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# Etching Gold using Oxford Ion Mill Tool

**Object:** To get the etch rate and selectivity ($Al_2O_3$ as an etch mask), as well as etch profile, of Au by using Oxford Ion Mill tool.

**Experimental:**

1) **Wafer Clean**: two 4" Si wafers cleaned by a) soaking in acetone (2' in ultrasonic bath) and methanol (1' in ultrasonic bath), then, DI water rinse; b) dipping them in buffered HF in 1', then, DI water rinse and nitrogen gas blow dry.

2) **Depositing** Ti/Au (10/500 nm: nominal thickness) using E-beam#4.

3) **Lithography** for making the etch pattern:

a) Gasonics: #3 for 3 minutes.

b) Spinning-on HMDS: 3000 rpm for 30 s.

c) Spinning-on SF-8 (PMGI): 1500 rpm for 40 s.

d) Bake at 200 C for 3 minutes.

e) Spinning-on SPR955-0.9: 3000 rpm for 30 s.

f) Bake at 95 C for 90 s.

g) Exposing using Auto-stepper200 for shooting an 11X11 array with 0.38 s (Recipe name: Ning) using the calibration reticle.

h) Post Exposure bake at 110 C for 90 s.

i) Development in AZ300MIF for 2 minutes.

j) $O_2$ plasma descum 300mT/100W 60 s.

4) **Depositing** $Al_2O_3$ (target thickness: 200 nm, actual thickness: 206 nm, Tooling factor: 149.2) using E-beam#2.

5) **Lifting-off $Al_2O_3$**: a) soaking in 1165 striper in 80 C hot-plate for 4h40m; b) soaking in fresh 1165 in 70 C hot-water ultrasonic wave bath for 5 minutes (ultrasonic wave was on); c) soaking in Isopropanol in room-temperature water ultrasonic wave bath for 3 minutes (ultrasonic wave was on), then, DI water rinse and nitrogen gas blow dry; d) Gasonics: recipe: #3 for 3 minutes.

6) **Cleaving** the wafer into sample pieces for ion-mill.

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## Results:

Table 1. Etch rate and selectivity ($Au/Al_2O_3$), and side-wall angle of Au under different ion-mill conditions (both Ar flow rates to neutralizer and beam are 5 sccm; platen and chamber wall temperatures are 10 and 40 C, respectively; platen rotation speed is 20 rpm).

| Sample# | date | In (mA) | Prf (W) | Ib (mA) | Vb (V) | Va (V) | Incident Angle ($^o$) | Etch Time (minute) | Etch Rate (nm/min) | Etch Selectivity ($Au/Al_2O_3$) | Side-wall angle ($^o$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Au#1B-00 | 7/14/2015 | unetched, $Al_2O_3$ Thickness=206 nm | | | | | | | | | 65. 8 |
| Au#1B-01 | 7/14/2015 | 250 | 250 | 50 | 500 | 500 | -15 | 15 | 28.7 | 13.9 | 65.9 |
| Au#1B-02 | 7/14/2015 | 250 | 250 | 150 | 500 | 500 | -15 | 3 | 103.3 | 12.9 | 62.6 |
| Au#1B-03 | 7/14/2015 | 250 | 250 | 150 | 500 | 500 | -30 | 3 | 100 | 4.5 | 72.5 |
| Au#1B-04 | 7/16/2015 | 250 | 250 | 150 | 500 | 500 | -24.2 | 3 | 102.7 | 5.6 | 70 |
| Au#1B-05 | 7/16/2015 | 250 | 250 | 150 | 500 | 500 | 24.2 | 3 | 100 | 5.2 | 72.3 |
| Au#1B-06 | 7/22/2015 | 250 | 250 | 150 | 500 | 500 | 0 | 3.5 | 114.3 | 7.9 | 62.2 |
| Au#1B-07 | 7/22/2015 | 250 | 250 | 150 | 500 | 500 | -27.8 | 3.5 | 97.7 | 5.6 | 72.1 |
| Au#1B-08 | 7/22/2015 | 250 | 250 | 150 | 500 | 500 | 27.8 | 3.5 | 94.6 | 4.8 | 76 |
| Au#1B-09 | 8/25/2015 | 250 | 200 | 50 | 500 | 500 | -27.8 | 14 | 25.6 | 6.2 | 72.1 |
| Au#1B-10 | 8/25/2015 | 250 | 200 | 50 | 500 | 500 | 27.8 | 14 | 25.4 | 4.5 | 74.6 |
| Au#1B-11 | 9/11/2015 | 250 | 200 | 100 | 500 | 500 | 27.8 | 7 | 56.9 | 5.1 | 75.1 |
| Au#1B-12 | 9/11/2015 | 250 | 200 | 100 | 500 | 500 | -27.8 | 7 | 58.4 | 6.5 | 73.5 |
| Au#1B-13 | 9/16/2015 | 250 | 200 | 150 | 350 | 500 | 27.8 | 5.5 | 76.7 | 4.3 | 72.5 |
| Au#1B-14 | 9/16/2015 | 250 | 200 | 150 | 200 | 500 | 27.8 | 7 | 49 | 4.6 | 70.4 |
| Au#1B-16 | 9/21/2015 | 250 | 250 | 200 | 1000 | 500 | -27.8 | 2.333333333 | 163 | 6.4 | 74.8 |
| Au#1B-17 | 9/24/2015 | 250 | 250 | 150 | 1000 | 500 | 27.8 | 3.5 | 106 | 5.3 | 77.9 |
| Au#1B-18 | 9/24/2015 | 250 | 250 | 150 | 750 | 500 | 27.8 | 4 | 108 | 4.9 | 76 |
| Au#1B-19 | 9/24/2015 | 250 | 250 | 100 | 1000 | 500 | 27.8 | 5 | 63 | 7.2 | 77.1 |
| Au#1B-20 | 9/24/2015 | 250 | 250 | 50 | 1000 | 500 | 27.8 | 10 | 32.3 | 4.7 | 78 |
| Au#1B-21 | 10/8/2015 | 250 | 200 | 25 | 1000 | 500 | 27.8 | 20 | 13 | 4.5 | 78.3 |

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Figure 1 Cross-section of Au layer and $Al_2O_3$ mask pattern before ion-mill. The average mask thickness and sidewall angle are 206 nm and 65.8$^o$, respectively.

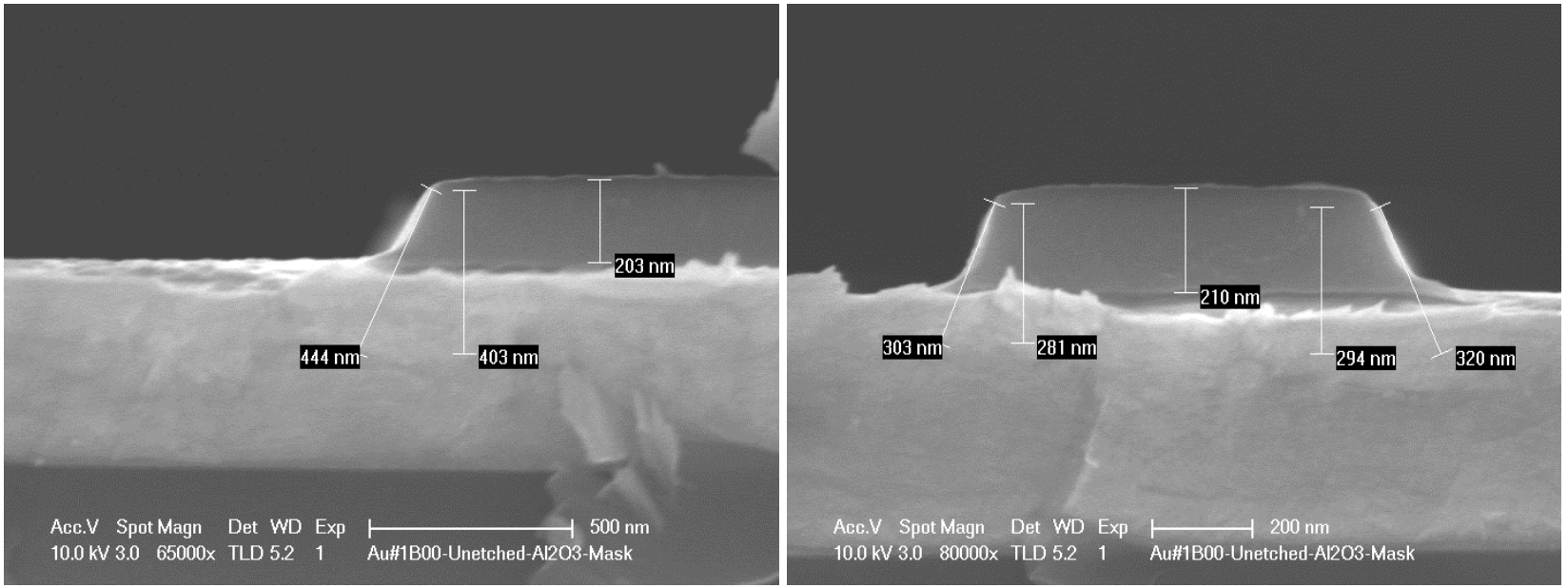


Figure 2 (a) and (b) Cross-section of the milled sample Au01 with $I_n$=250mA, $P_{rf}$=250W, $I_b$=50mA, $V_b$=500V, $V_a$=500V, incident angle=-15$^o$, and time=15 minutes.

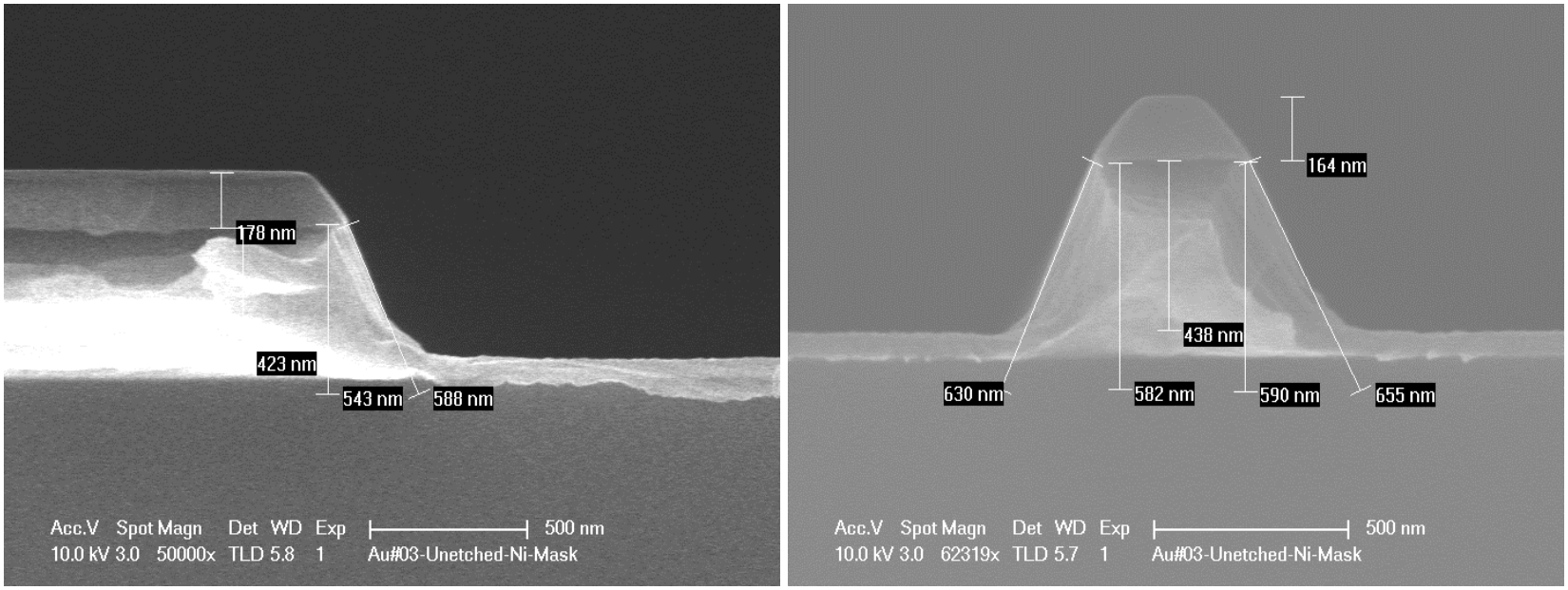


Figure 3 (a) and (b) Cross-section of the milled sample Au02 with $I_n$=250mA, $P_{rf}$=250W, $I_b$=150mA, $V_b$=500V, $V_a$=500V, incident angle=-15$^o$, and time=3 minutes.

