InP Etch Results – ICP RIE

Prepared by Matthew Haines

Note: Read notes found on each slide – they
contain important process information!

Project Inspiration

Project Inspiration

- ICP reactive ion etching
  - Independent control of plasma density/ion energy
  - User-defined etch
  - High etch rates

- $Cl_2/CH_4/Ar$ ICP RIE process
  - Superior etch results

InP nanostructures can be used for numerous nanophotonic systems, such as Bragg mirrors, waveguides, etc.

Compared to typical RIE systems, ICP RIE systems enable independent control of plasma density (through coil power adjustment) and ion energy (through platen power adjustment). This enables the user to define the etch – one can ensure either an ionic-based etch or a chemical-based etch. Additionally, high etch rates are attainable with ICP RIE systems.

Cl2/CH4/Ar ICP processes have been shown to result in superior etch results relative to other etch mechanisms. This is due to surface passivation as well as increased indium volatility. The purpose of Ar is to increase plasma stability as well as to promote the desorption of etch products.
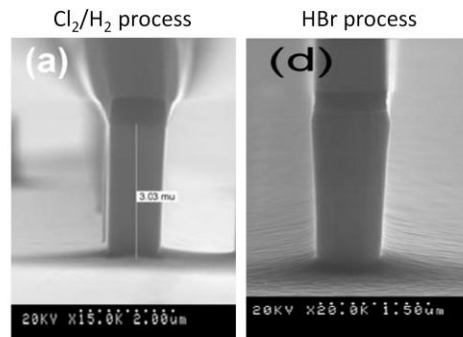
Project Inspiration

- Bouchoule et al. *"Sidewall Passivation Assisted by a Silicon Coverplate During Cl_2/H_2 and HBr ICP Etching of InP for Photonic Devices"*

- Cl_2/H_2 & HBr ICP process results
  - High anisotropy
  - High selectivity (Cr mask)
  - Smooth sidewalls

Both ICP RIE processes (using Cl2/H2 and HBr) resulted in high anisotropy, high selectivity, and smooth sidewalls.

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- Bouchoule et al. *"Sidewall Passivation Assisted by a Silicon Coverplate During Cl_2/H_2 and HBr ICP Etching of InP for Photonic Devices"*

- Major process drawbacks
  1. Si coverplate passivation source
  2. Inconsistent etch – lack of temperature control

The use of a Si coverplate as a passivation source is industrially impractical; during future ICP RIE processes, 4" InP wafers will be used instead of silicon.

Project Inspiration

- Wang et al. *"Deep InP Gratings for Opto-Electronic Devices Etched by Cl_2/CH_4/Ar Inductively Coupled Plasma"*

- Cl_2/CH_4/Ar ICP process parameters

| Cl_2/CH_4/Ar Flow Rate (sccm)	Platen Power	ICP Power	Chamber Pressure	Temp	Mask	Crsytalbond
14/12/3	120 W	1250 W	4 mTorr	17°C	SiN	None

  – Carrier wafer: unspecified
  – InP area: unspecified

Project Inspiration

- Wang et al. *"Deep InP Gratings for Opto-Electronic Devices Etched by Cl_2/CH_4/Ar Inductively Coupled Plasma"*

- Cl_2/CH_4/Ar ICP process results
  - High anisotropy
  - High selectivity (SiN mask)
  - High aspect ratio
  - Smooth sidewalls

Project Inspiration

- Wang et al. *"Deep InP Gratings for Opto-Electronic Devices Etched by Cl_2/CH_4/Ar Inductively Coupled Plasma"*

InP sample with mask — Etch result
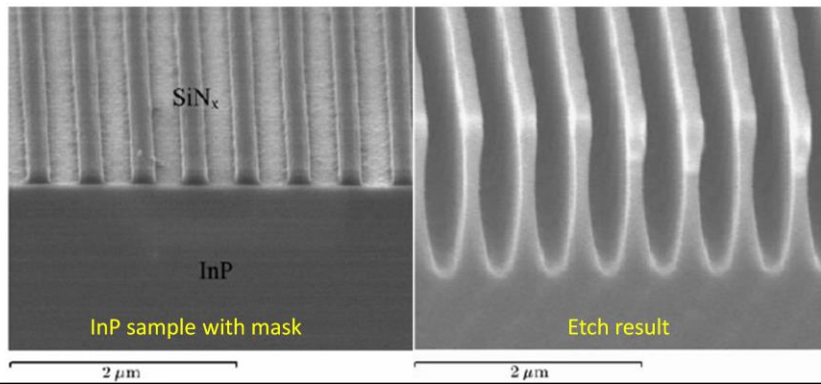
Project Inspiration

