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Etching Nickel 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 nickel 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/Ni (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): 3000 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 0.25 s using the calibration reticle.

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

i) Development in AZ300MIF for 90 s.

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

4) **Depositing** Al_2O_3 (target thickness: 200 nm, actual thickness: 235 nm, Tooling factor: 149.2) using E-beam#2.

5) **Lifting-off Al_2O_3**: a) soaking the wafer in 1165 striper on 80 C hot-plate for 4h40m; b) soaking them 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 experiment.

Results:

Table 1. Etch rate, selectivity (Ni/Al_2O_3), and side-wall angle of Ni under different ion-mill conditions (both Ar flow rates to neutralizer and samples 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 (Ni/Al_2O_3)	Side-wall angle (^{o})
Ni#2-00	7/23/2015	unetched, Al_2O_3 Thickness=235 nm									67. 8
Ni#2-01	7/23/2015	250	250	150	500	500	0	6	42	2.9	58.7
Ni#2-02	7/23/2015	250	250	150	500	500	-15	6	42.5	2.5	58.2
Ni#2-03	7/23/2015	250	250	150	500	500	-30	6	43.5	1.7	67.4
Ni#2-04	7/27/2015	250	250	150	500	500	31.3	6.5	42.9	1.4	71.7
Ni#2-05	7/27/2015	250	250	150	500	500	-31.3	6.5	41.1	1.9	71.2
Ni#2-06	7/29/2015	250	250	150	500	500	-35	6.5	40.6	1.6	70
Ni#2-07	7/29/2015	250	200	100	500	500	-31.3	9.75	26.7	1.7	67.1
Ni#2-08	7/29/2015	250	200	50	500	500	-31.3	19.5	12	1.8	68.7
Ni#2-09	10/14/2015	250	250	150	1000	500	31.3	4.5	55.6	1.6	71.9
Ni#2-10	10/14/2015	250	250	100	1000	500	31.3	7	31	1.6	70.6
Ni#2-11	10/14/2015	250	250	150	1000	500	-31.3	4.5	53.6	1.7	71.6
Ni#2-12	11/20/2015	250	200	50	1000	500	31.3	18	15.4	1.5	67.9
Ni#2-13	11/20/2015	250	250	150	1250	500	31.3	4.5	57.8	1.6	72.8
Ni#2-14	11/24/2015	250	250	100	1250	500	31.3	6.75	37.2	1.5	70.5
Ni#2-15	11/24/2015	250	250	200	1250	500	31.3	3.42	72.3	1.6	69.7

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Figure 1 Cross-section of Ni layer and Al_2O_3 mask pattern before ion-mill. The average mask thickness and sidewall angle are 235 nm and 67.8°, respectively.

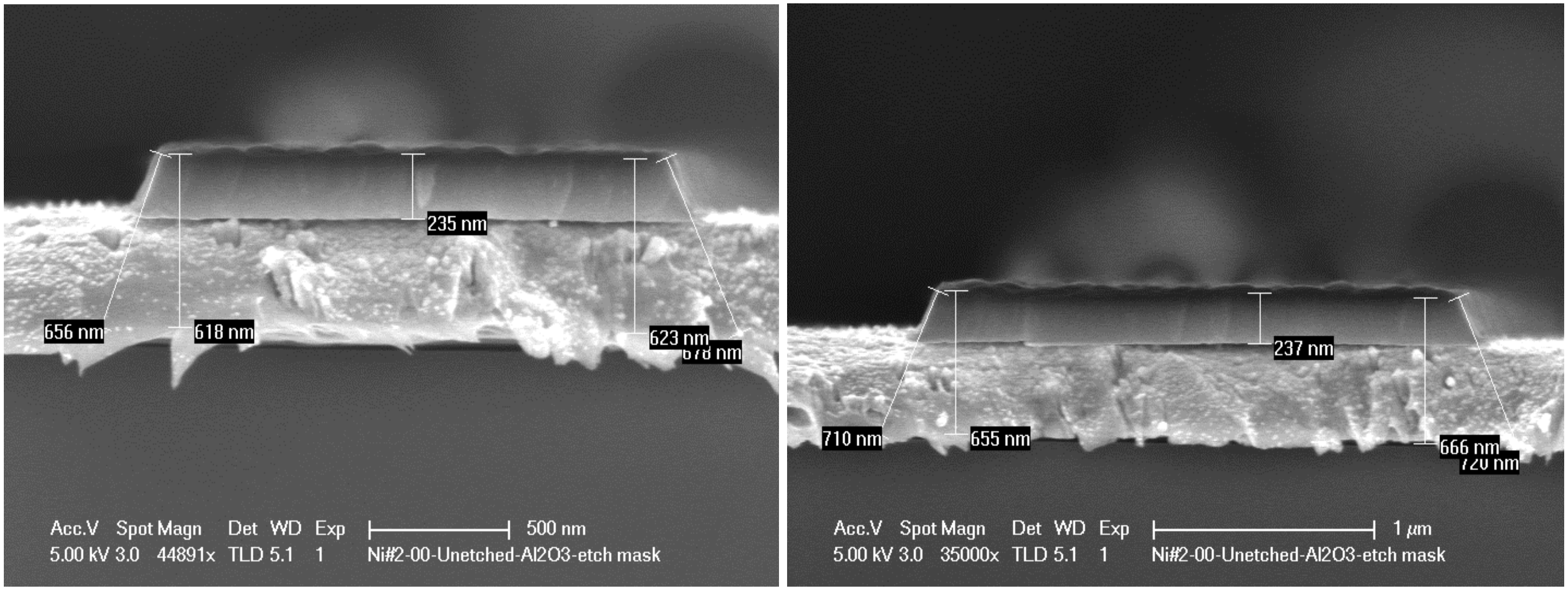
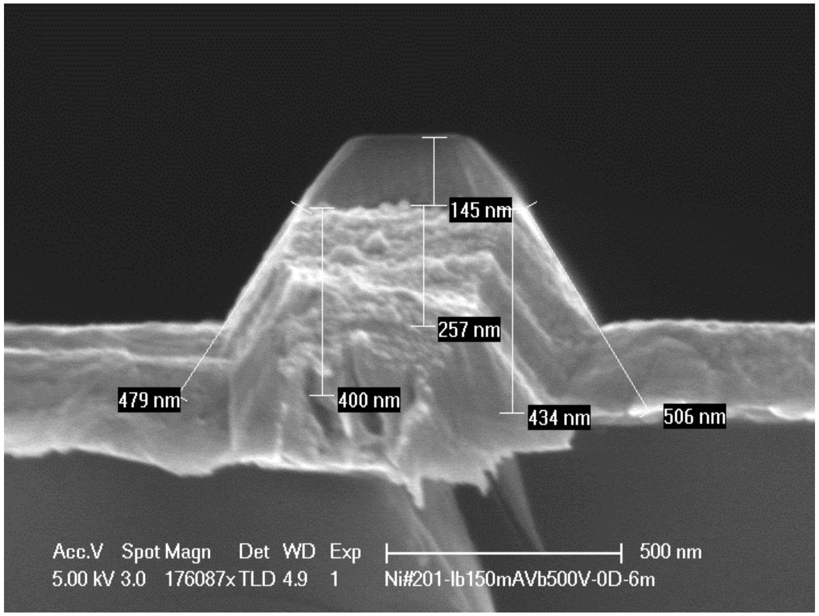


Figure 2 (a) and (b) Cross-section of the milled sample Ni#2-01 with I_n=250mA, P_{rf}=250W, I_b=150mA, V_b=500V, V_a=500V, incident angle=0º, and time=6 minutes. As one can see, there is a slight micro-trenching at the bottom corners of ridge, which is due to that Ar ions hit on the ridge sidewall, glancing toward the corners.



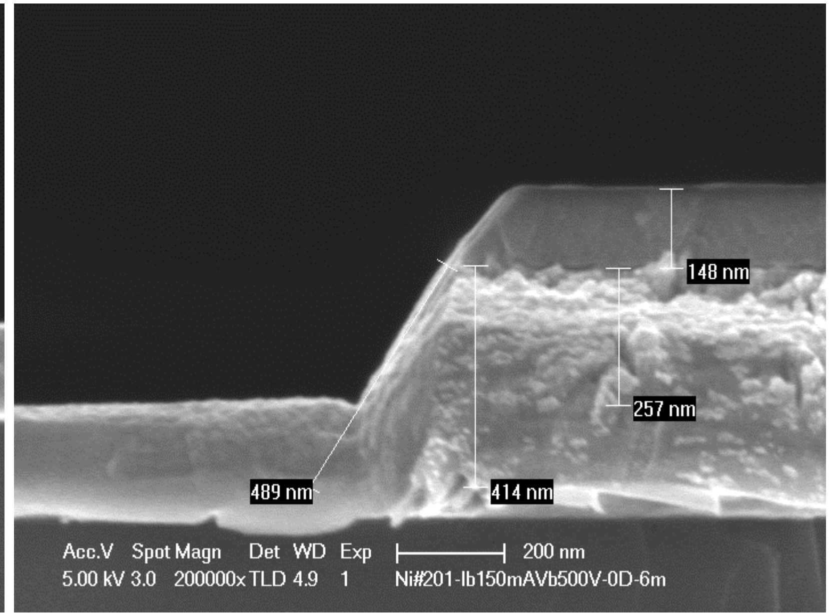
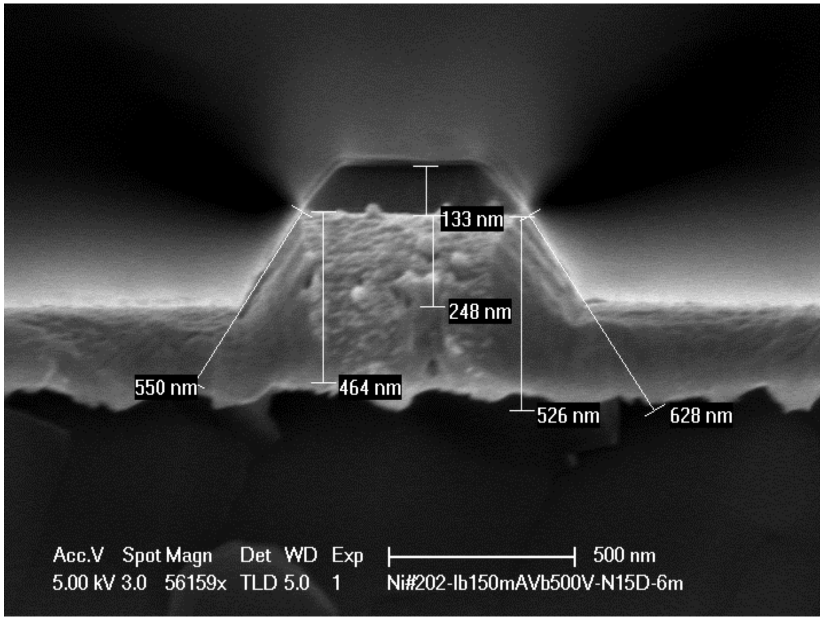


Figure 3 (a) and (b) Cross-section of the milled sample Ni#2-02 with I_n=250mA, P_{rf}=250W, I_b=150mA, V_b=500V, V_a=500V, incident angle=-15^o, and time=6 minutes. As one can see, there is still a slight micro-trenching at the bottom corners of ridge, which is due to that Ar ions hit on the ridge sidewall, glancing toward the corners.