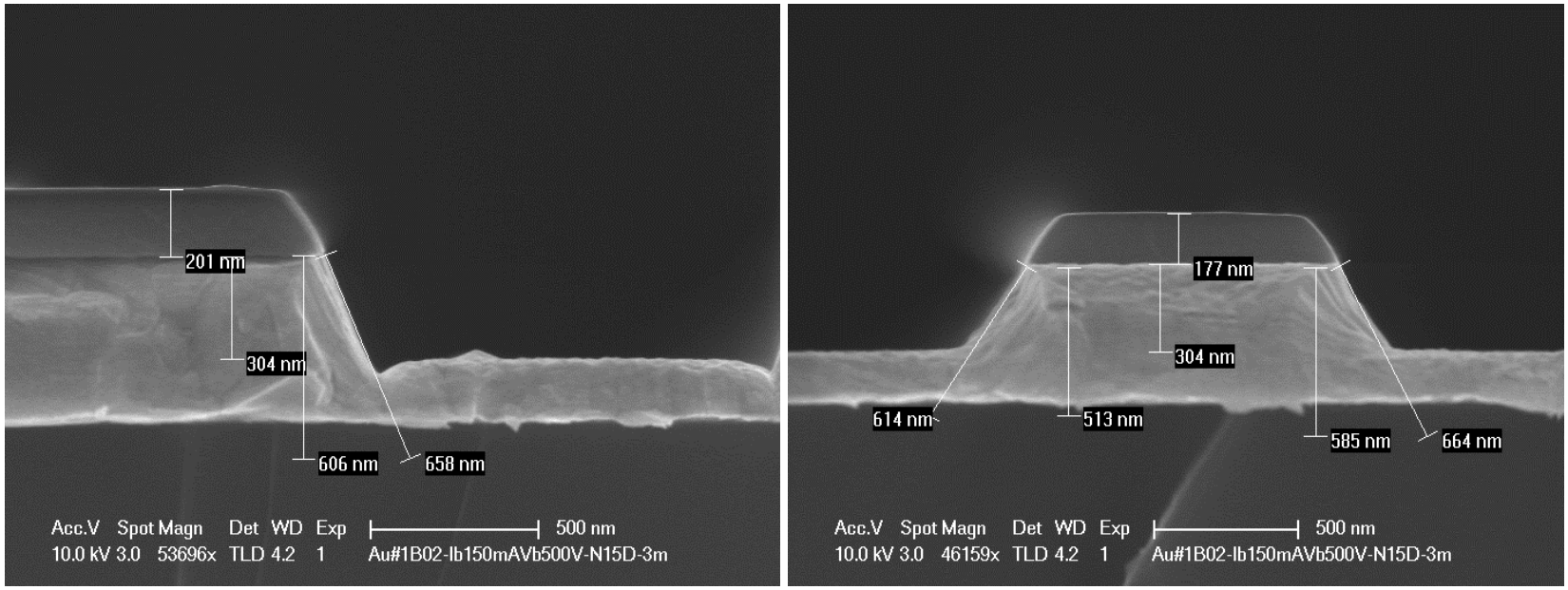


Figure 4 (a) and (b) Cross-section of the milled sample Au03 with $I_n$=250mA, $P_{rf}$=250W, $I_b$=150mA, $V_b$=500V, $V_a$=500V, incident angle=-30$^o$, and time=3 minutes.

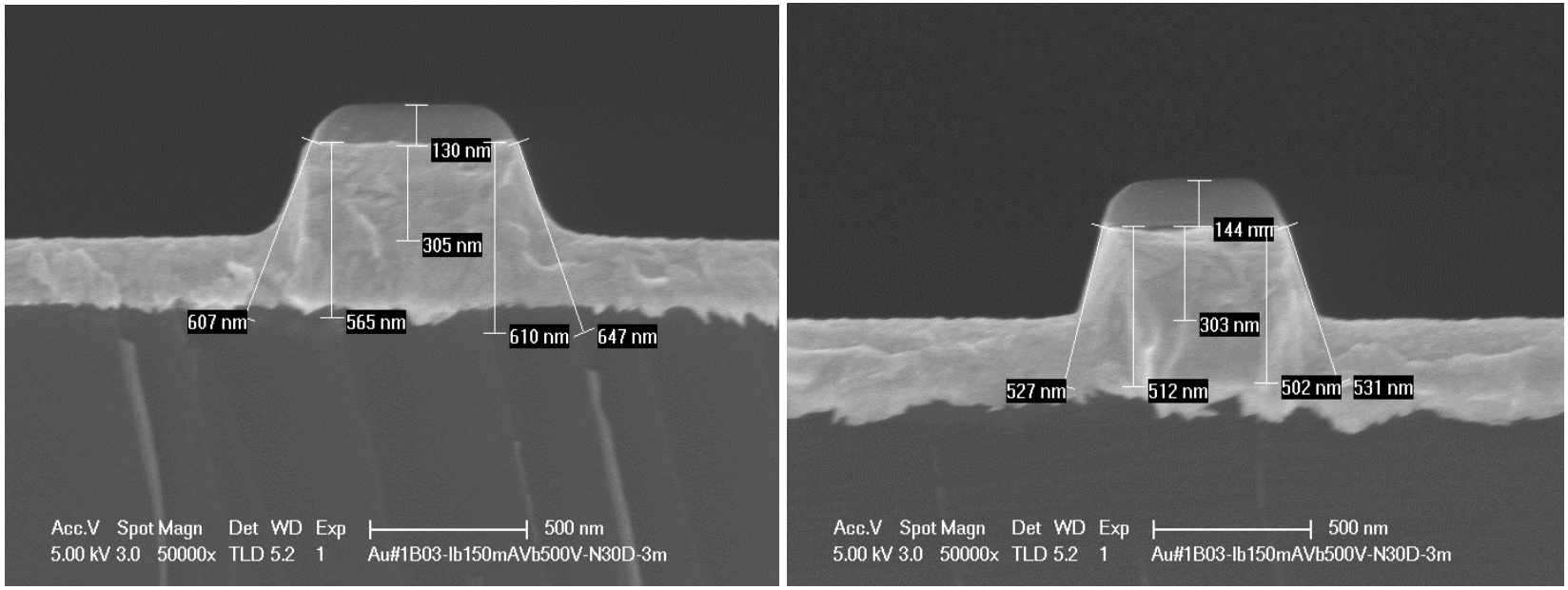
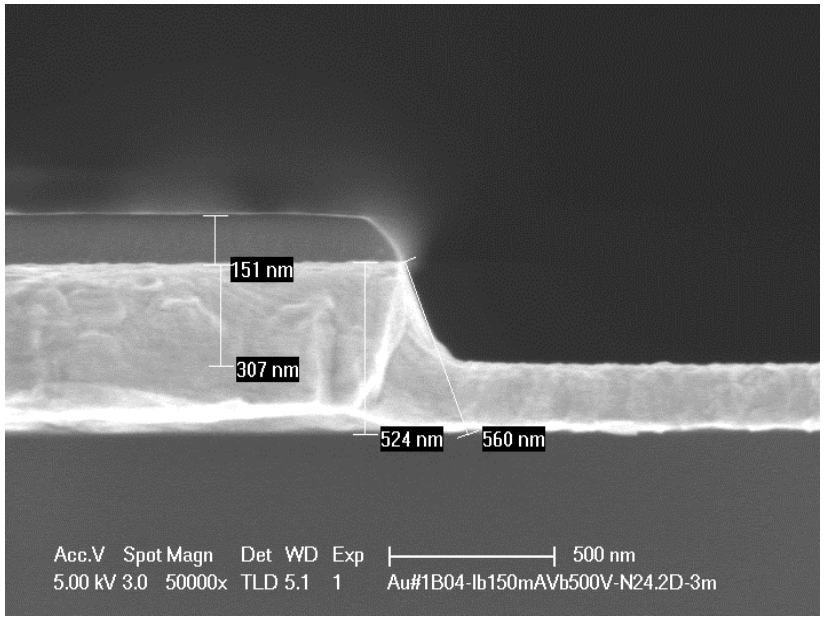


Figure 5 (a) and (b) Cross-section of the milled sample Au04 with $I_n$=250mA, $P_{rf}$=250W, $I_b$=150mA, $V_b$=500V, $V_a$=500V, incident angle=-24.2$^o$, and time=3 minutes.



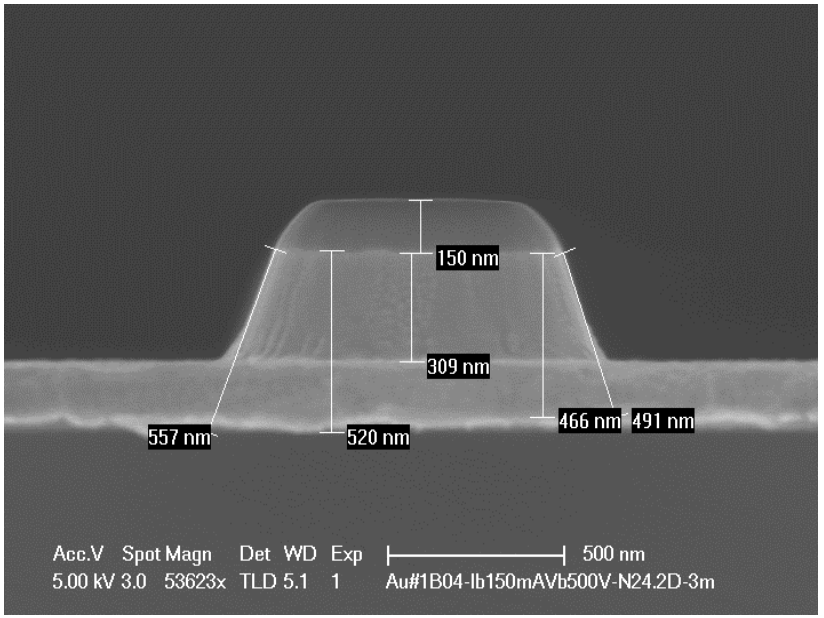



Figure 6 (a) and (b) Cross-section of the milled sample Au05 with $I_n$=250mA, $P_{rf}$=250W, $I_b$=150mA, $V_b$=500V, $V_a$=500V, incident angle=24.2$^o$, and time=3 minutes.

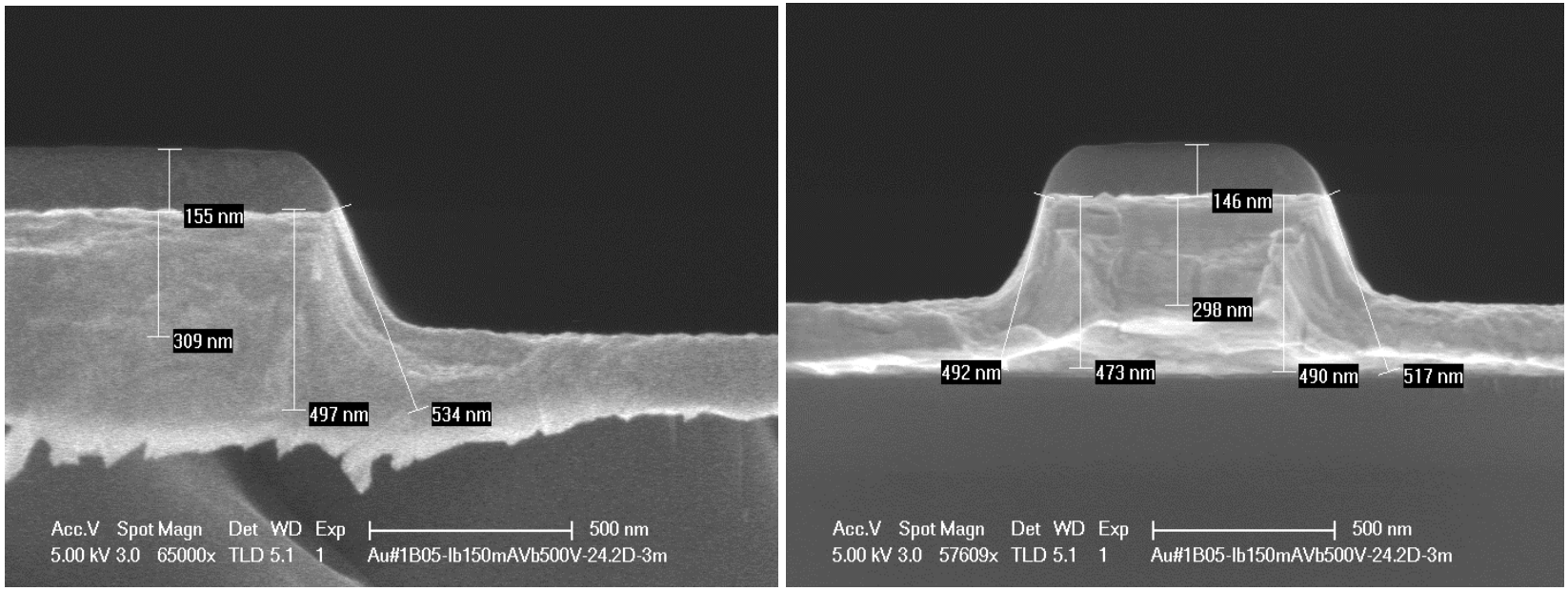
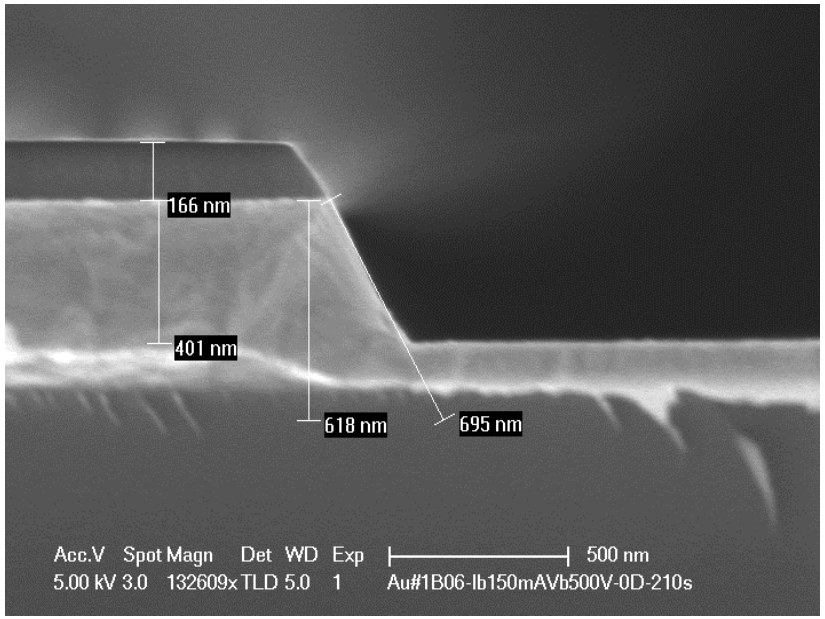


Figure 7 (a) and (b) Cross-section of the milled sample Au06 with $I_n$=250mA, $P_{rf}$=250W, $I_b$=150mA, $V_b$=500V, $V_a$=500V, incident angle=0$^o$, and time=3.5 minutes.