- Wang et al. *"Deep InP Gratings for Opto-Electronic Devices Etched by Cl_2/CH_4/Ar Inductively Coupled Plasma"*

- Major process drawbacks
  1. Inconsistent etch – lack of temperature control
  2. Unspecified information – carrier wafer, InP area

Objectives

Primary Project Objectives

1. Develop consistent/controllable ICP recipe
   – Temperature control; crystalbond 590
   – Sapphire carrier wafer

1. Obtain InP nanostructures with
   – Smooth sidewalls
   – High anisotropies
   – High selectivities
   – Large aspect ratios

Sapphire carrier wafer usage ensures that passivation is gas-based, not carrier wafer-based

Secondary Project Objectives

1. Develop laser interferometer model
   - Accurate dynamic etch depth/rate evaluation

2. Develop consistent OES models
   - Different etch stages
   - Cleaning/preconditioning termination

Note: The OES has thus far only been utilized to determine termination time during cleaning and preconditioning phases of the ICP process. However, it can be used for many more applications (i.e. radical generation rate determination, etc)
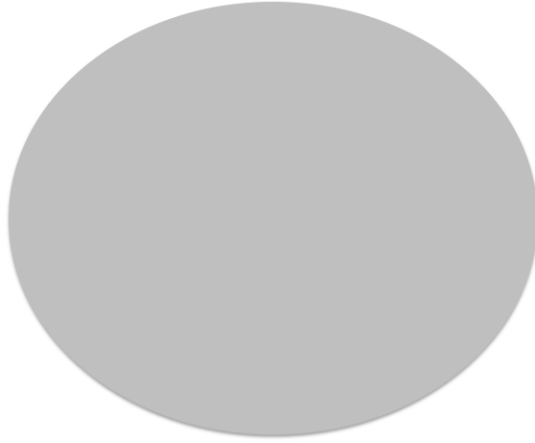
Sample Preparation

Sample Preparation

InP dummy wafer

InP sample

Sapphire carrier
wafer
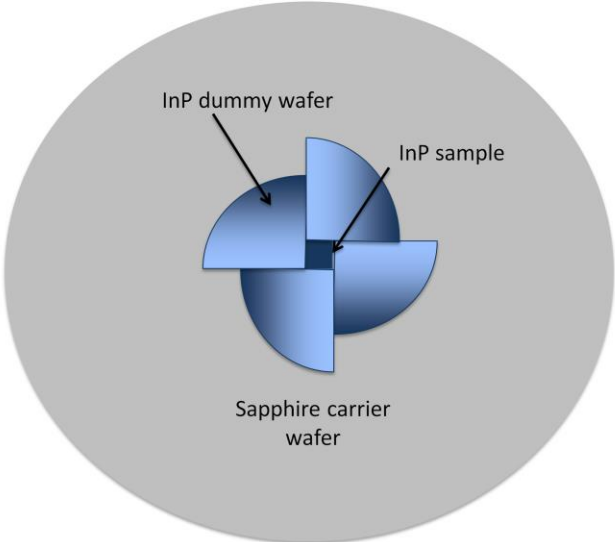
Sample Preparation

