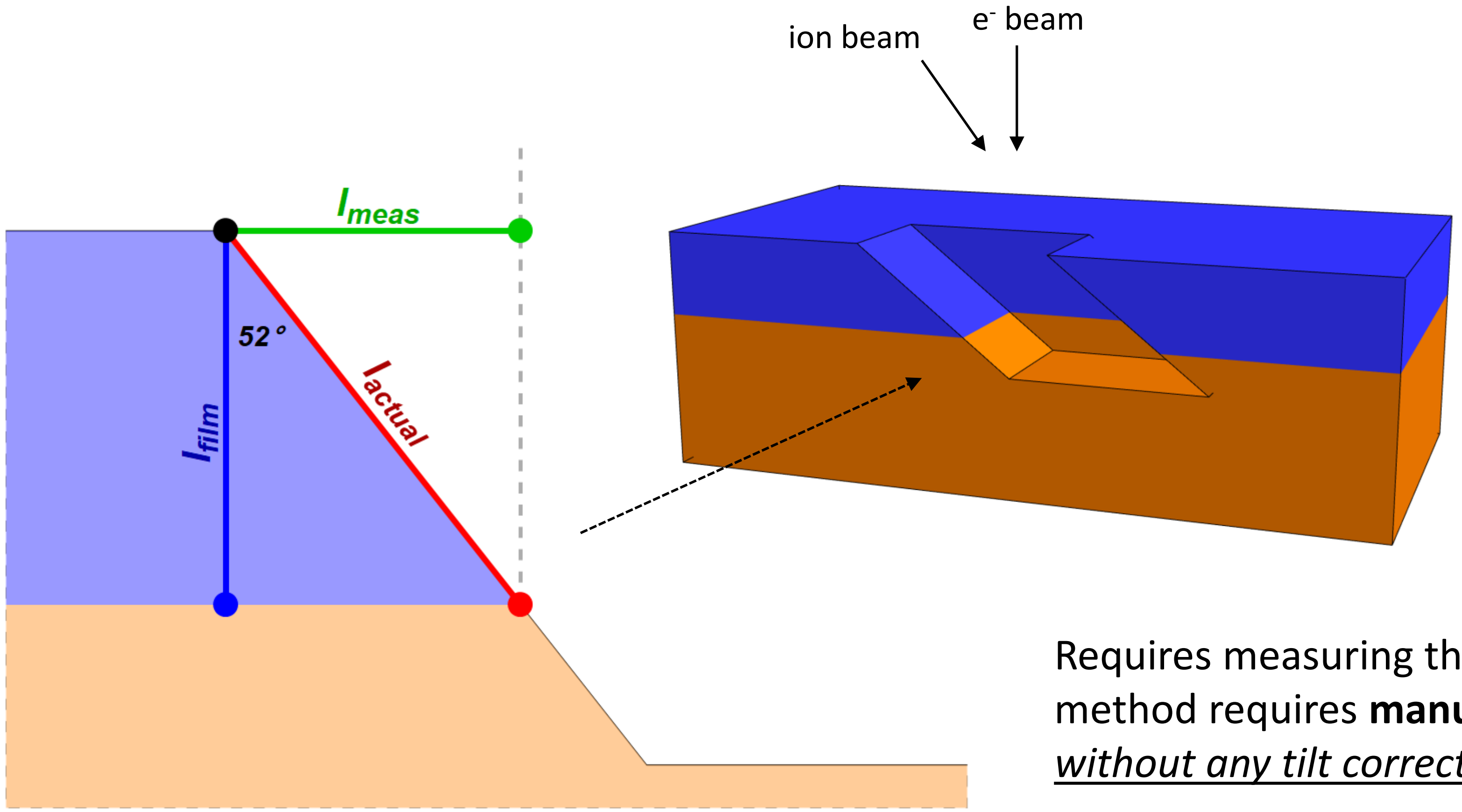
Ag layer
~2.6µm in ~22s
= ~175µm$^3$/min
= ~35µm$^3$/min/nA

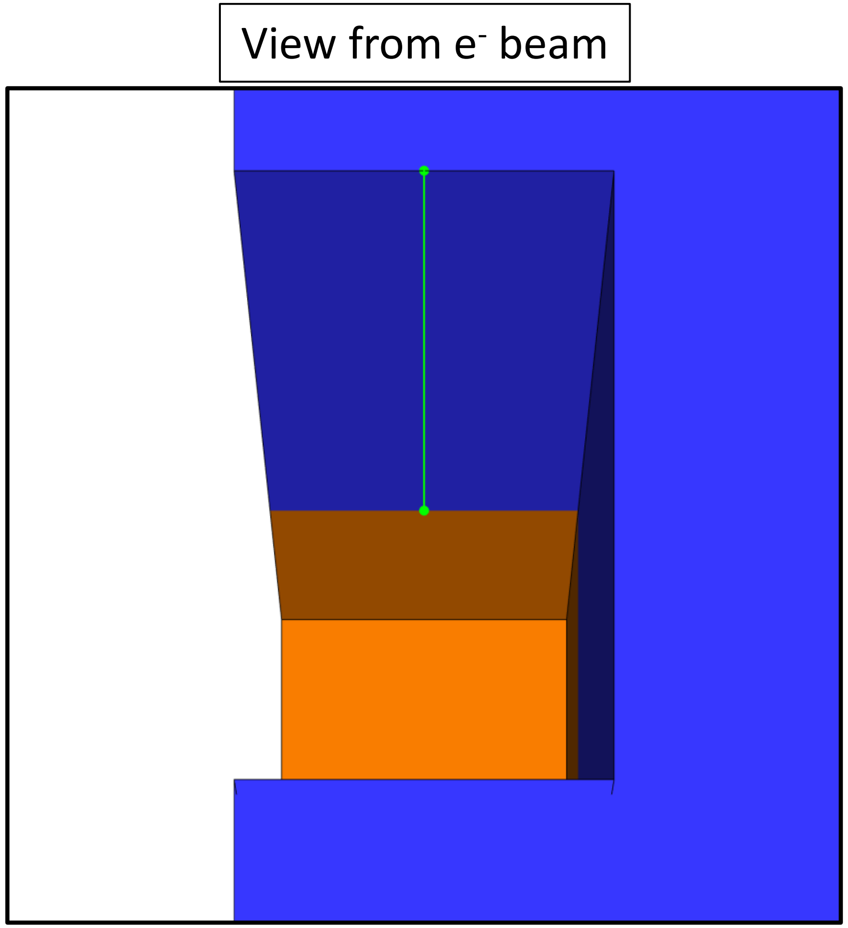
SiC layer
~1.3µm in ~38s
= ~52µm$^3$/min
= ~10µm$^3$/min/nA

**FIB: I = 5nA**
5x5µm, 60s

**Oblique Milling** (ie milling w/o tilting the sample perpendicular to the ion beam). Useful for:

- Samples that aren't easily tilted
- Analysis of very fine films – angled cut elongates the exposed cross-section





Requires measuring the thickness of an exposed film via this method requires **manual** conversion. Using the length acquired *without any tilt correction*, use the following:

$$l_{act} = \frac{l_{meas}}{\sin(52°)} = 1.27 * l_{meas}$$

$$l_{film} = \frac{l_{meas}}{\tan(52°)} = 0.78 * l_{meas}$$