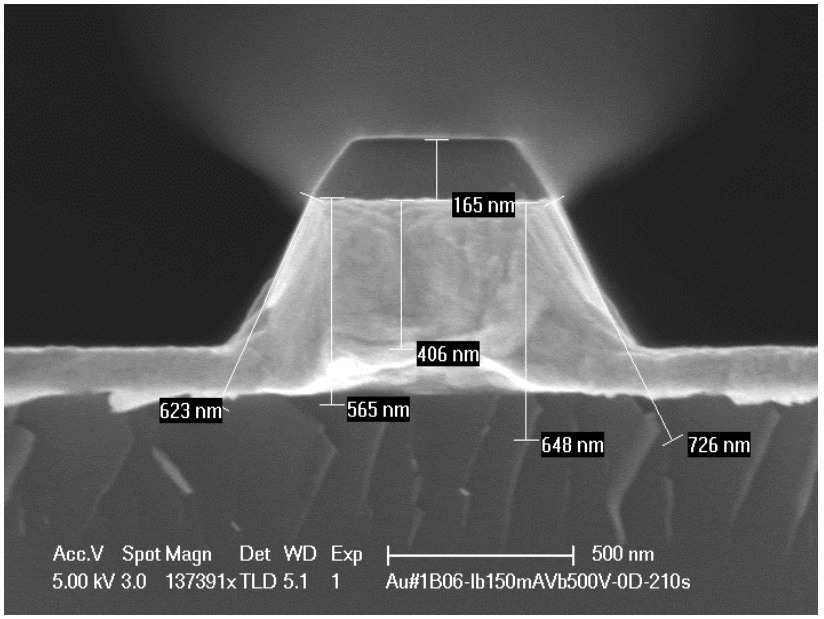
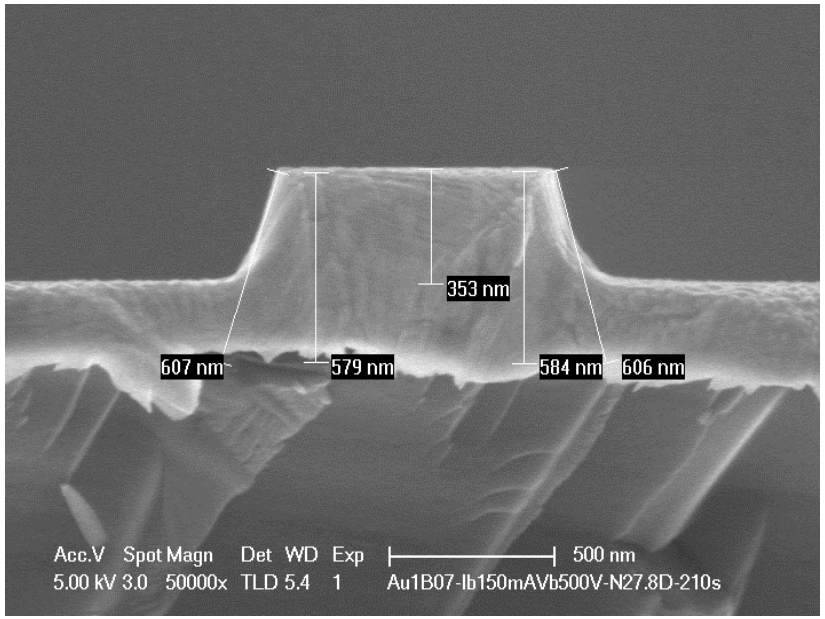



Figure 8 (a) and (b) Cross-section of the milled sample Au07 with $I_n$=250mA, $P_{rf}$=250W, $I_b$=150mA, $V_b$=500V, $V_a$=500V, incident angle=-27.8$^o$, and time=3.5 minutes.



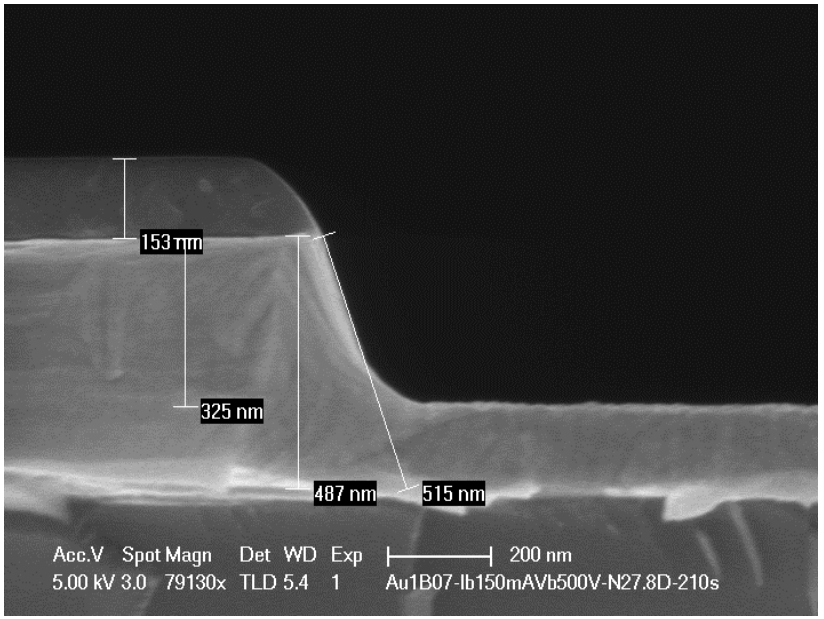



Figure 9 (a) and (b) Cross-section of the milled sample Au08 with $I_n$=250mA, $P_{rf}$=250W, $I_b$=150mA, $V_b$=500V, $V_a$=500V, incident angle=27.8$^o$, and time=3.5 minutes.

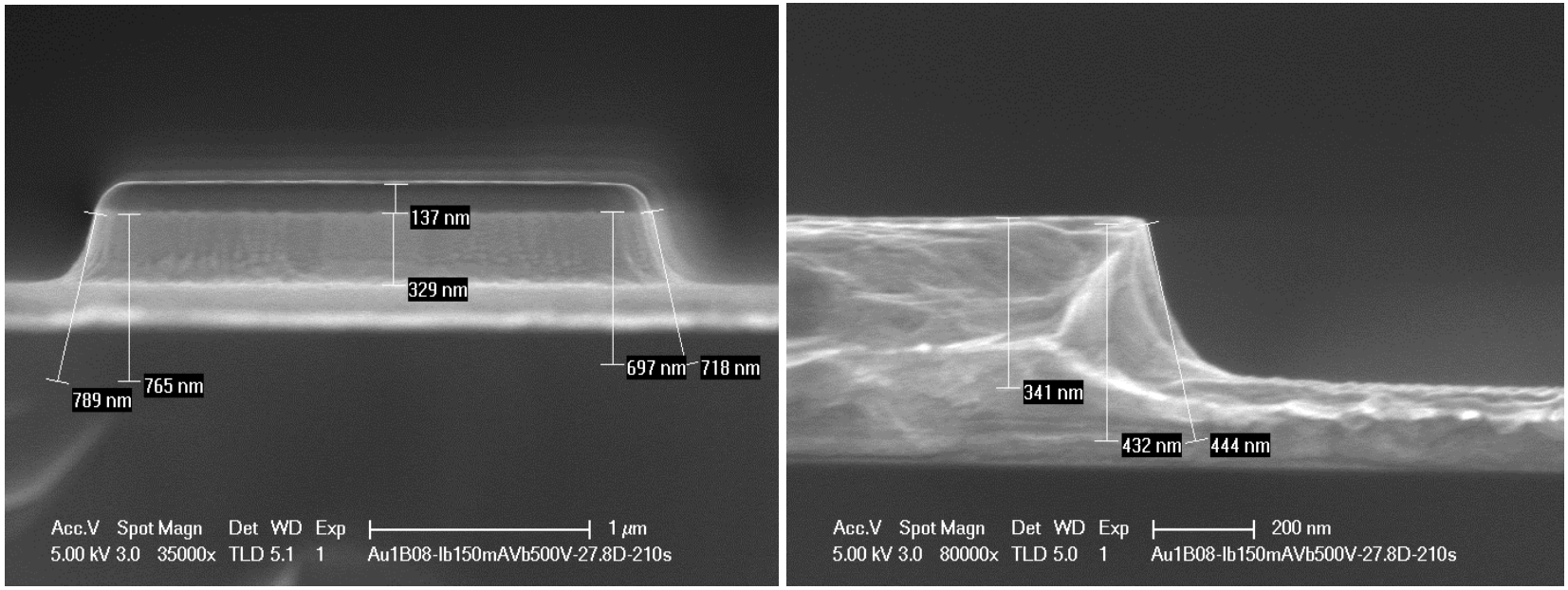


Figure 10 (a) and (b) Cross-section of the milled sample Au09 with $I_n$=250mA, $P_{rf}$=250W, $I_b$=50mA, $V_b$=500V, $V_a$=500V, incident angle=-27.8$^o$, and time=14 minutes.

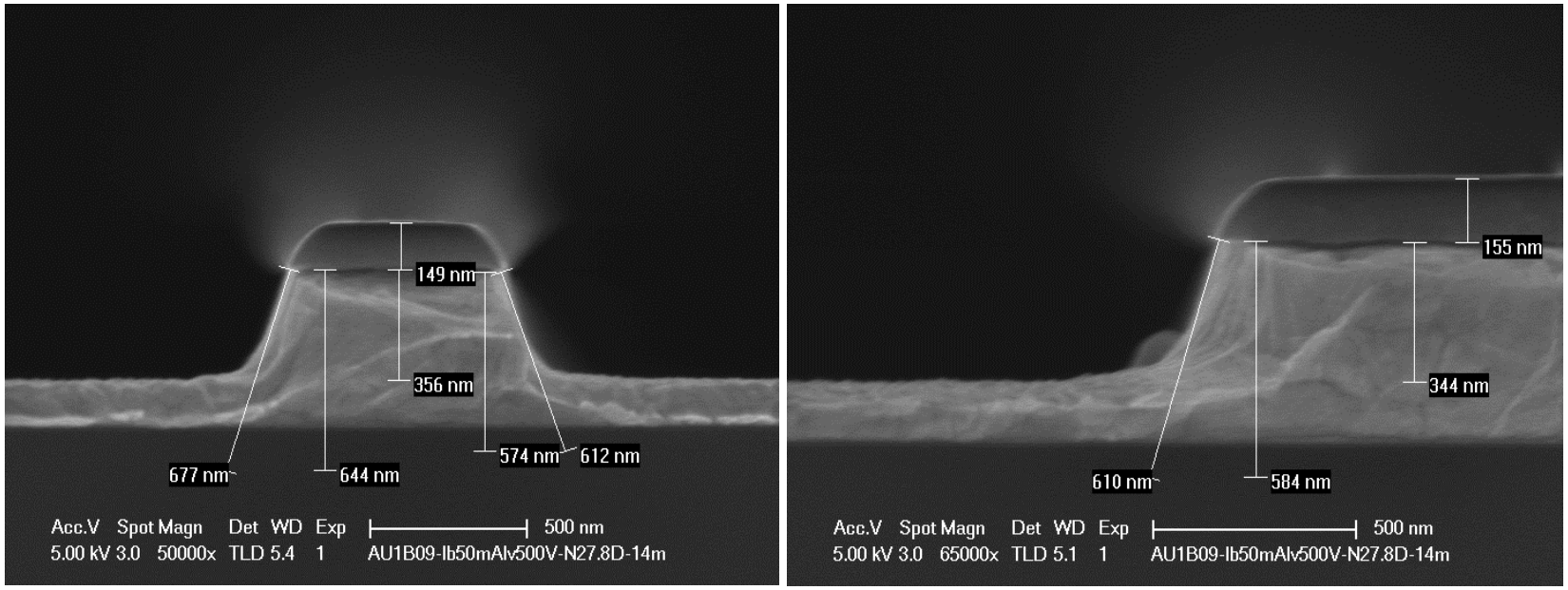


Figure 11 (a) and (b) Cross-section of the milled sample Au10 with $I_n$=250mA, $P_{rf}$=250W, $I_b$=50mA, $V_b$=500V, $V_a$=500V, incident angle=27.8$^o$, and time=14 minutes.