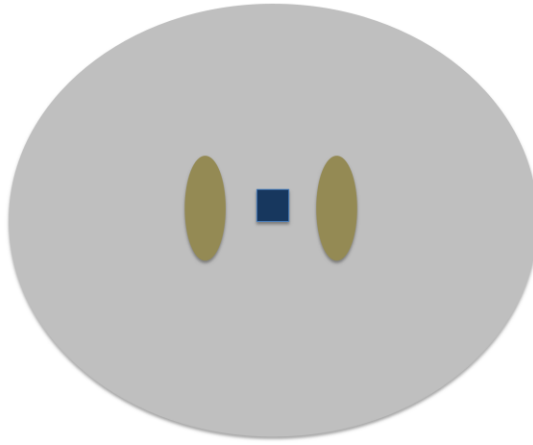1. Heat sapphire carrier to 180°C

Sample Preparation
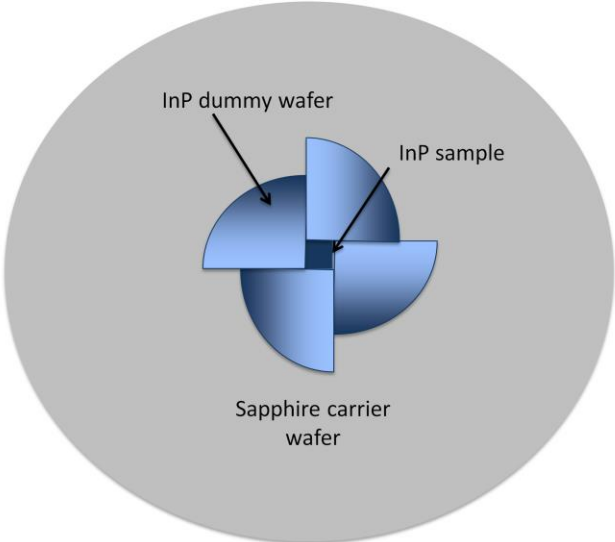
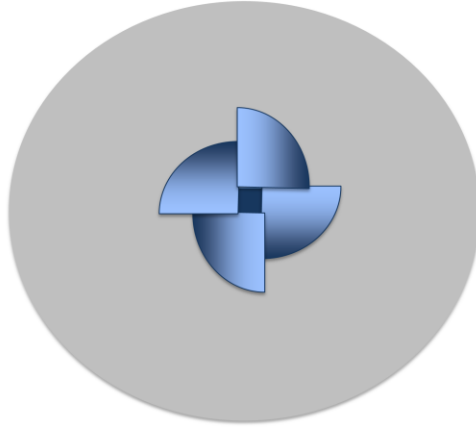2. Apply crystalbond 590

Sample Preparation

3. Place InP sample

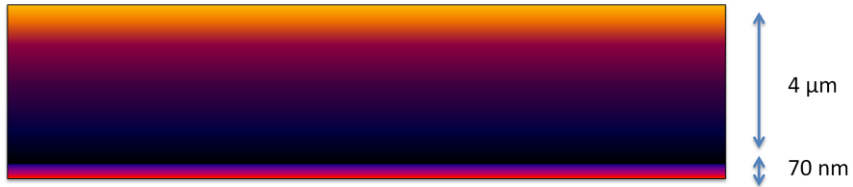# Sample Preparation

Sample Preparation

4. Place InP dummy wafer

Sample Wafer Structure

- Double-side polished
- 70 nm InGaAs/4 µm InP

4 µm

70 nm

Sample Mask Structure

- HSQ e-beam etch mask
  - 450 nm thickness

- Trench gratings
  - 50, 100, 200, 300, 400, 500, & 1000 nm variations
  - 100 nm variation = most practically significant

Note: 100 nm trench grating is most practically significant for Bragg mirror applications, and therefore will be utilized throughout the analysis section of this presentation.

Sample Mask Structure

- Mask preparation
  - Wafer D810
  - E-beam resist: FOX-15

- Mask exposure
  - Current: 6 nA
 - Dose: 4000 μC/cm^2
  - Shot 4

Note: 100 nm trench grating is most practically significant for Bragg mirror applications, and therefore will be utilized throughout the analysis section of this presentation.

Sample Mask Structure

50 nm trench grating
100 nm trench grating
200 nm trench grating
300 nm trench grating
400 nm trench grating
500 nm trench grating
1000 nm trench grating
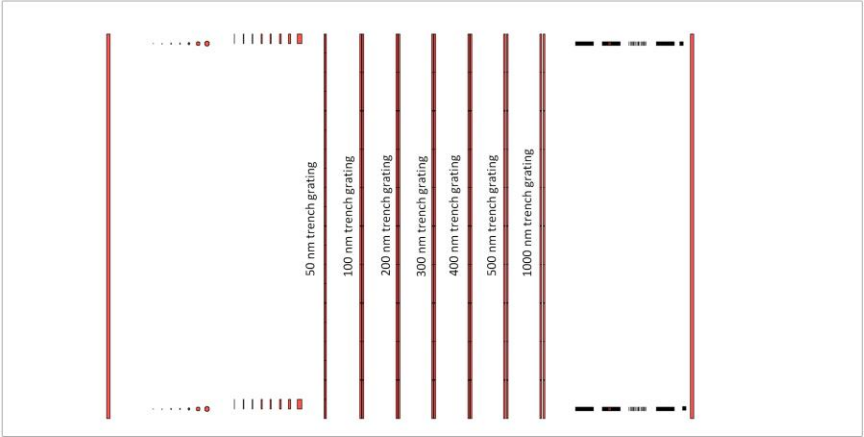
Sample Cleaning