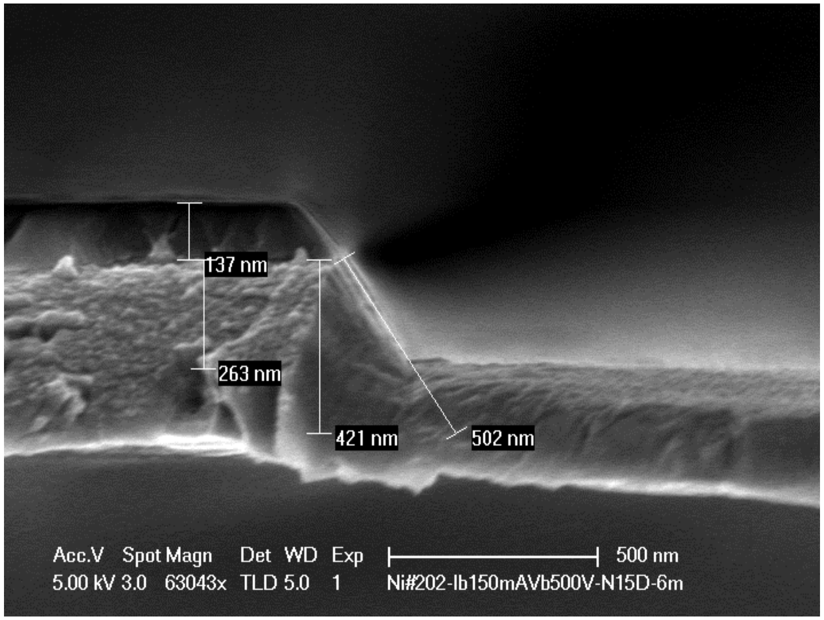


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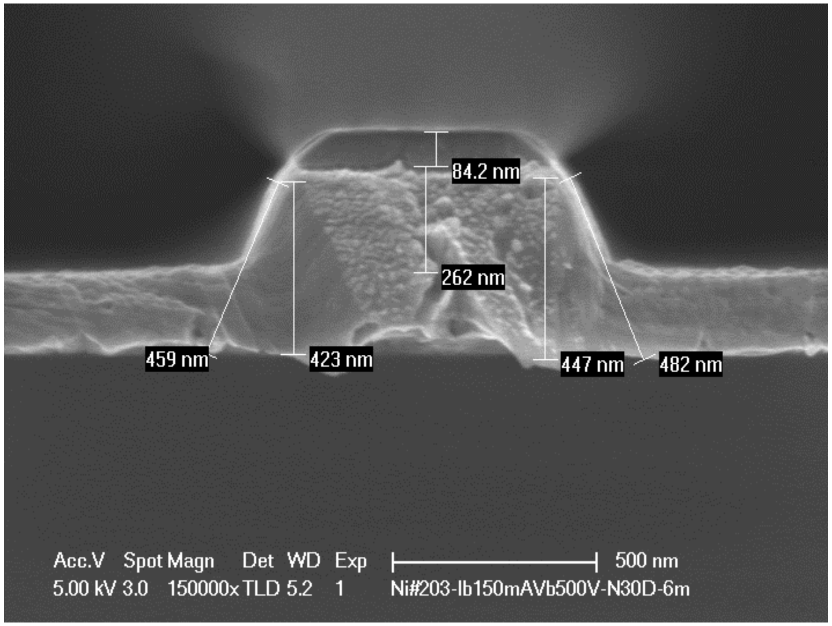
Figure 4 (a) and (b) Cross-section of the milled sample Ni#2-03 with I_n=250mA, P_{rf}=250W, I_b=150mA, V_b=500V, V_a=500V, incident angle=-30º, and time=6 minutes. As one can see, there is a slight tail developed at the bottom corners of ridge, which is due to the ion shielding effect.



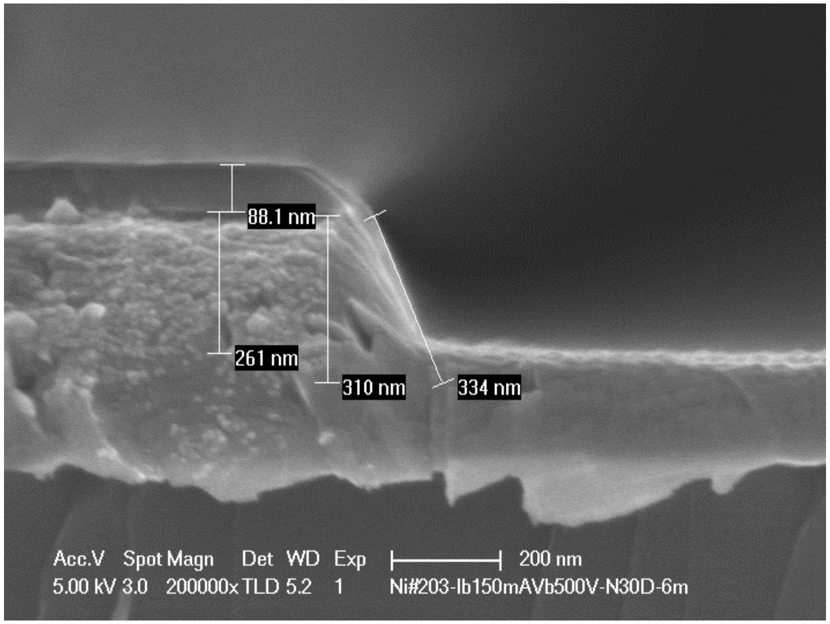


Figure 5 (a) and (b) Cross-section of the milled sample Ni#2-04 with I_n=250mA, P_{rf}=250W, I_b=150mA, V_b=500V, V_a=500V, incident angle=31.3^o, and time=6.5 minutes. As one can see, there is a big tail developed at the bottom corners of ridge, which is due to the ion shielding effect.

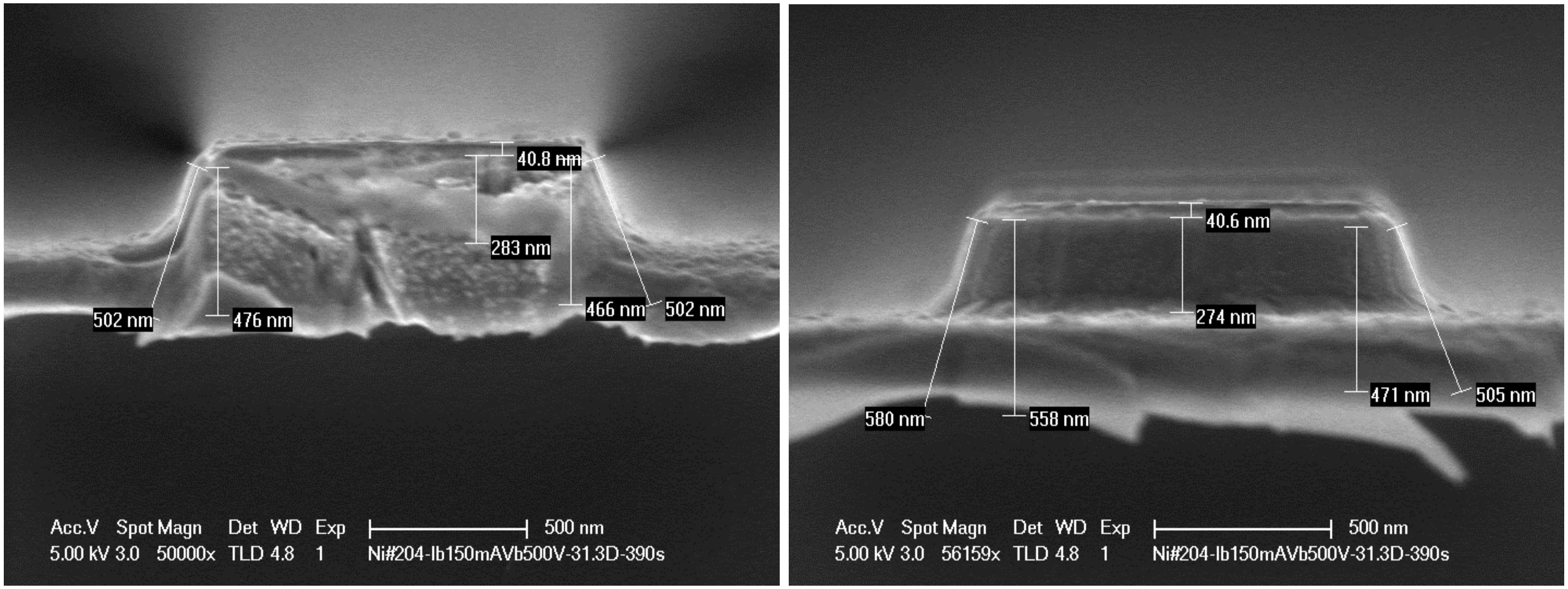


Figure 6 (a) and (b) Cross-section of the milled sample Ni#2-05 with I_n=250mA, P_{rf}=250W, I_b=150mA, V_b=500V, V_a=500V, incident angle=-31.3°, and time=6.5 minutes. As one can see, there is a slight tail developed at the bottom corners of ridge, which is due to the ion shielding effect.