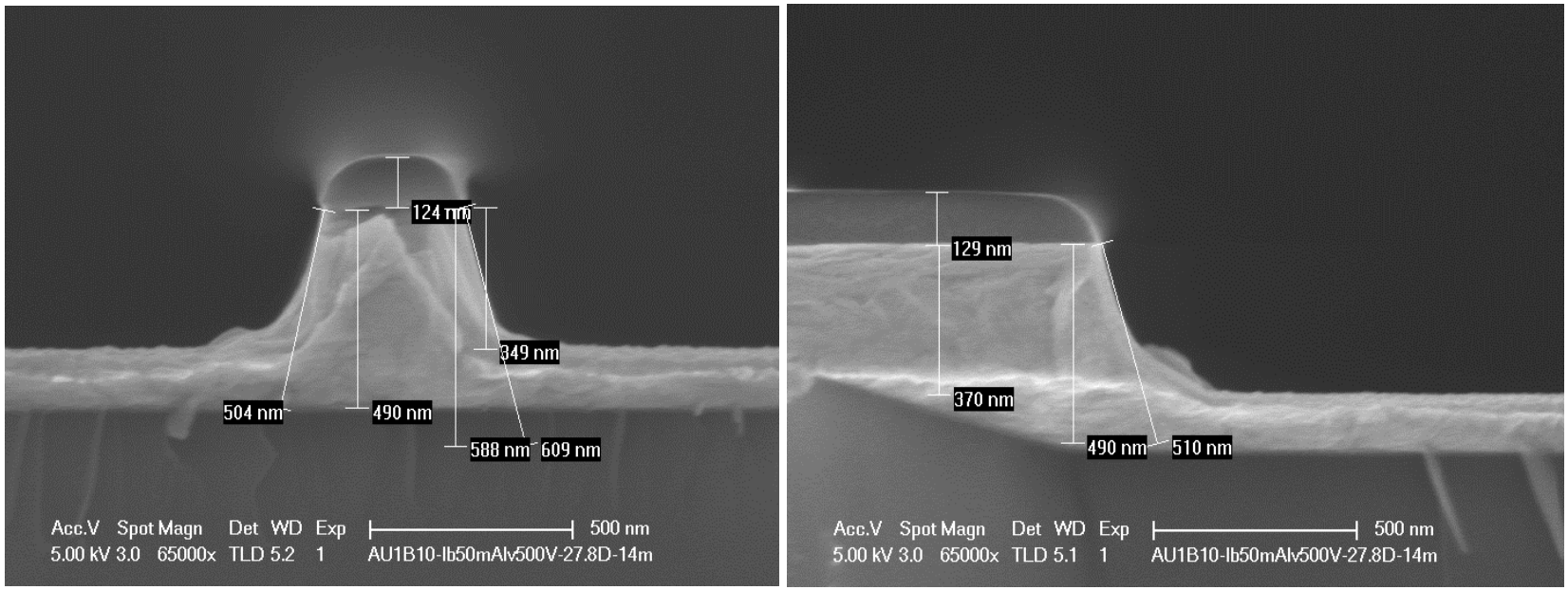
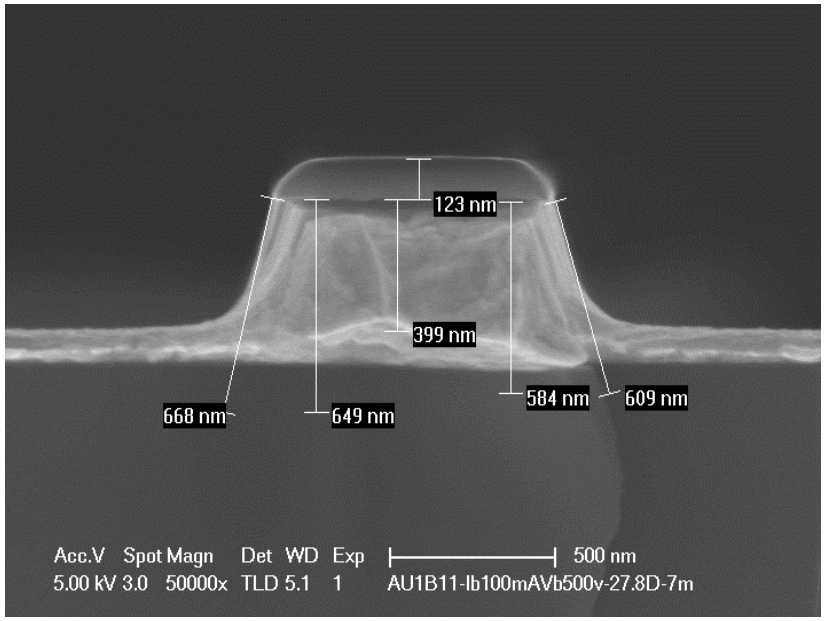


Figure 12 (a) and (b) Cross-section of the milled sample Au11 with $I_n$=250mA, $P_{rf}$=250W, $I_b$=100mA, $V_b$=500V, $V_a$=500V, incident angle=27.8$^o$, and time=7 minutes.



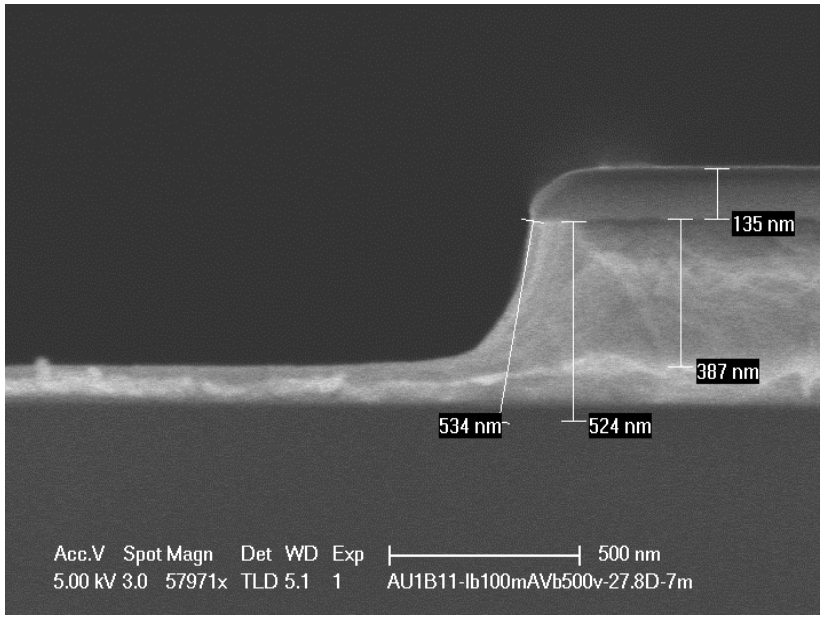



Figure 13 (a) and (b) Cross-section of the milled sample Au12 with $I_n$=250mA, $P_{rf}$=250W, $I_b$=100mA, $V_b$=500V, $V_a$=500V, incident angle=-27.8$^o$, and time=7 minutes.

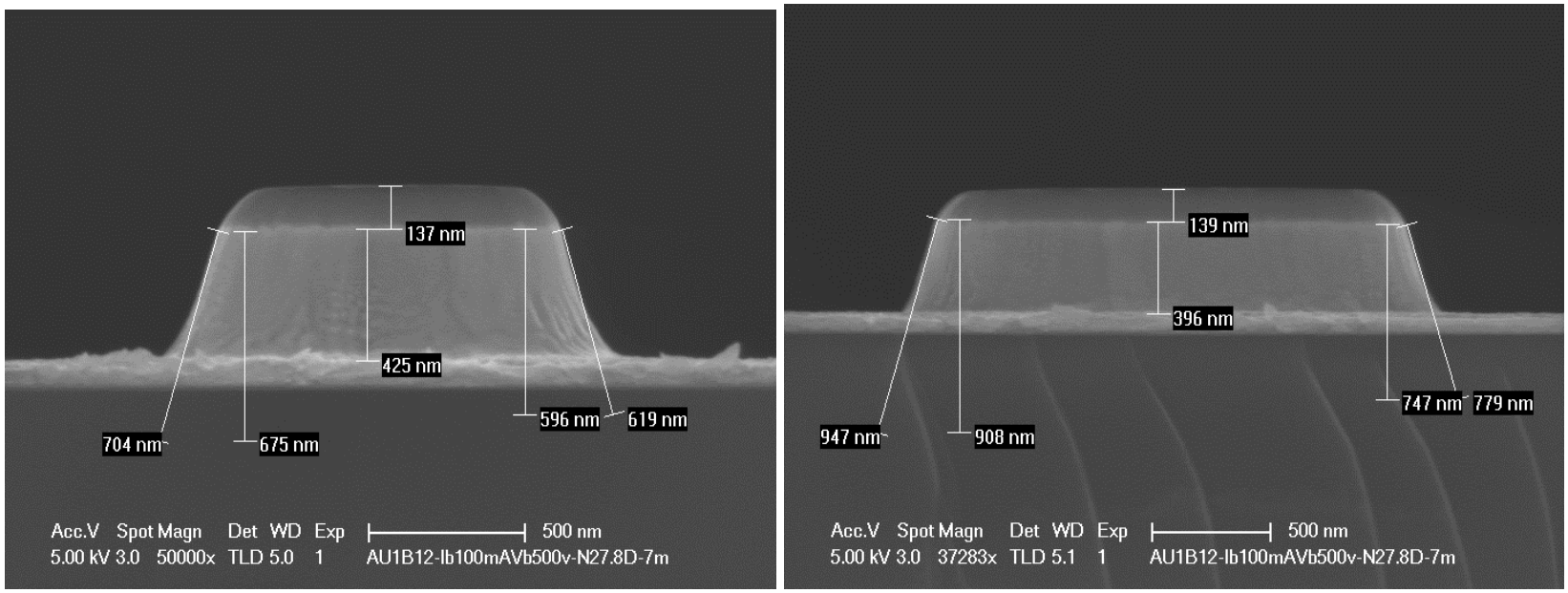


Figure 14 (a) and (b) Cross-section of the milled sample Au13 with $I_n$=250mA, $P_{rf}$=200W, $I_b$=150mA, $V_b$=350V, $V_a$=500V, incident angle=27.8º, and time=5.5 minutes.

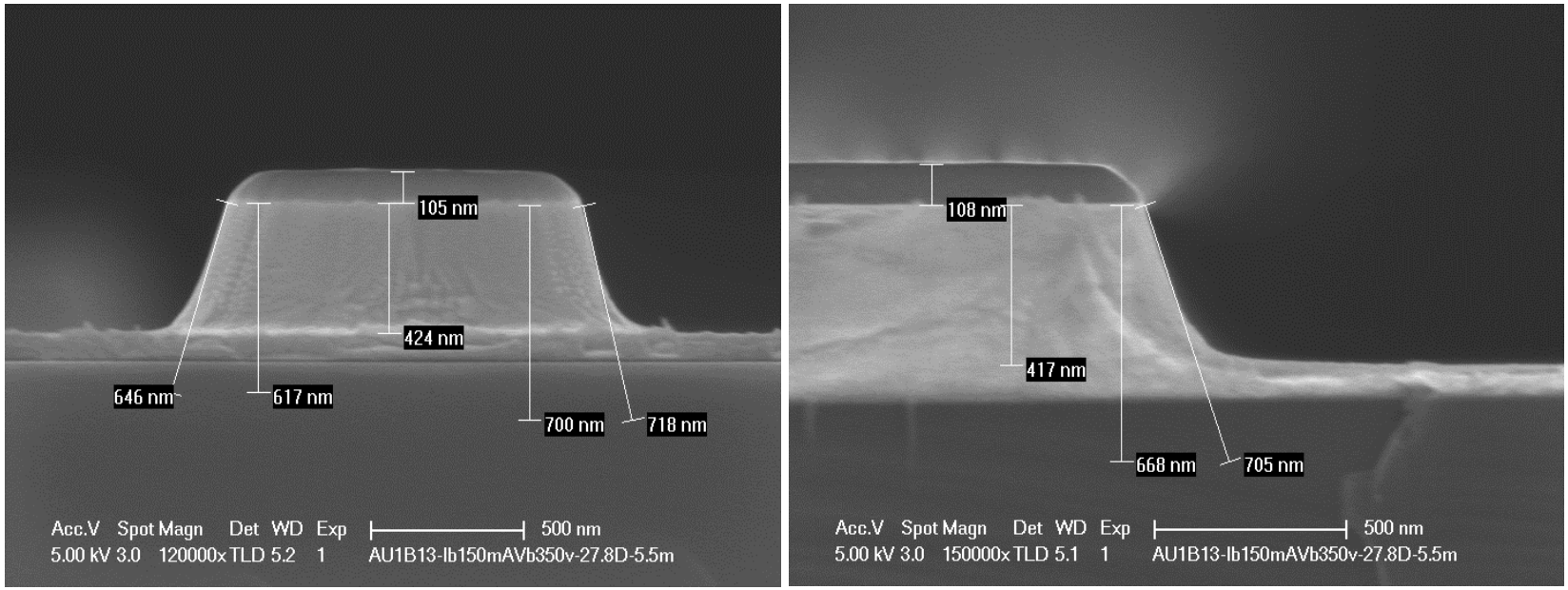


Figure 15 (a) and (b) Cross-section of the milled sample Au14 with $I_n$=250mA, $P_{rf}$=200W, $I_b$=150mA, $V_b$=200V, $V_a$=500V, incident angle=27.8$^o$, and time=7 minutes.