Sample Cleaning (Following Etch)

- InP dummy wafers
  1. 7 min. H_2SO_4/H_2O_2 = 4:1 treatment
     - Removes crystalbond & polymer

- Sapphire carrier wafers
  1. 7 min. H_2SO_4/H_2O_2 = 4:1 treatment
     - Removes most polymer & other residue
  2. 5 min. O2 plasma treatment
     - Removes remaining polymer

Standard ICP RIE Process

Standard ICP RIE Process

1. Increase ICP temperature to 180°C

2. 10 minute O_2 plasma clean
   - Wafer: Sapphire cleaning/precondition wafer
   - Purpose: Reduce chamber contamination

3. 30 second O_2 plasma clean
   - Wafer: InP sample
   - Purpose: Reduce sample contamination

All relevant recipes can be found within the ICP directory on the designated III-V ICP etcher computer: Recipes\users\mhai

Standard ICP RIE Process

4. 2 minute O_2 plasma clean
    - Wafer: Sapphire cleaning/precondition wafer
    - Purpose: Reduce chamber contamination

5. 15 minute ICP chamber precondition
    - Wafer: Sapphire cleaning/precondition wafer
    - Purpose: Attain steady-state ICP chamber chemical composition

Standard ICP RIE Process

6. ICP reactive ion etch
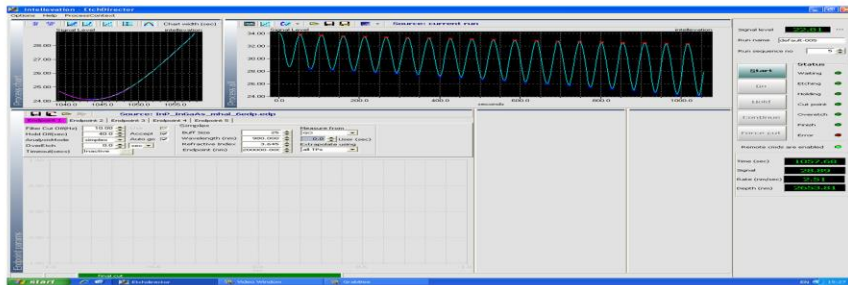   - Wafer: InP sample
   - Purpose: Etch InP sample

7. 20 minute O_2 plasma clean
   - Wafer: Sapphire cleaning/precondition wafer
   - Purpose: Reduce ICP chamber contamination

Etch Results

Laser Interferometer Model

- Single-layer SIMPLEX model
  - (Etch Depth/Turning Point) = λ/4n

- Intensity signal: Periodic interference pattern

Since the etch process involves only a single materialistic layer, the single-layer SIMPLEX model can be effectively utilized in order to determine the dynamic etch depth of the indium phosphide samples. Should the etch process involve several materialistic layers, a full-scale model would be needed, which requires accurate knowledge of layer thicknesses as well as refractive indices.

In the above equation, λ refers to the light wavelength whereas n refers to the meterialistis refractive index (n~3.900 for InP at a temperature of 180C and a wavelength of 980 nm).

Laser Interferometer Model

- Relevent user-defined parameters
  1. Buffer size
  2. Filter cutoff
  3. Holdoff time
  4. Analysis mode
  5. Endpoint

- Refer to interferometer manual
  - Provides parameter-related information

Since the etch process involves only a single materialistic layer, the single-layer SIMPLEX model can be effectively utilized in order to determine the dynamic etch depth of the indium phosphide samples. Should the etch process involve several materialistic layers, a full-scale model would be needed, which requires accurate knowledge of layer thicknesses as well as refractive indices.
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OES Models