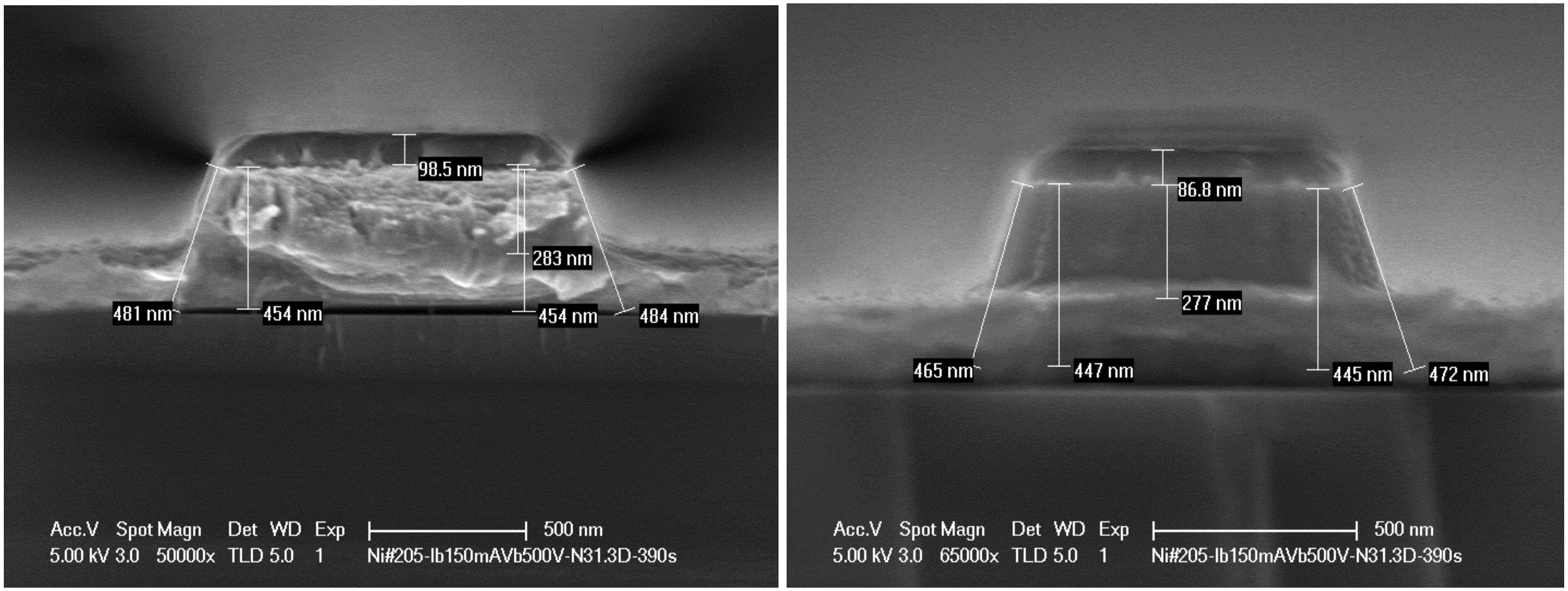
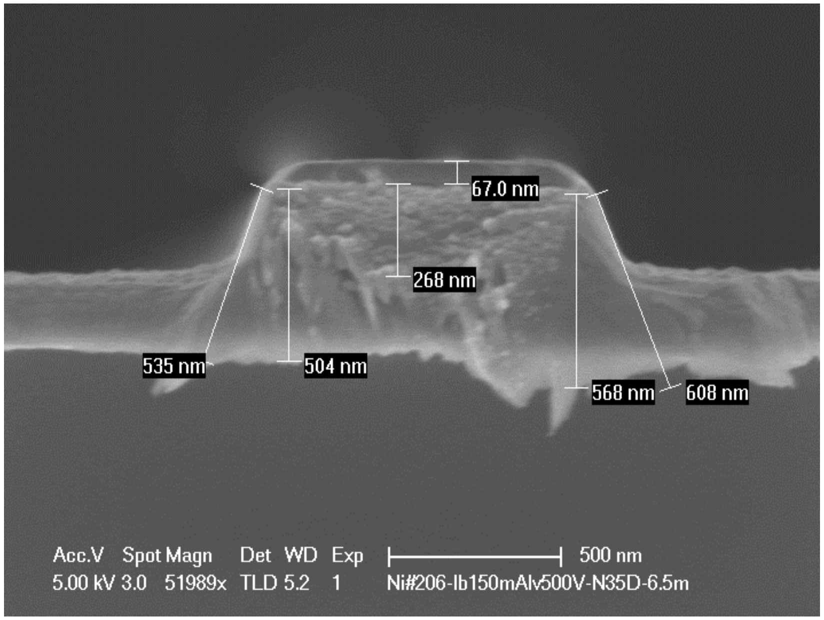


Figure 7 (a) and (b) Cross-section of the milled sample Ni#2-06 with I_n=250mA, P_{rf}=250W, I_b=150mA, V_b=500V, V_a=500V, incident angle=-35°, and time=6.5 minutes. As one can see, there is a slight tail developed at the bottom corners of ridge, which is due to the ion shielding effect.



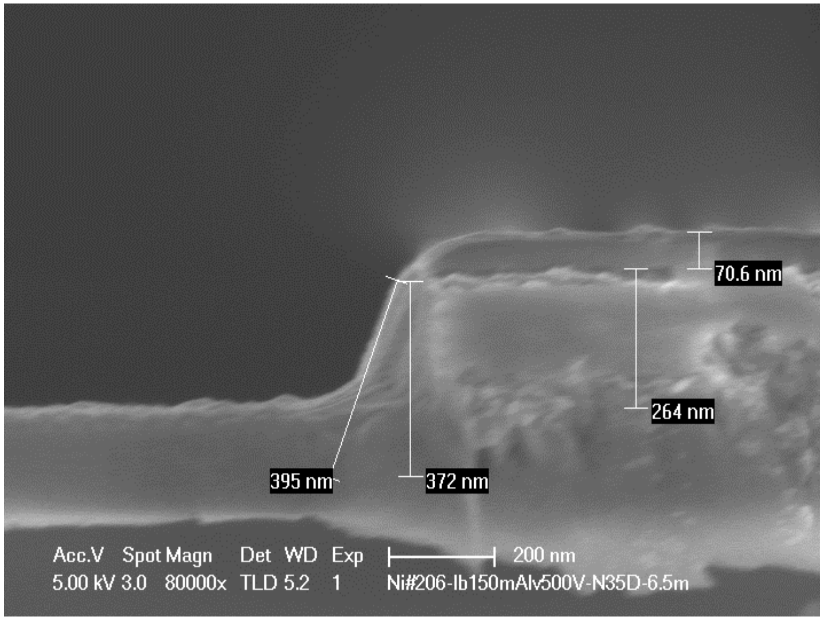


Figure 8 (a) and (b) Cross-section of the milled sample Ni#2-07 with I_n=250mA, P_{rf}=200W, I_b=100mA, V_b=500V, V_a=500V, incident angle=-31.3º, and time=9.75 minutes. As one can see, there is a slight tail developed at the bottom corners of ridge, which is due to the ion shielding effect.

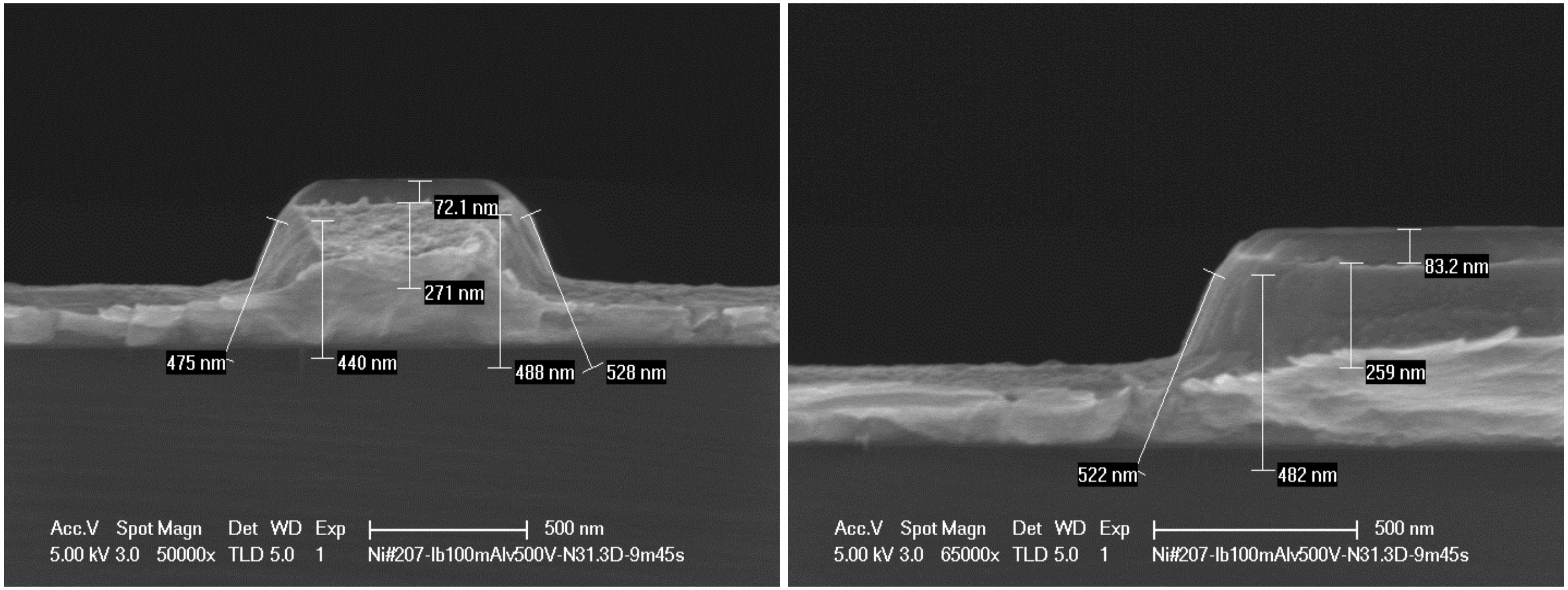


Figure 9 (a) and (b) Cross-section of the milled sample Ni#2-08 with I_n=250mA, P_{rf}=200W, I_b=50mA, V_b=500V, V_a=500V, incident angle=-31.3°, and time=19.5 minutes. As one can see, there is a slight tail developed at the bottom corners of ridge, which is due to the ion shielding effect.