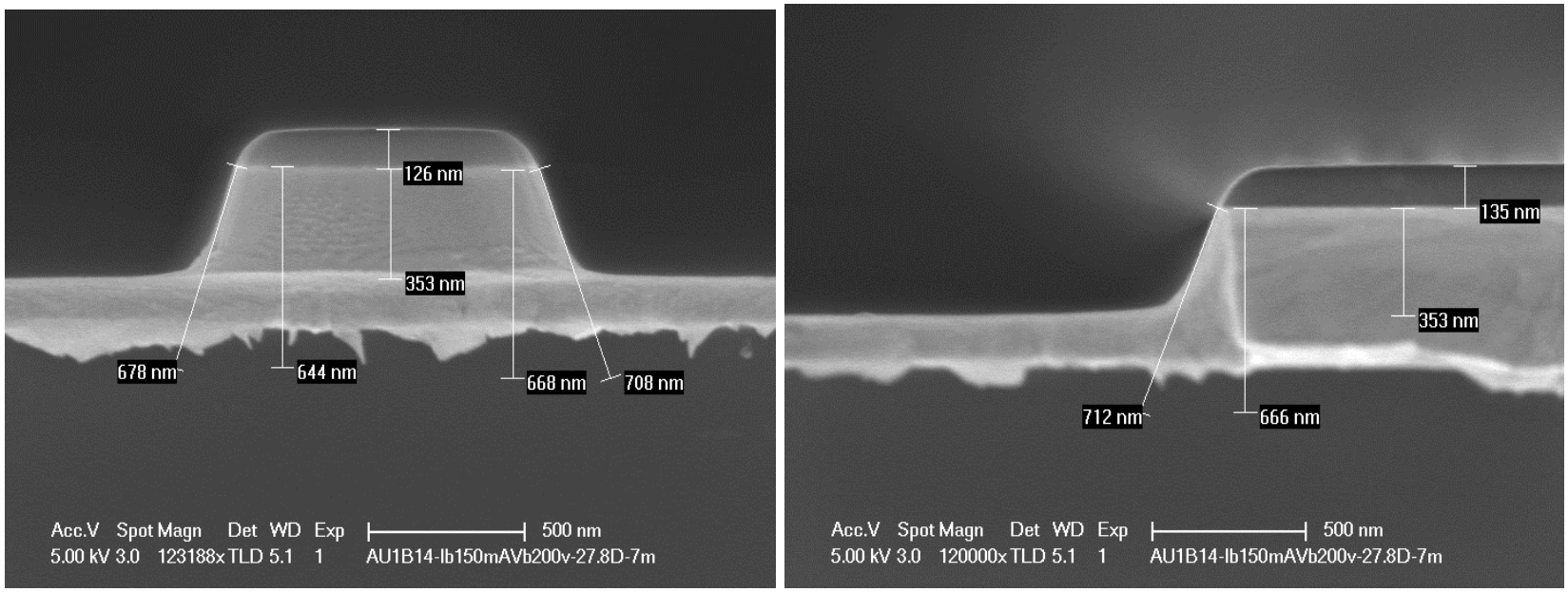
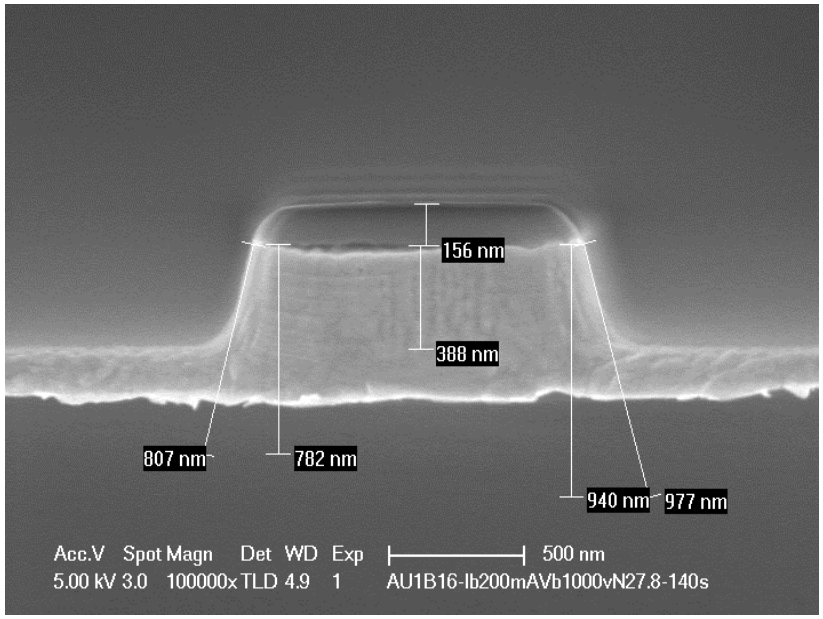


Figure 16 (a) and (b) Cross-section of the milled sample Au16 with $I_n$=250mA, $P_{rf}$=250W, $I_b$=200mA, $V_b$=1000V, $V_a$=500V, incident angle=-27.8$^o$, and time=140 s.



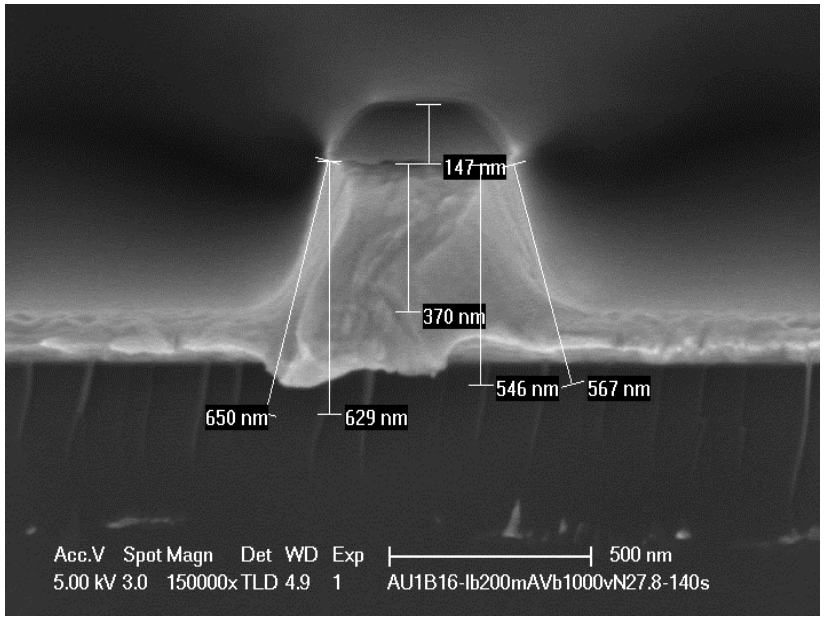



Figure 17 (a) and (b) Cross-section of the milled sample Au17 with $I_n$=250mA, $P_{rf}$=250W, $I_b$=150mA, $V_b$=1000V, $V_a$=500V, incident angle=27.8º, and time=3.5 minutes.

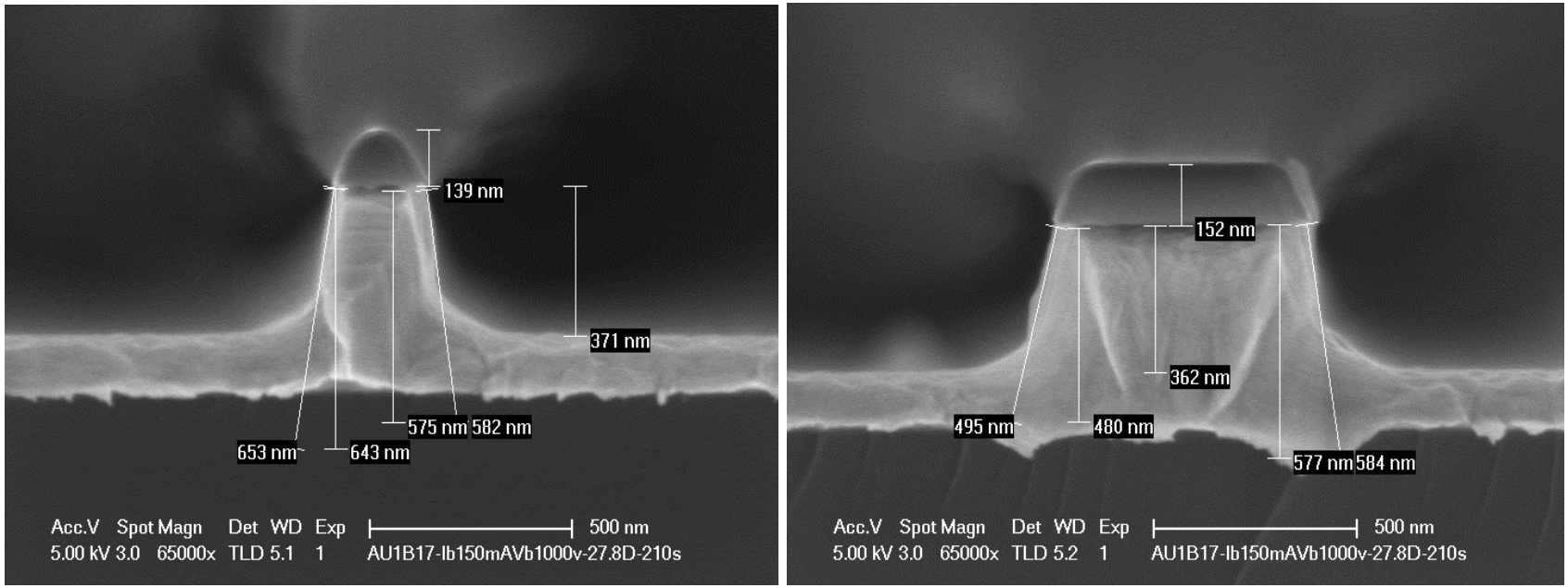
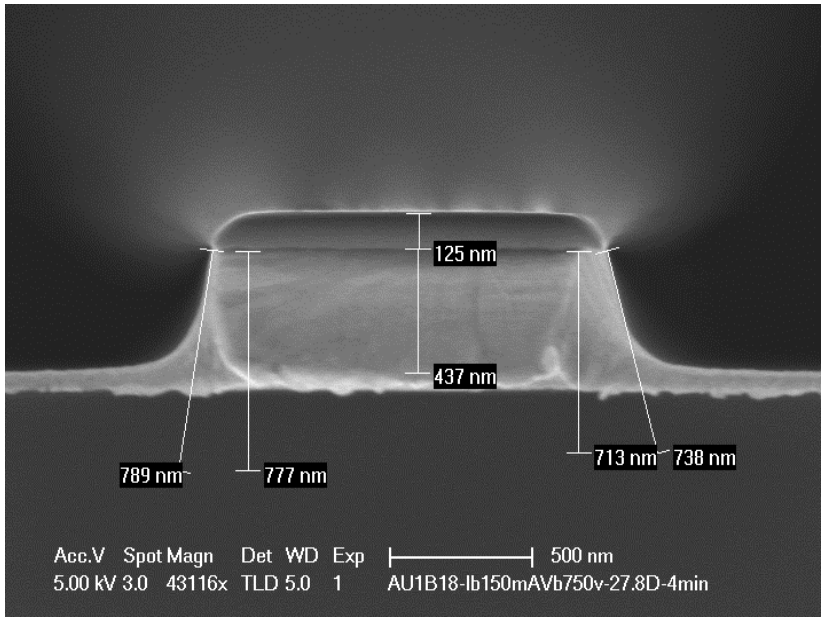


Figure 18 (a) and (b) Cross-section of the milled sample Au18 with $I_n$=250mA, $P_{rf}$=250W, $I_b$=150mA, $V_b$=750V, $V_a$=500V, incident angle=27.8$^o$, and time=4 minutes.



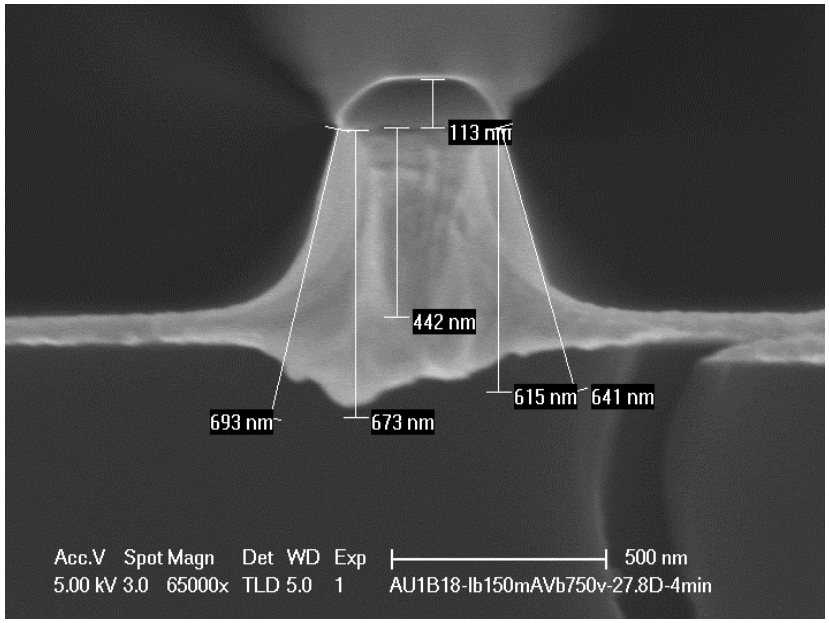



Figure 19 (a) and (b) Cross-section of the milled sample Au19 with $I_n$=250mA, $P_{rf}$=250W, $I_b$=100mA, $V_b$=1000 v, $V_a$=500V, incident angle=27.8$^o$, and time=5 minutes.

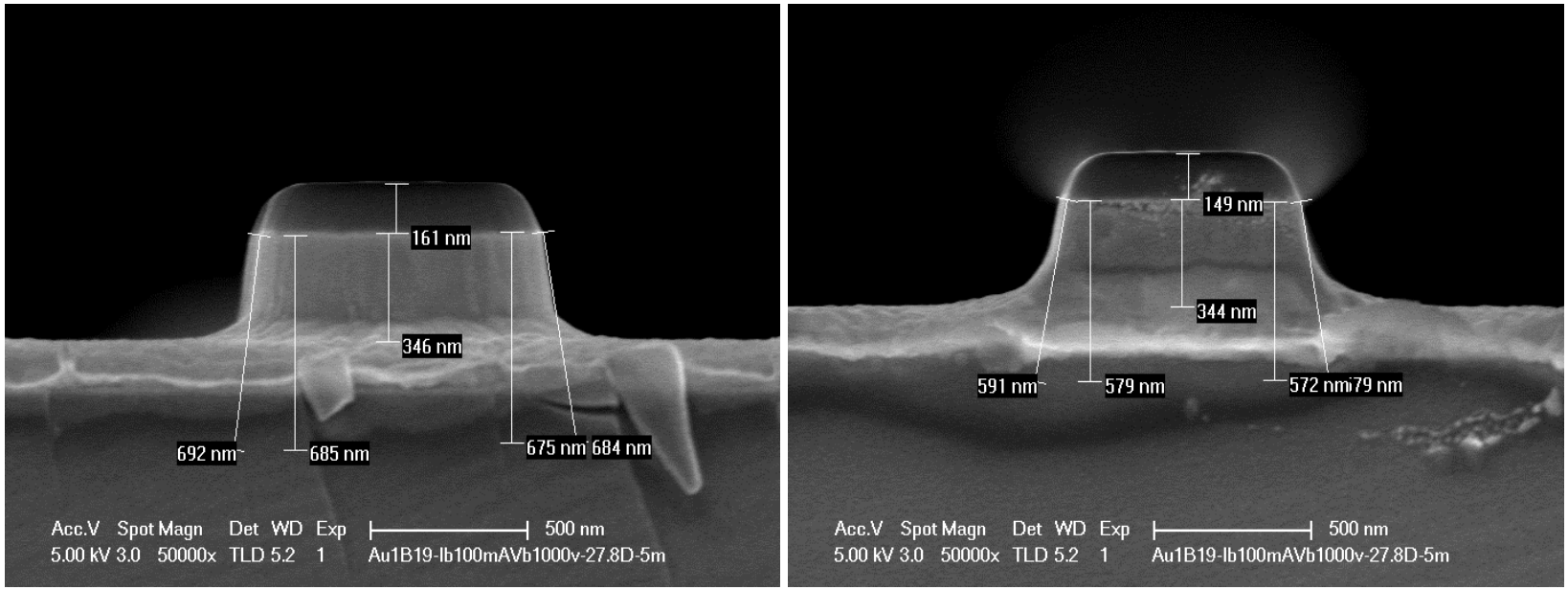
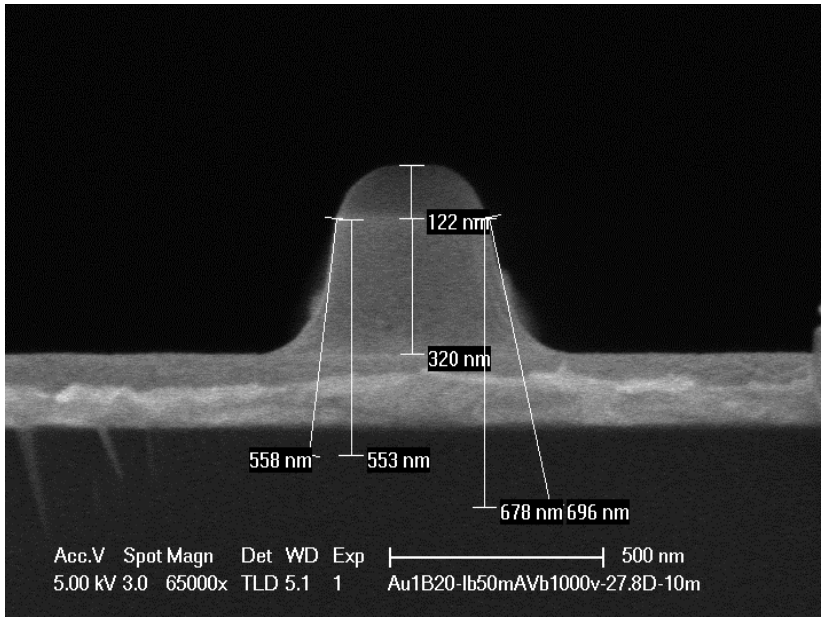


Figure 20 (a) and (b) Cross-section of the milled sample Au20 with $I_n$=250mA, $P_{rf}$=200W, $I_b$=50mA, $V_b$=1000 v, $V_a$=500V, incident angle=27.8$^o$, and time=10 minutes.



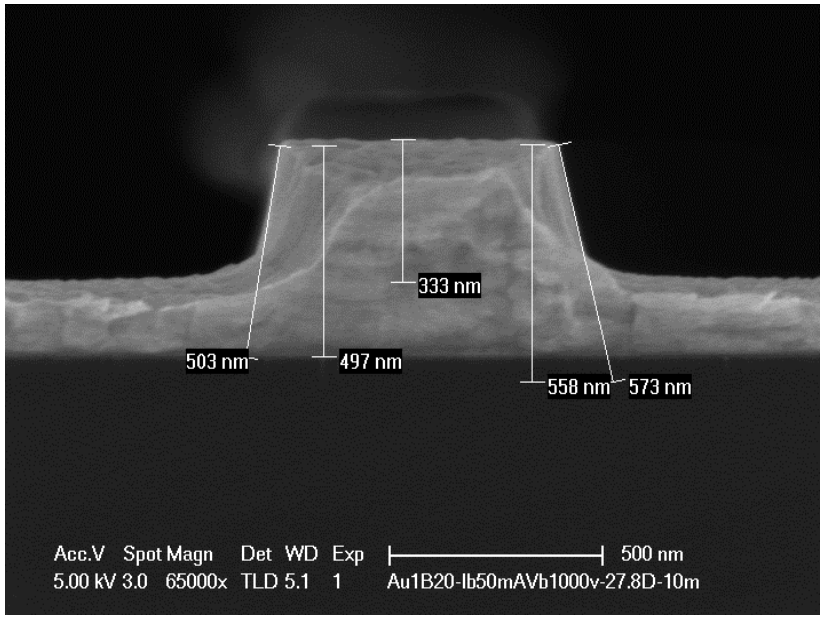
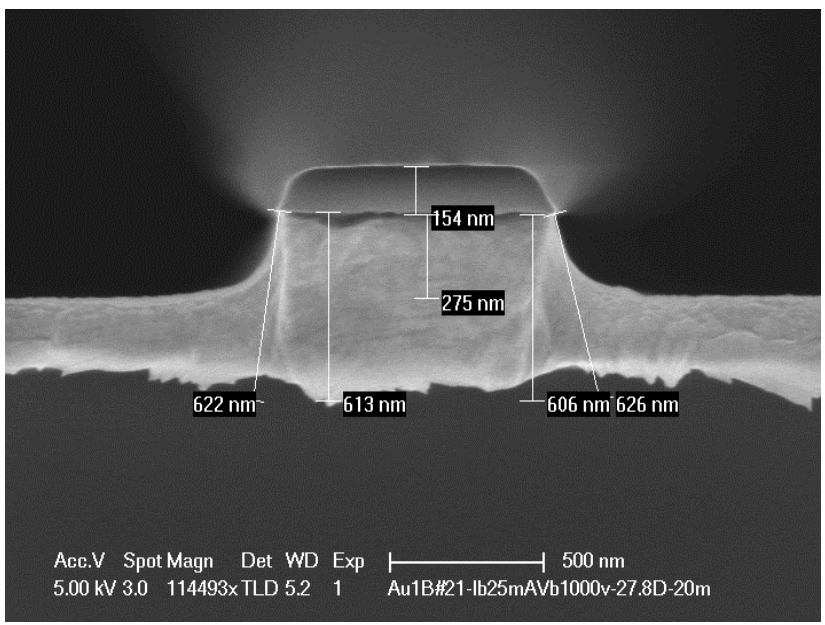



Figure 21 (a) and (b) Cross-section of the milled sample Au21 with $I_n$=250mA, $P_{rf}$=200W, $I_b$=25mA, $V_b$=1000 v, $V_a$=500V, incident angle=27.8º, and time=20 minutes.



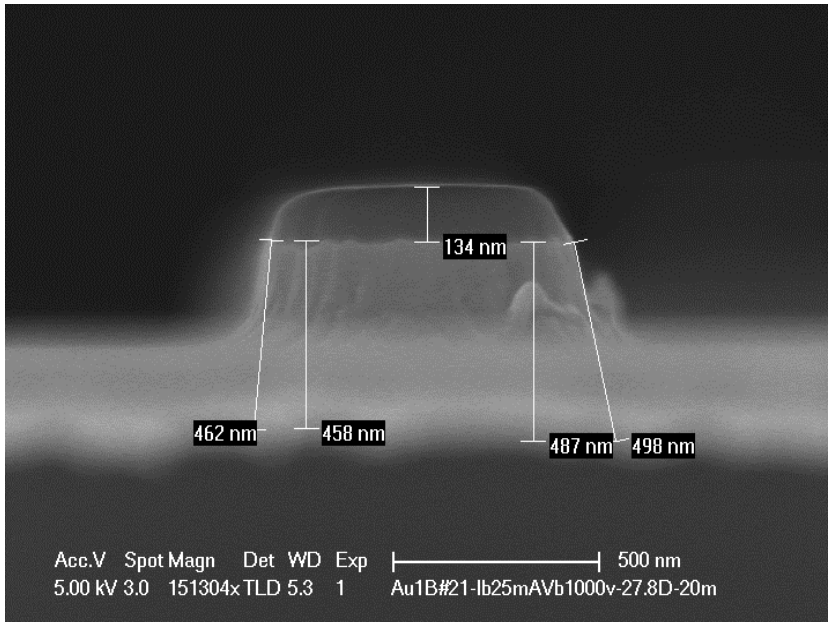



Figure 22 Etch rate of gold and selectivity ($Au/Al_2O_3$) as functions of Ar-ion Incident angle while keeping $I_n$=250mA, $P_{rf}$=250W, $I_b$=150mA, $V_b$=500V, and $V_a$=500V.