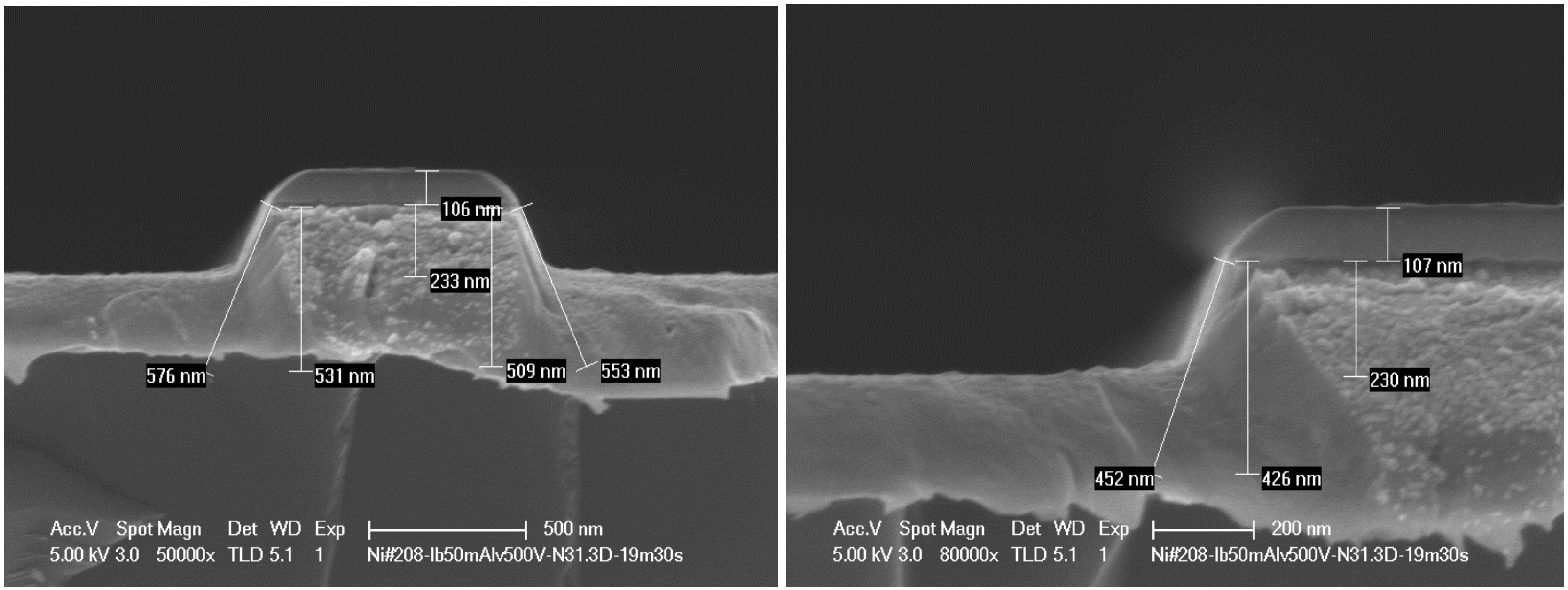


Figure 10 (a) and (b) Cross-section of the milled sample Ni#2-09 with I_n=250mA, P_{rf}=250W, I_b=150mA, V_b=1000V, V_a=500V, incident angle=31.3^o, and time=4.5 minutes. As one can see, there is a slight tail developed at the bottom corners of ridge, which is due to the ion shielding effect.

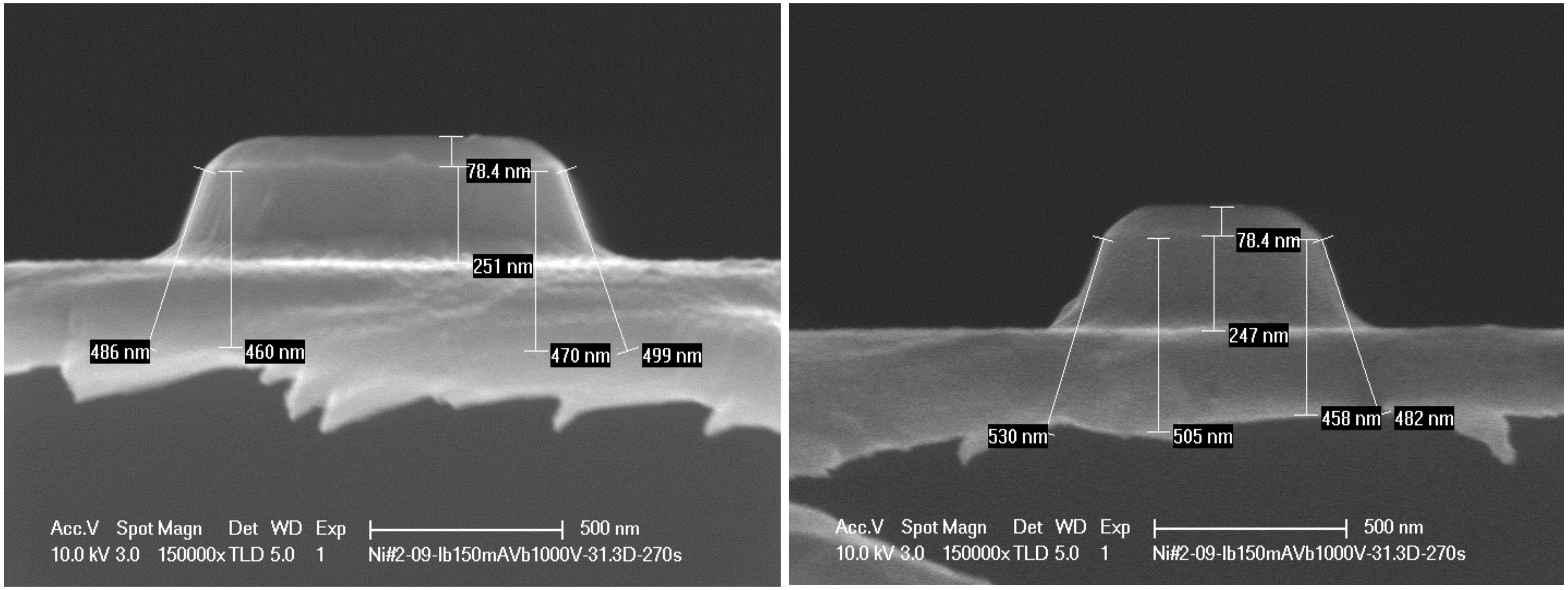


Figure 11 (a) and (b) Cross-section of the milled sample Ni#2-10 with I_n=250mA, P_{rf}=250W, I_b=100mA, V_b=1000V, V_a=500V, incident angle=31.3^o, and time=7 minutes. As one can see, there is a slight tail developed at the bottom corners of ridge, which is due to the ion shielding effect.

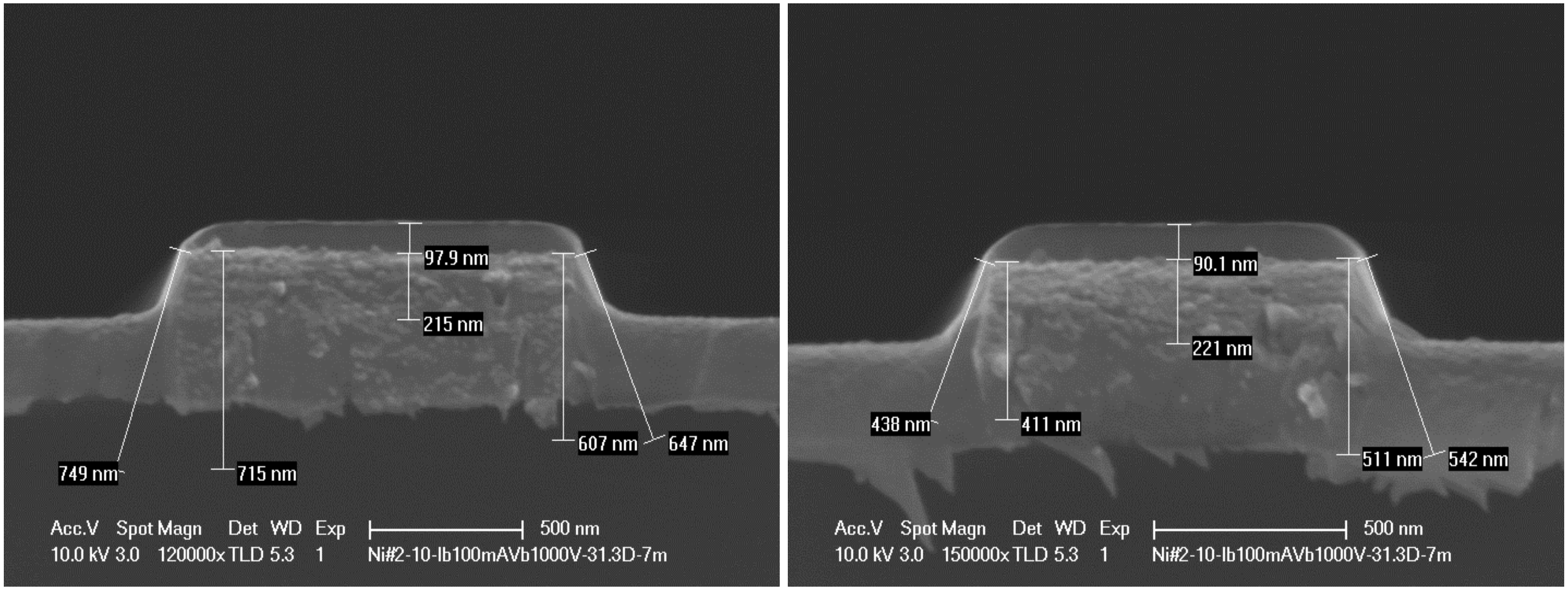


Figure 12 (a) and (b) Cross-section of the milled sample Ni#2-11 with I_n=250mA, P_{rf}=250W, I_b=150mA, V_b=1000V, V_a=500V, incident angle=-31.3^o, and time=4.5 minutes. As one can see, there is a slight tail developed at the bottom corners of ridge, which is due to the ion shielding effect.

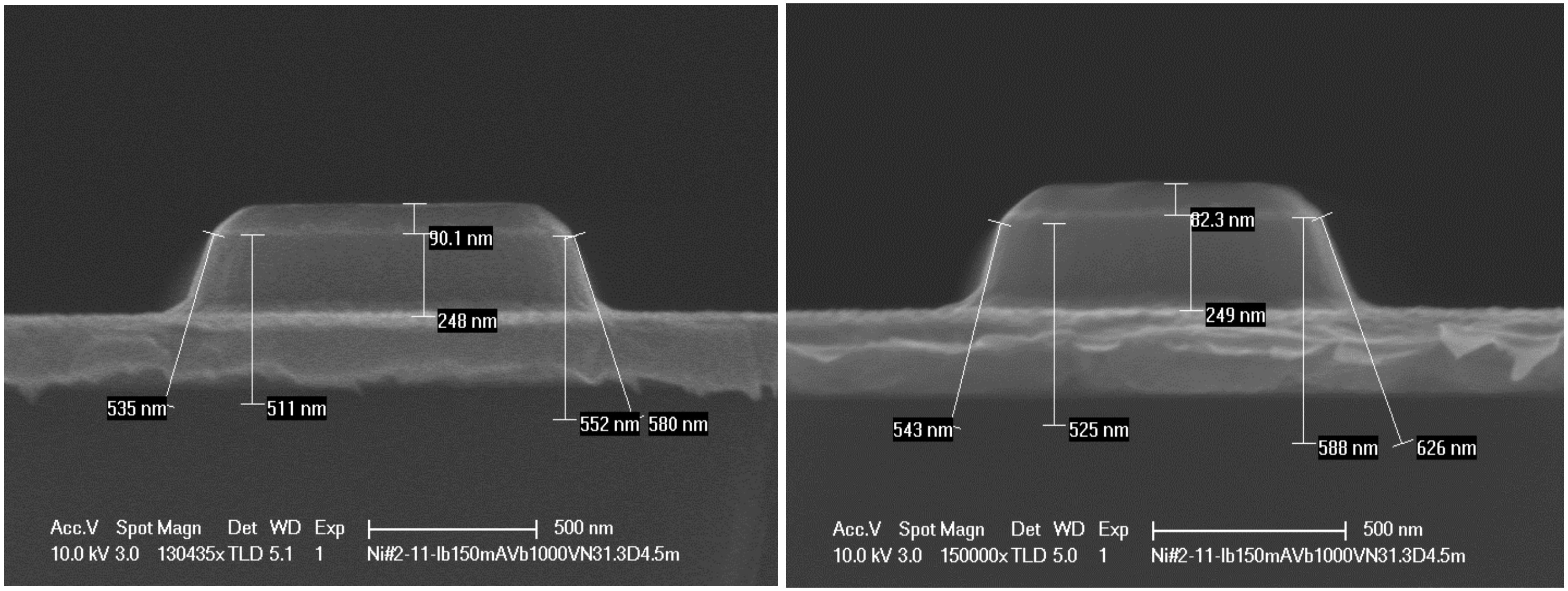


Figure 13 (a) and (b) Cross-section of the milled sample Ni#2-12 with I_n=250mA, P_{rf}=200W, I_b=50mA, V_b=1000V, V_a=500V, incident angle=31.3^o, and time=18 minutes. As one can see, there is a slight tail developed at the bottom corners of ridge, which is due to the ion shielding effect.