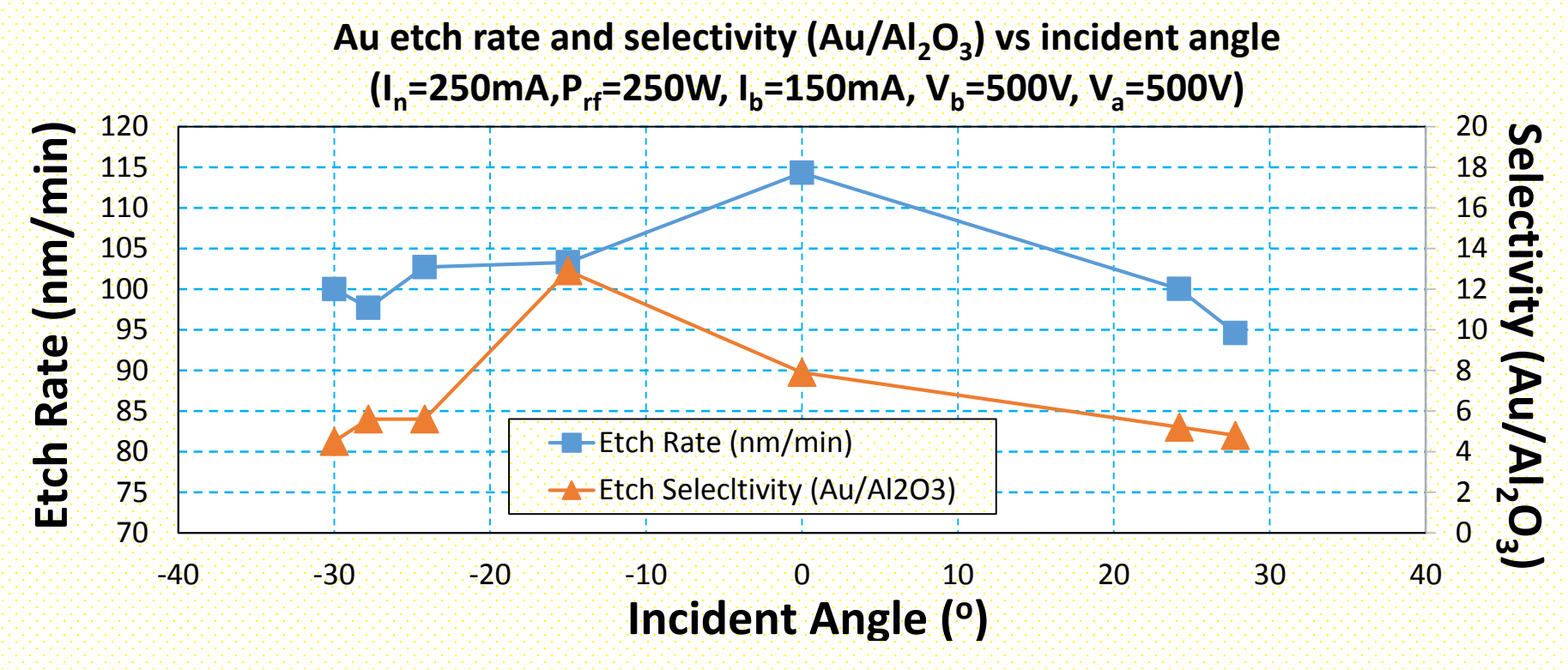


Figure 23 Etched side-wall angle of gold as a function of Ar-ion Incident angle while keeping $I_n$=250mA, $P_{rf}$=250W, $I_b$=150mA, $V_b$=500V, and $V_a$=500V.

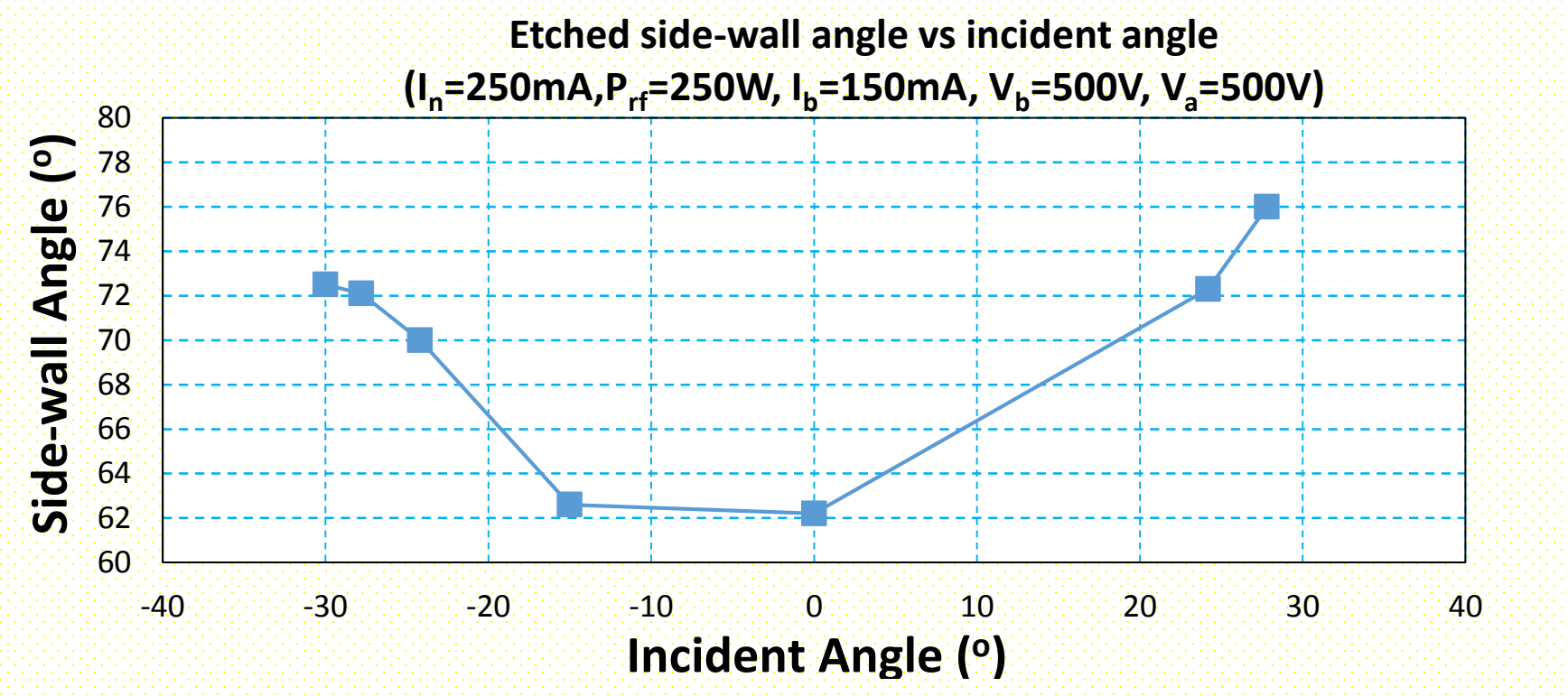


Figure 24 Etch rate and etch selectivity of gold as functions of beam current under the conditions of $I_n$=250mA, $V_b$=500 v, $V_a$=500 v, Ar Flow-rate=5 sccm for both neutralizer and beam, platen temperature=10$^o$C, chamber wall temperature=40$^o$C, and platen rotation=20 rpm.

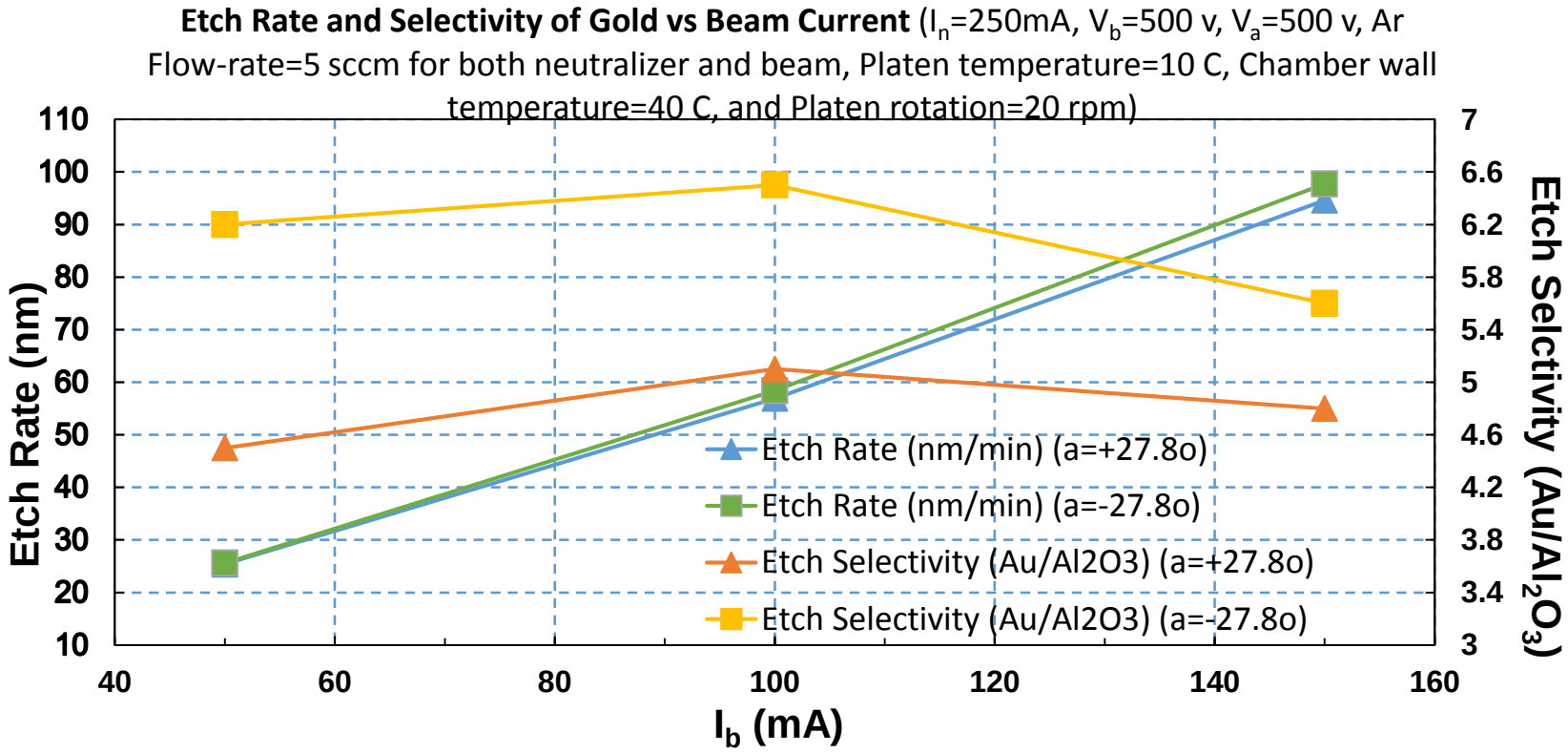


Figure 25 Sidewall angle of etched gold as a function of beam current under the conditions of $I_n$=250mA, $V_b$=500 v, $V_a$=500 v, Ar Flow-rate=5 sccm for both neutralizer and beam, platen temperature=10$^o$C, chamber wall temperature=40$^o$C, and platen rotation=20 rpm.

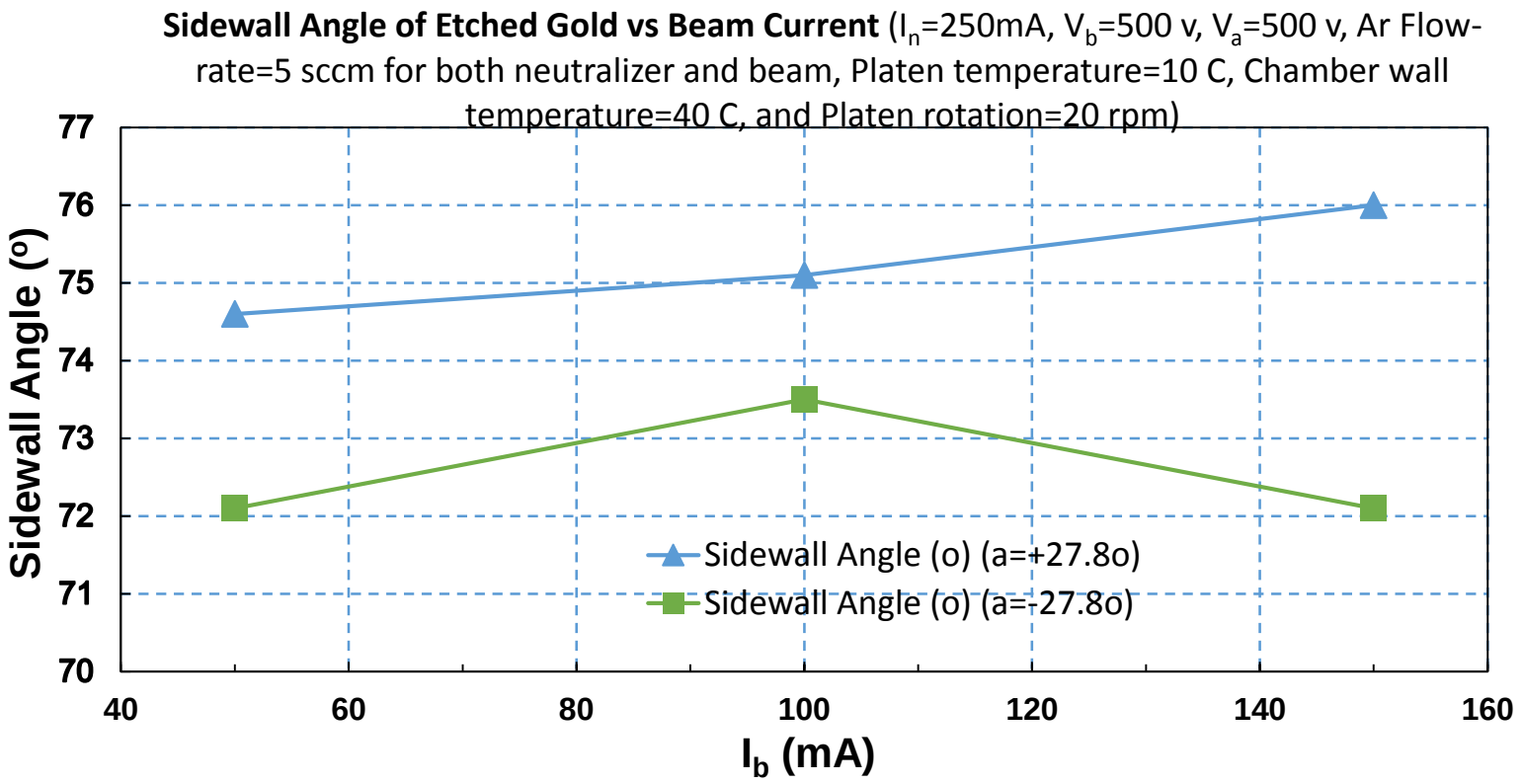


Figure 26 Etch rate and etched sidewall angle of gold as functions of beam voltage under the conditions of $I_n$=250mA, $I_b$=150 mA, $V_a$=500 v, incident angle=27.8°, Ar Flow-rate=5 sccm for both neutralizer and beam, platen temperature=10°C, chamber wall temperature=40°C, and platen rotation=20 rpm.