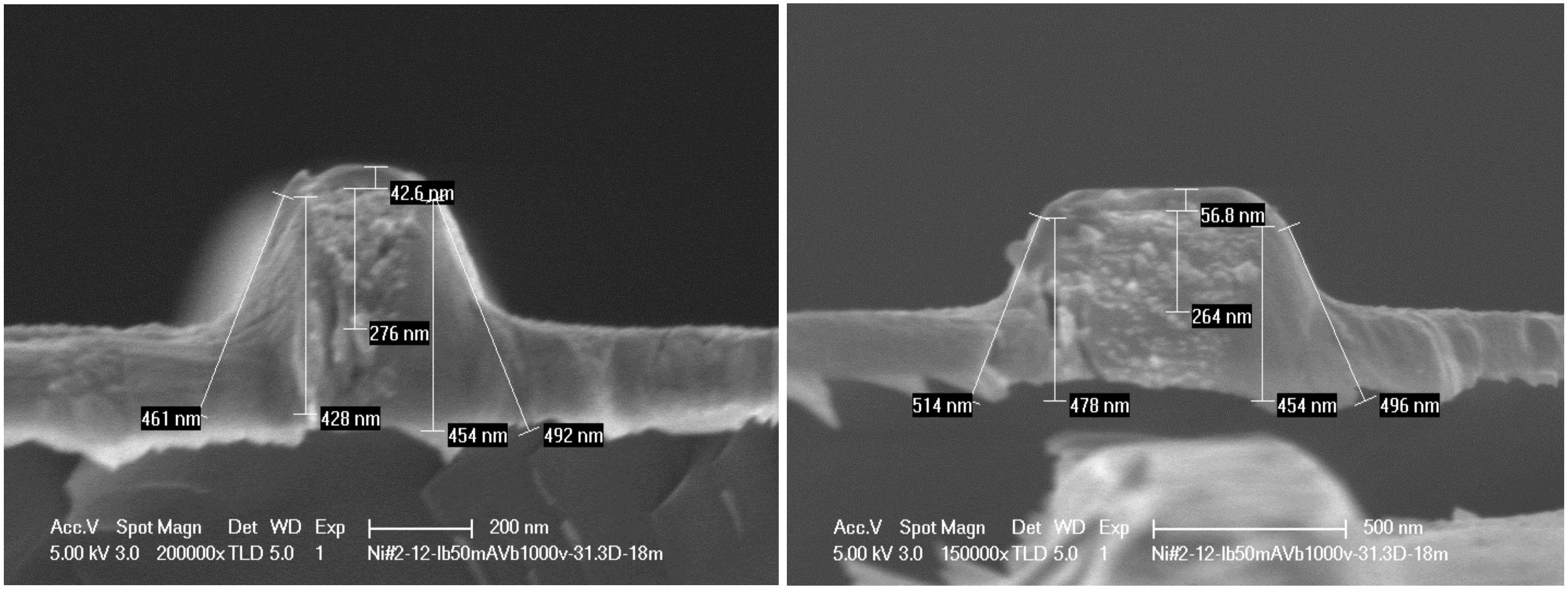
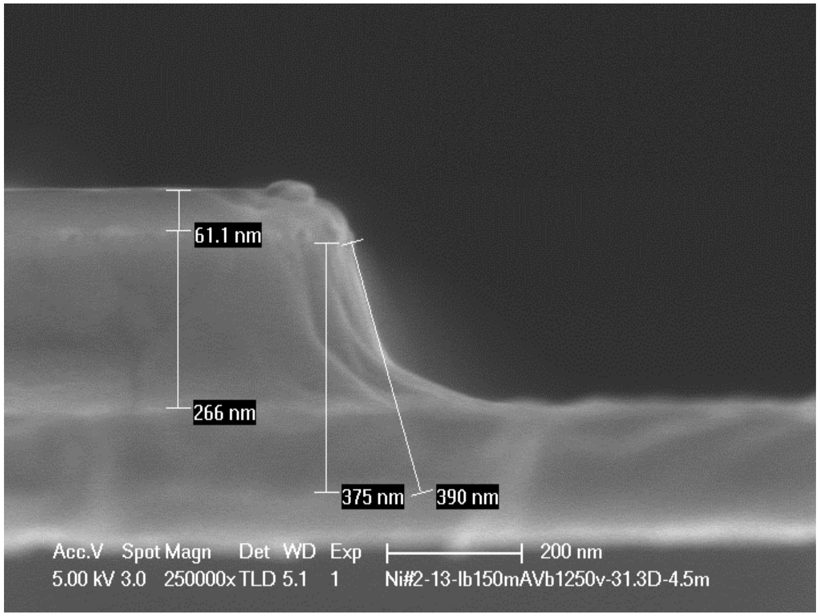


Figure 14 (a) and (b) Cross-section of the milled sample Ni#2-13 with I_n=250mA, P_{rf}=250W, I_b=150mA, V_b=1250V, V_a=500V, incident angle=31.3°, and time=4.5 minutes. As one can see, there is a slight tail developed at the bottom corners of ridge, which is due to the ion shielding effect.



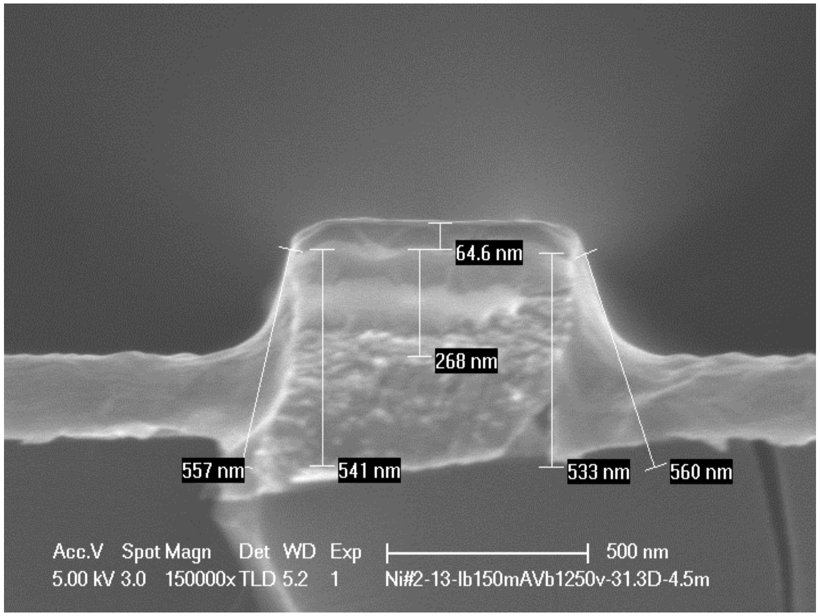
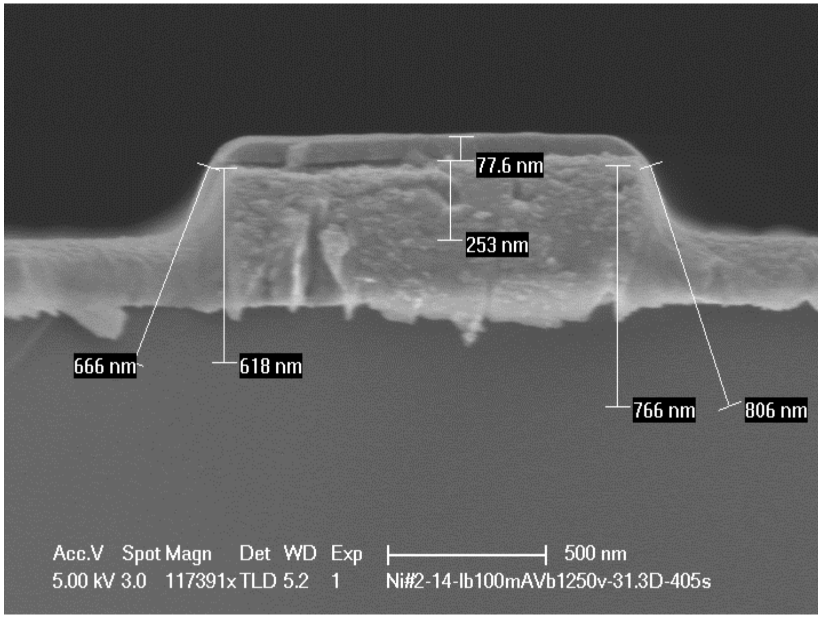


Figure 15 (a) and (b) Cross-section of the milled sample Ni#2-14 with I_n=250mA, P_{rf}=250W, I_b=100mA, V_b=1250V, V_a=500V, incident angle=31.3º, and time=405 seconds. As one can see, there is a slight tail developed at the bottom corners of ridge, which is due to the ion shielding effect.



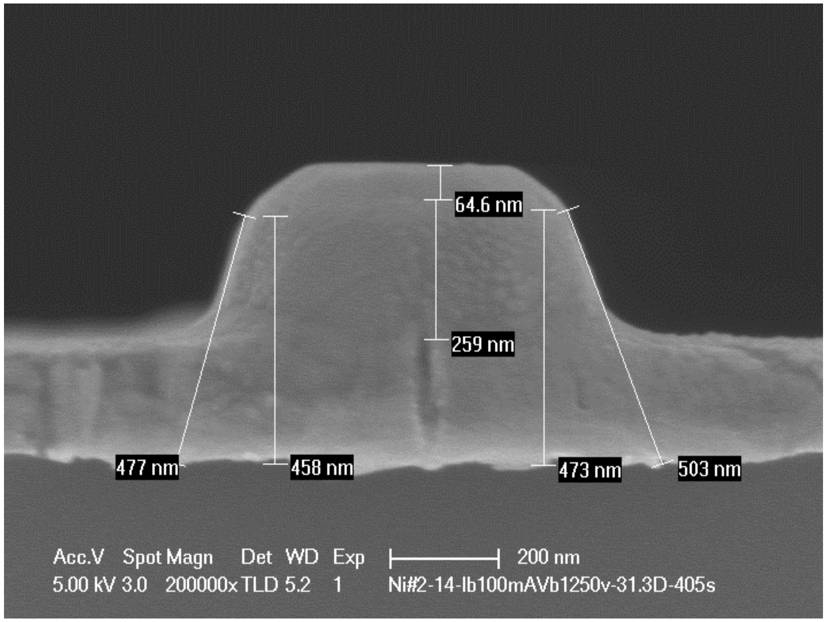


Figure 16 (a) and (b) Cross-section of the milled sample Ni#2-15 with I_n=250mA, P_{rf}=250W, I_b=200mA, V_b=1250V, V_a=500V, incident angle=31.3°, and time=205 seconds. As one can see, there is a slight tail developed at the bottom corners of ridge, which is due to the ion shielding effect.

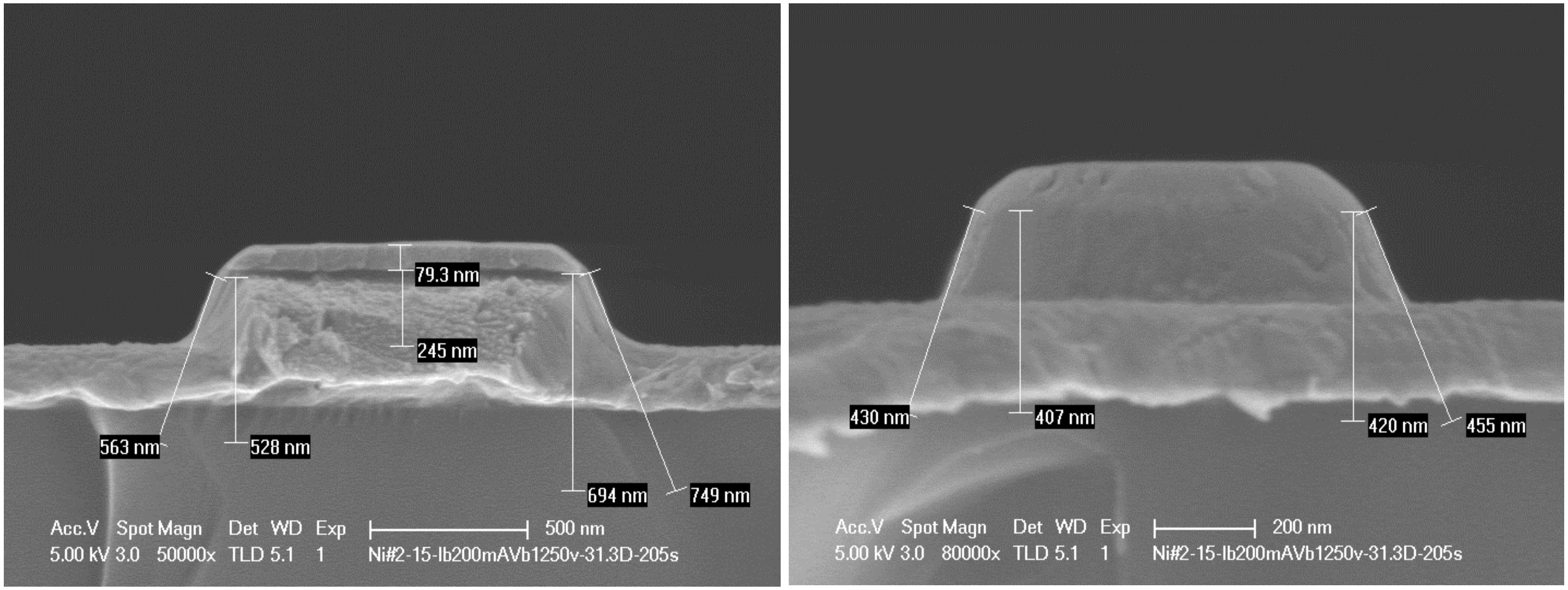


Figure 17 Etch rate and etch selectivity of Ni as functions of incident angle.

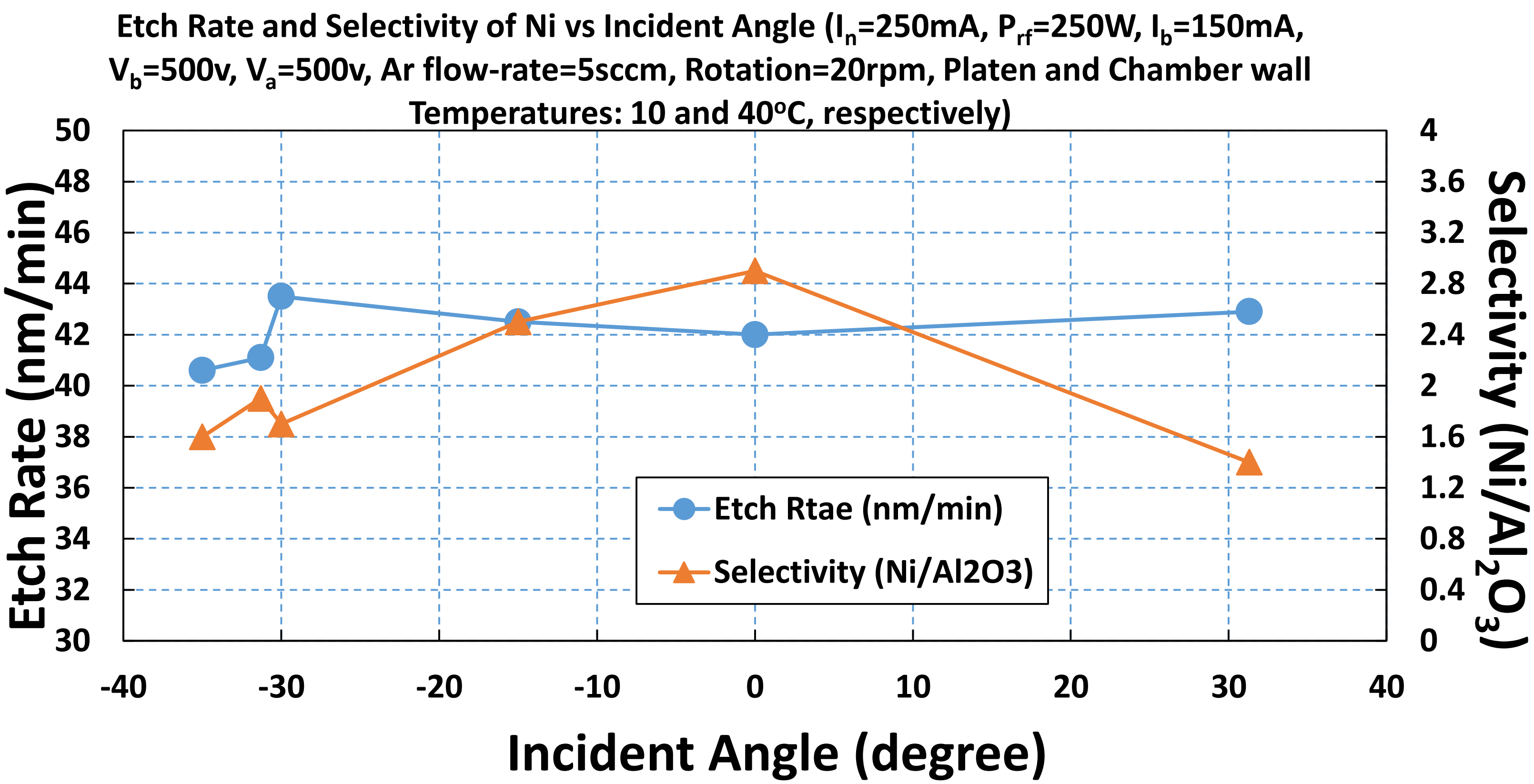


Figure 18 Etched sidewall angle of Ni as a function of incident angle.