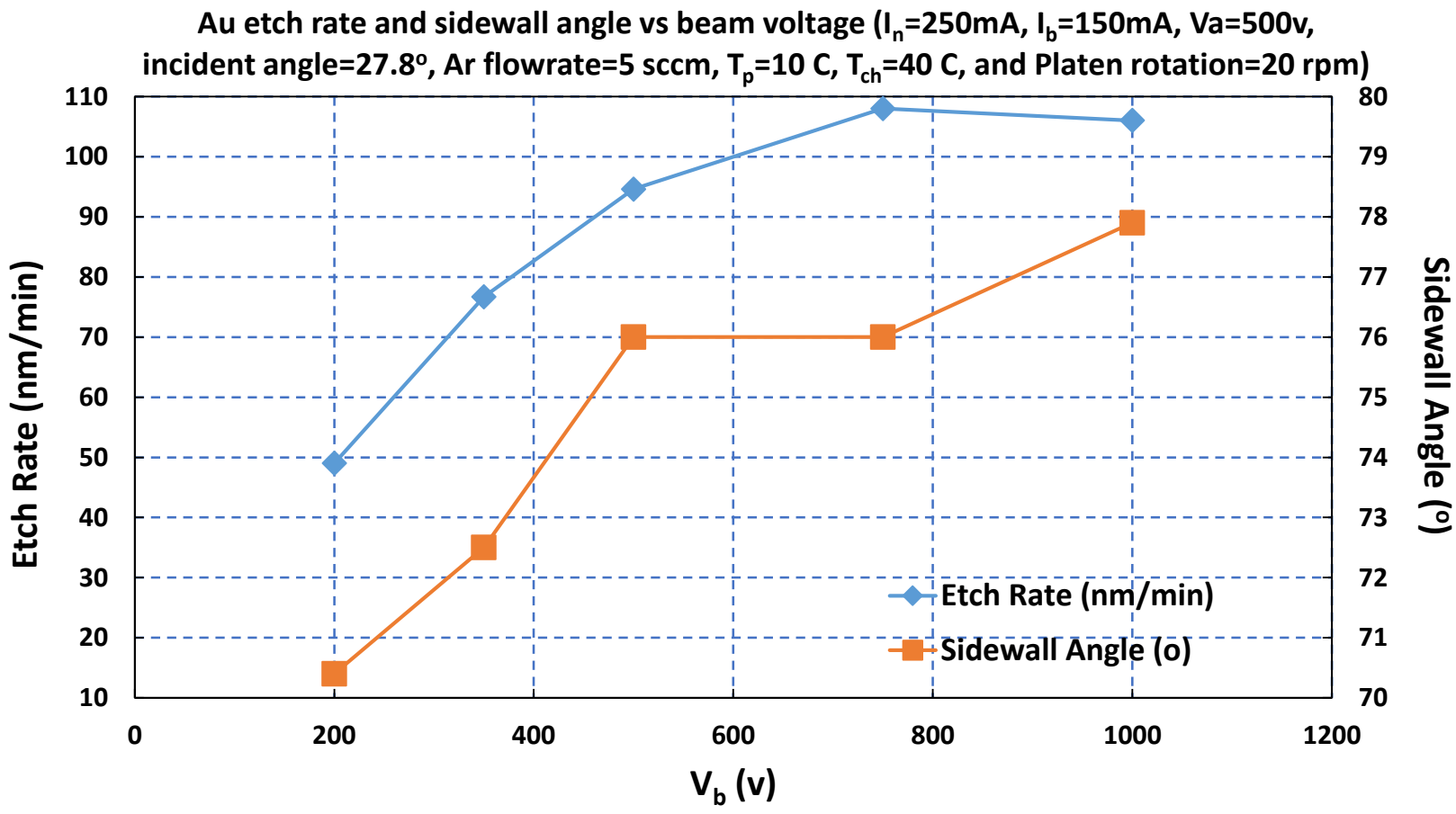


Figure 27 Etch selectivity (Au/Al2O3) as a function of beam voltage under the conditions of $I_n$=250mA, $I_b$=150 mA, $V_a$=500 v, incident angle=27.8°, Ar Flow-rate=5 sccm for both neutralizer and beam, platen temperature=10°C, chamber wall temperature=40°C, and platen rotation=20 rpm.

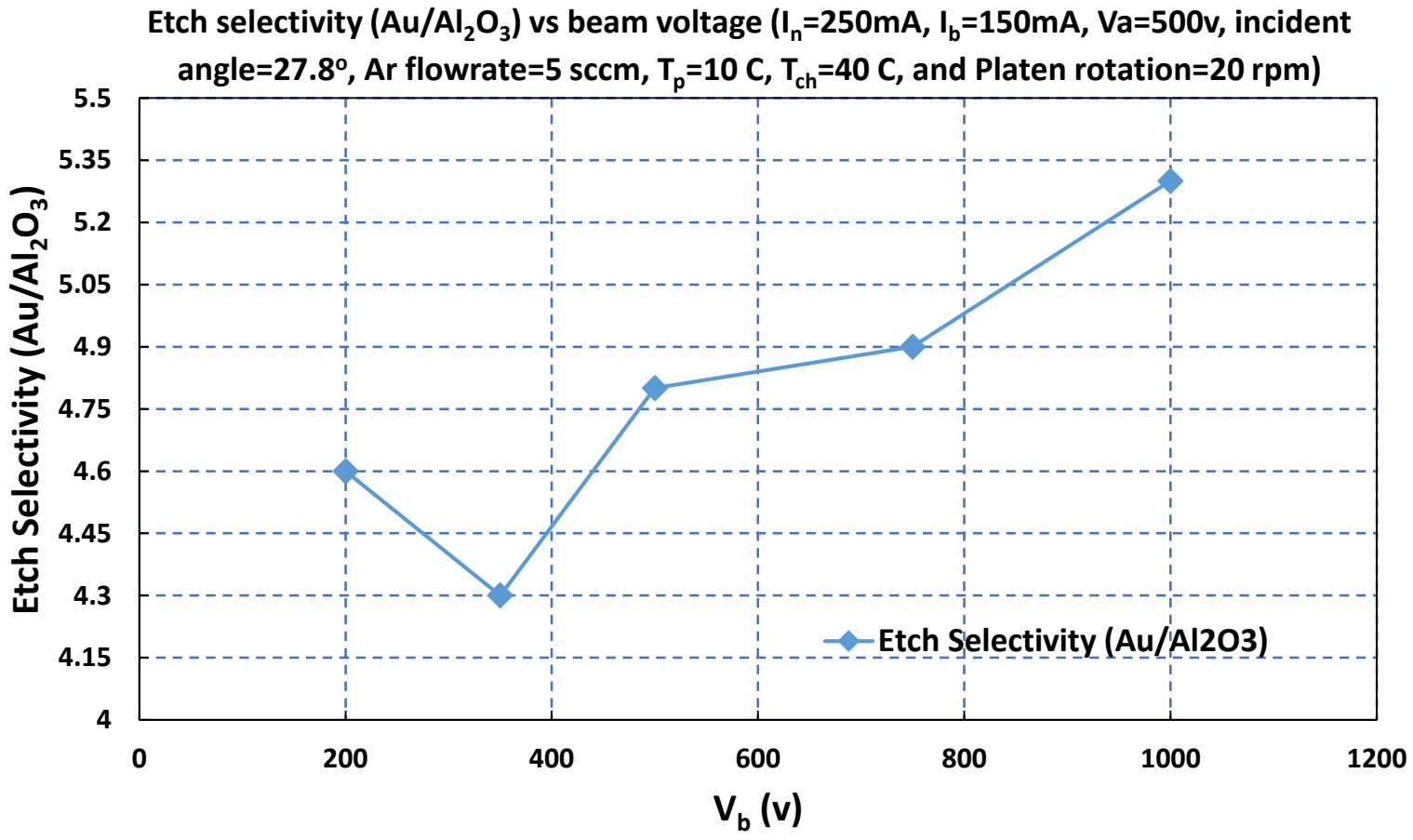


Figure 28 Etch rate and etch selectivity of gold as functions of beam current under the conditions of $I_n$=250mA, $V_b$=1000 v, $V_a$=500 v, incident angle=27.8°, Ar Flow-rate=5 sccm for both neutralizer and beam, platen temperature=10°C, chamber wall temperature=40°C, and platen rotation=20 rpm.

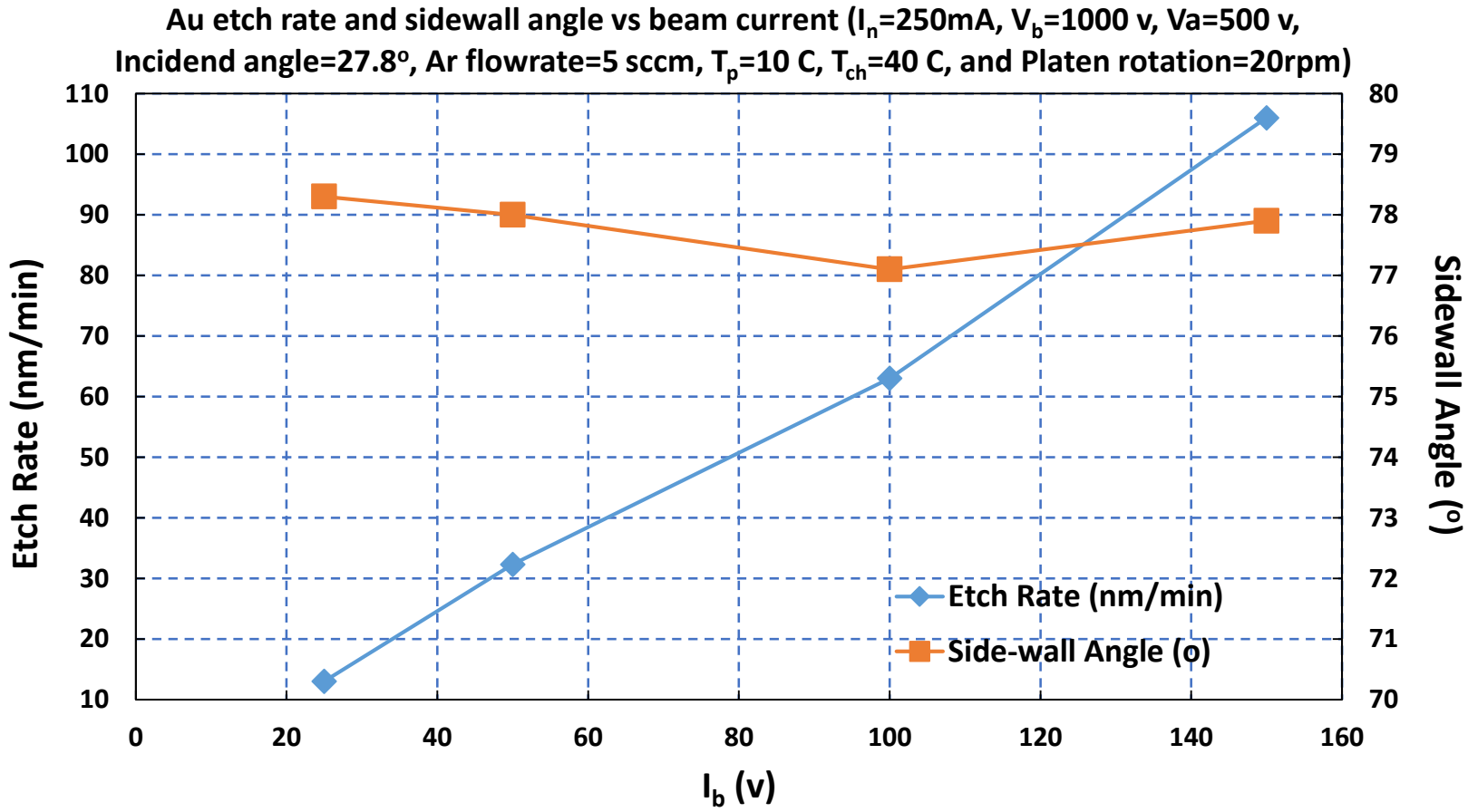


Figure 29 Sidewall angle of etched gold as a function of beam current under the conditions of $I_n$=250mA, $V_b$=500 v, $V_a$=500 v, incident angle=27.8°, Ar Flow-rate=5 sccm for both neutralizer and beam, platen temperature=10°C, chamber wall temperature=40°C, and platen rotation=20 rpm.