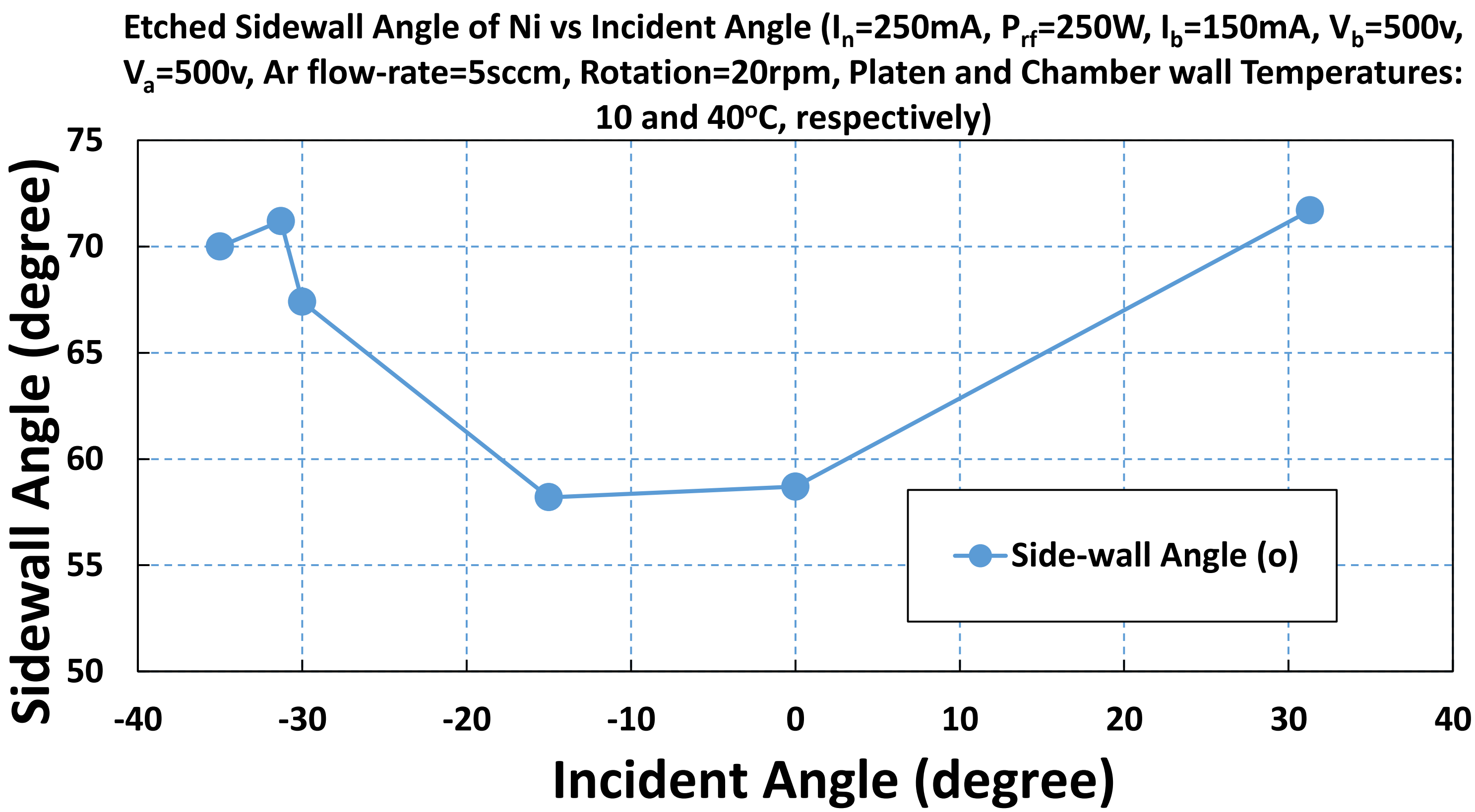


Figure 19 Etch rate and etch selectivity of Ni as functions of beam current (V_b=500v and Incident Angle=-31.3°).

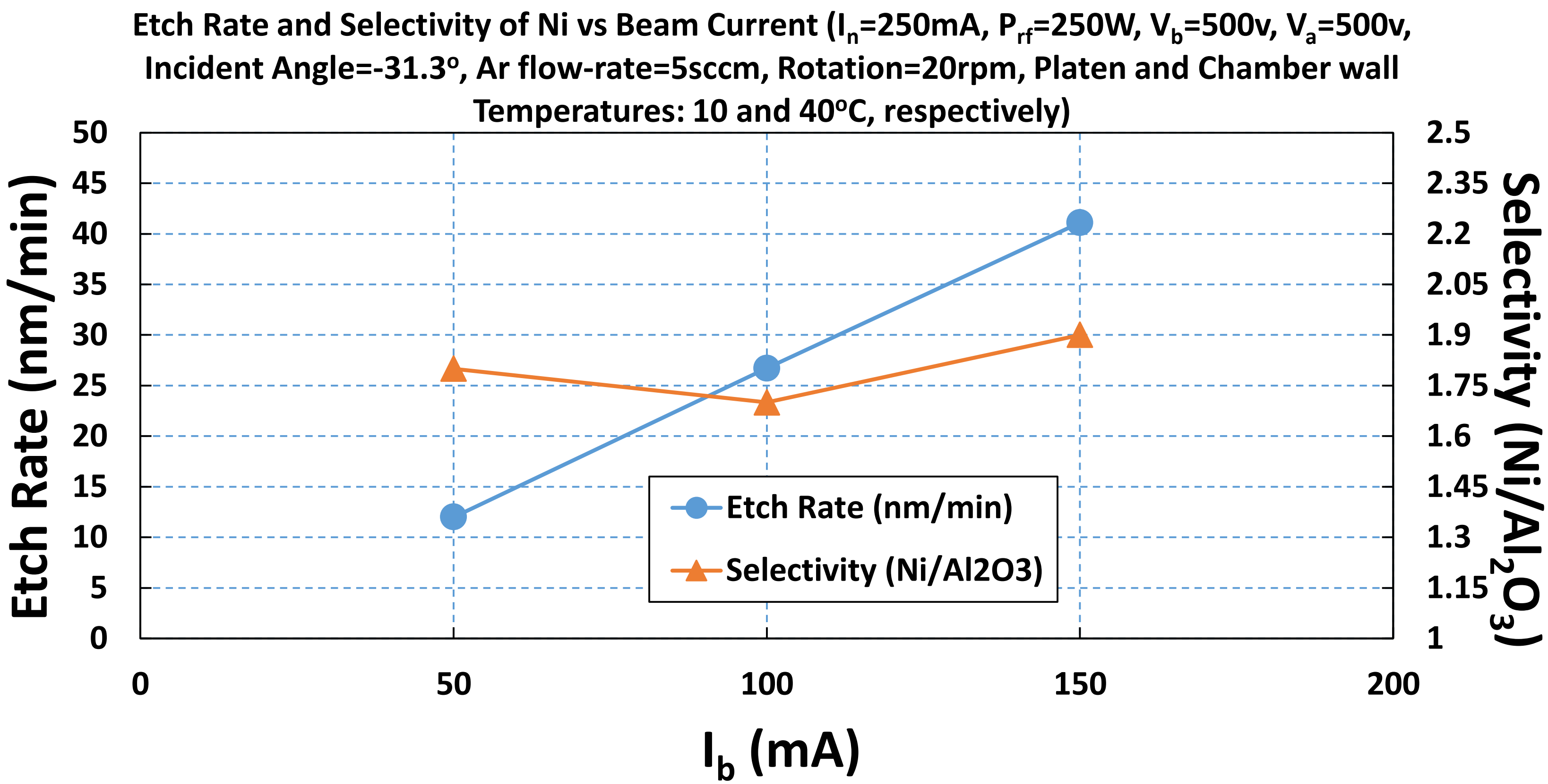


Figure 20 Etched sidewall angle of Ni as a function of beam current (V_b=500v and Incident Angle=-31.3°).

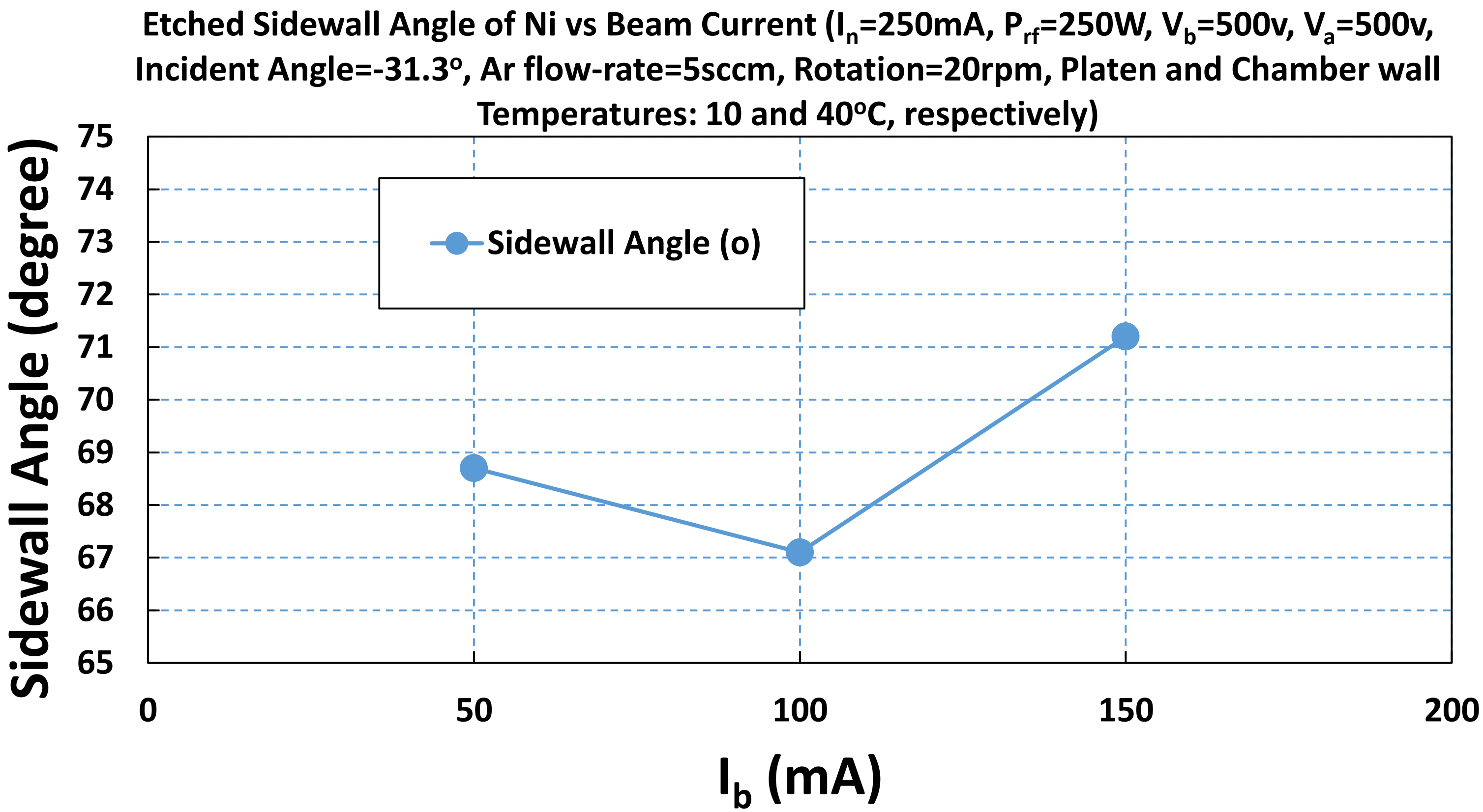


Figure 21 Etch rate and etch selectivity of Ni as functions of beam current (V_b=1000v and Incident Angle=31.3°).

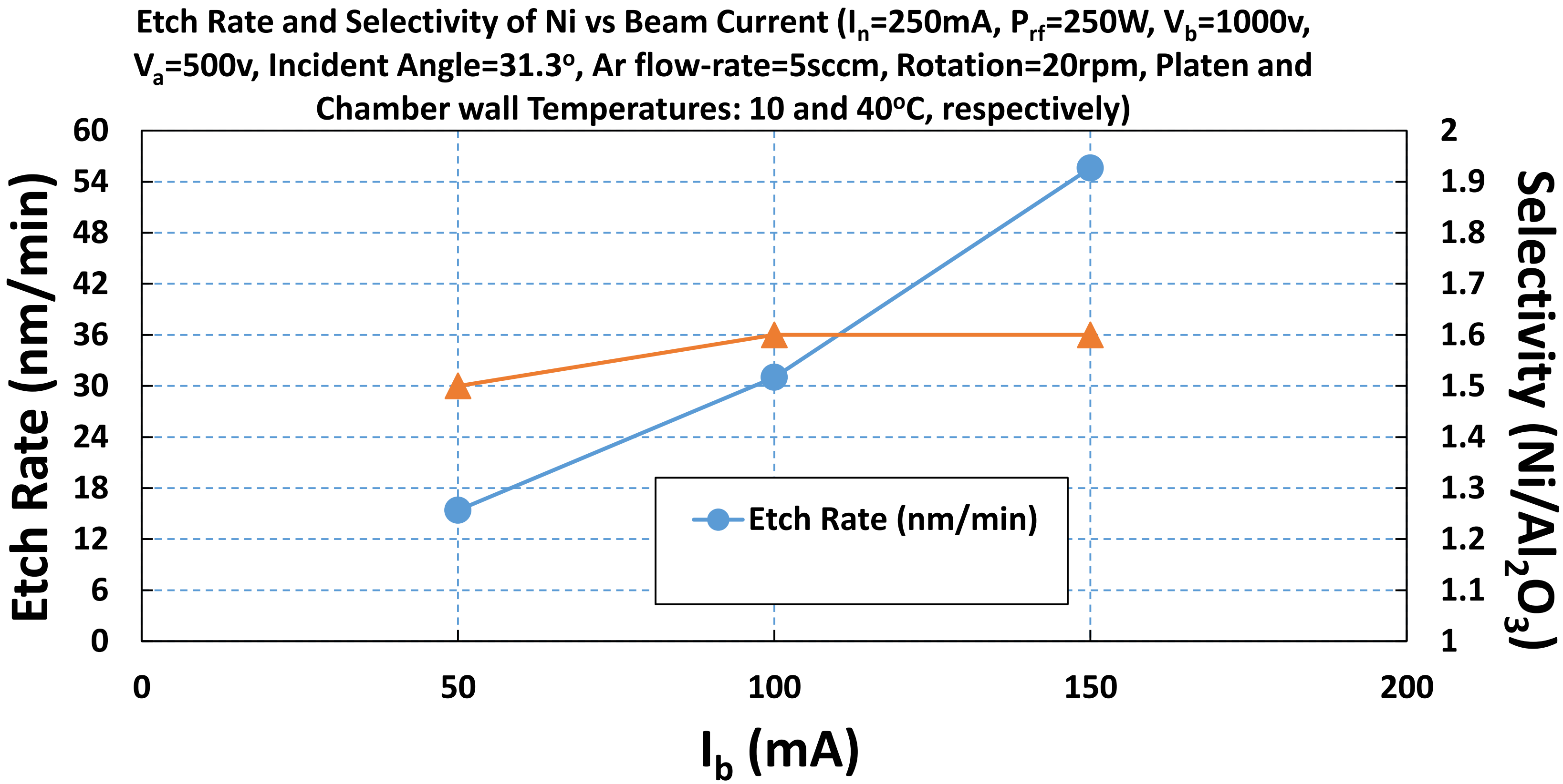


Figure 22 Etched sidewall angle of Ni as a function of beam current (V_b=1000v and Incident Angle=31.3^o).

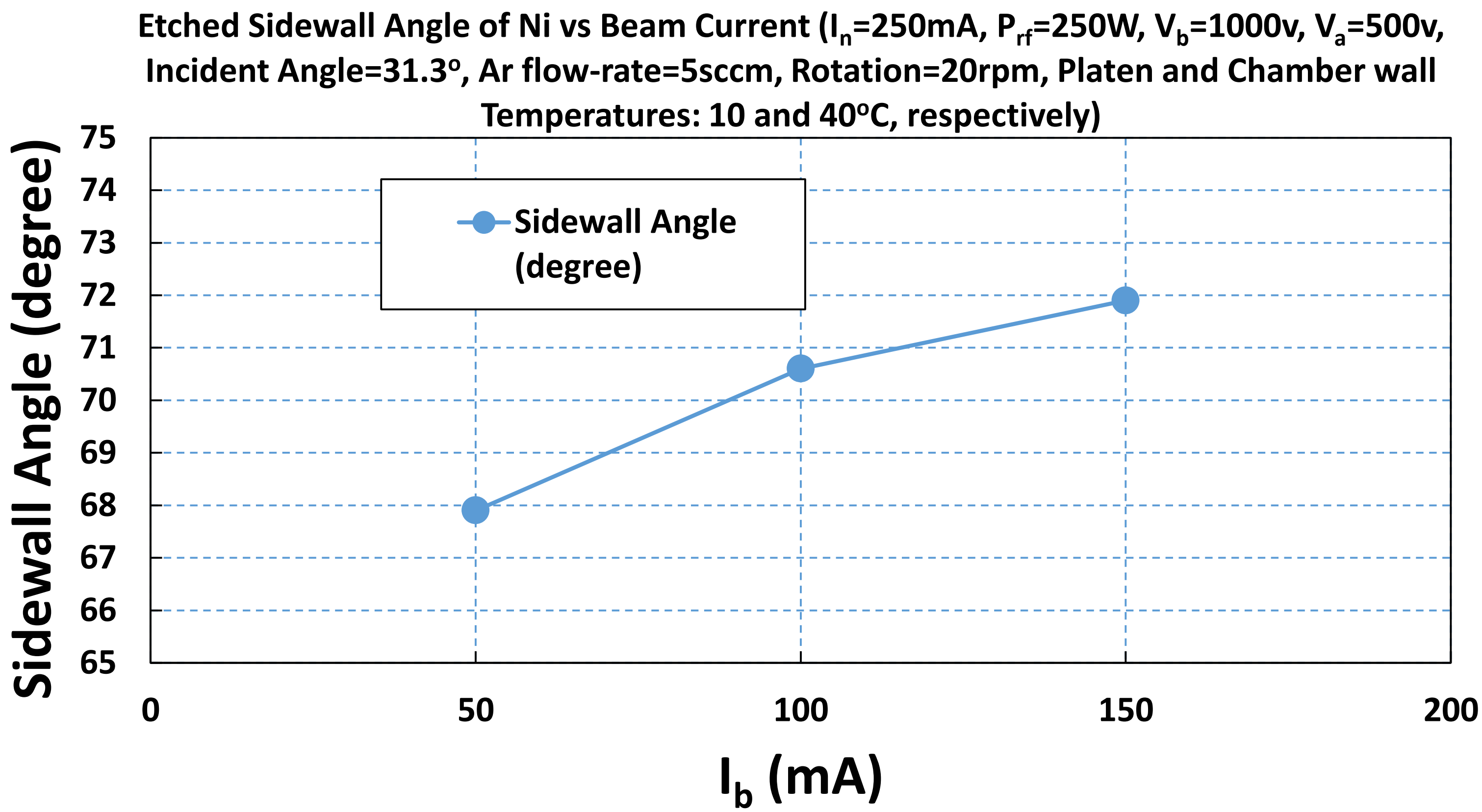


Figure 23 Etch rate and etch selectivity of Ni as functions of beam current (V_b=1250v and Incident Angle=31.3°).

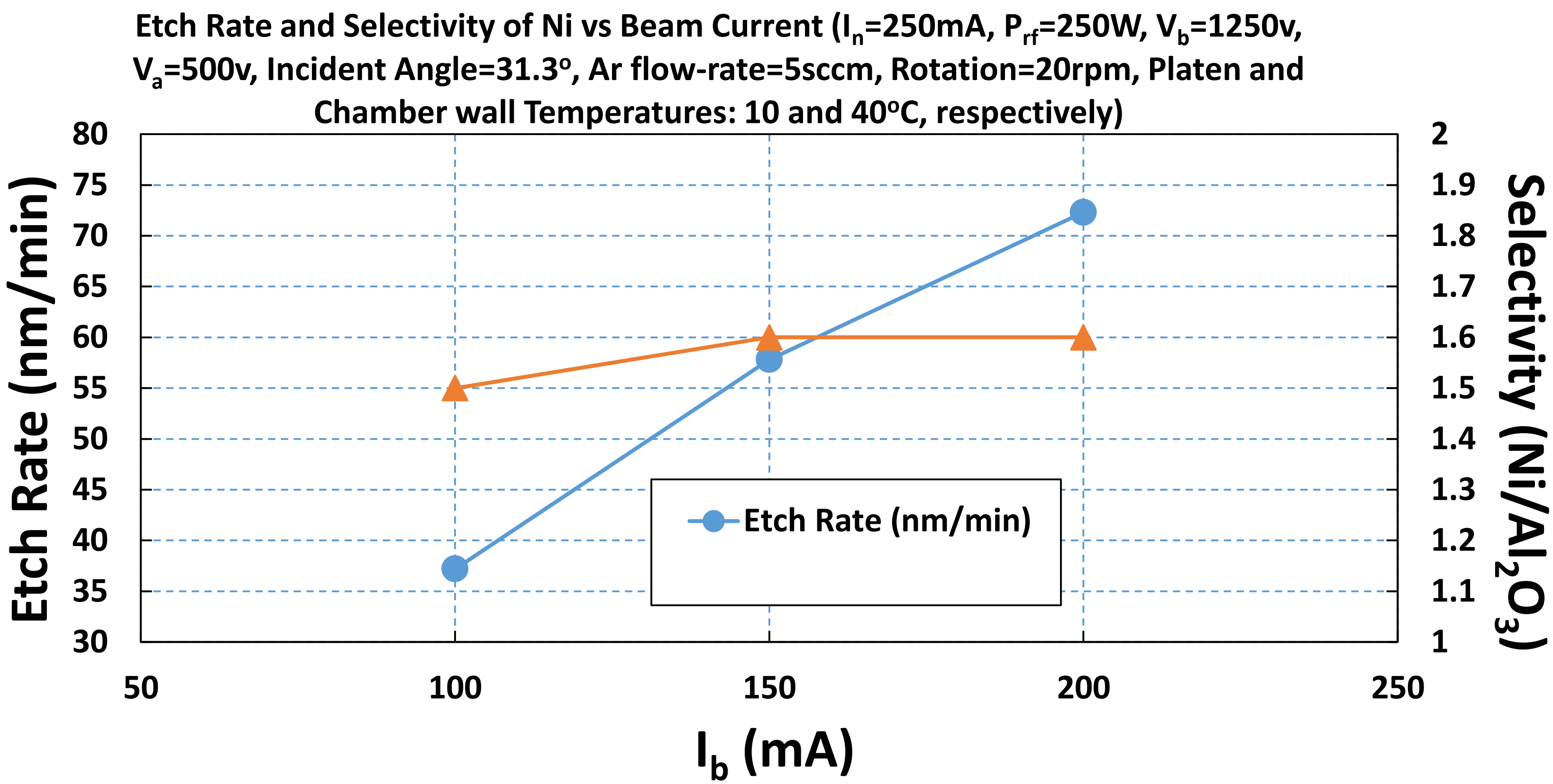


Figure 24 Etched sidewall angle of Ni as a function of beam current (V_b=1250v and Incident Angle=31.3°).