- OES: Optical emission spectroscopy
  - Measures signal intensities of relaxant species
  - Fiber optic input beneath ICP chuck
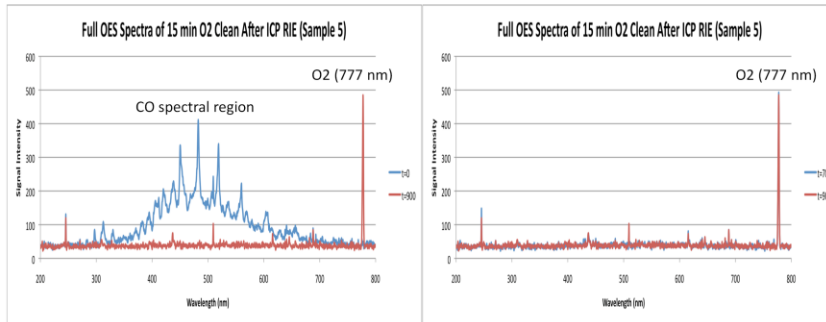
- Operating instructions
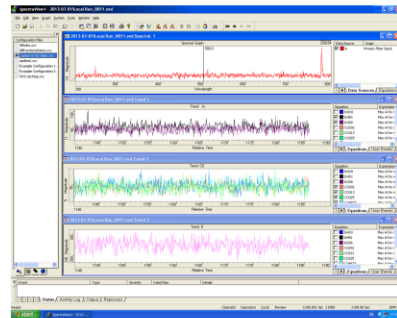
OES Models

- OES data collection
  - Each ICP process stage

- Steady-state OES spectrum
  - Cleaning/preconditioning termination

OES Models

- Example: Oxygen plasma clean following ICP RIE process

InP ICP Reactive Ion Etch

- Constant ICP Parameters
  - Etch time = 600 s

Cl$_2$ Flow Rate	Ar Flow Rate	Chamber Pressure	Temp.	Carrier Wafer	Crystalbond	Wafer Area
10 sccm	2 sccm	1 mT	180°C	Al$_2$O$_3$	590 HMP	2"

Note: Ar flow rate of 2 sccm utilized in order to obtain a stable plasma, low chamber pressure utilized in to order increase InCl volatility, high temperature utilized in order to increase InCl volatility, Al2O3 carrier utilized in order to achieve inert background environment, crystalbond 590 HMP used in order to achieve temperature control as well as sample adhesion, etch time selected based upon previous experimentation, 2" wafer size utilized as it is the largest commercially available InP wafer.
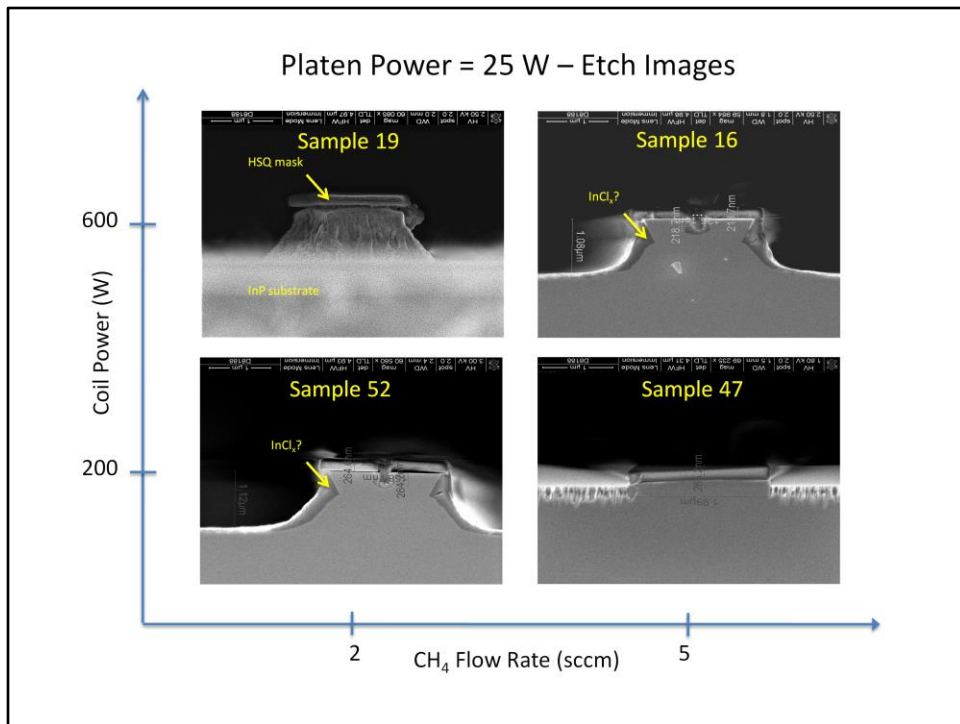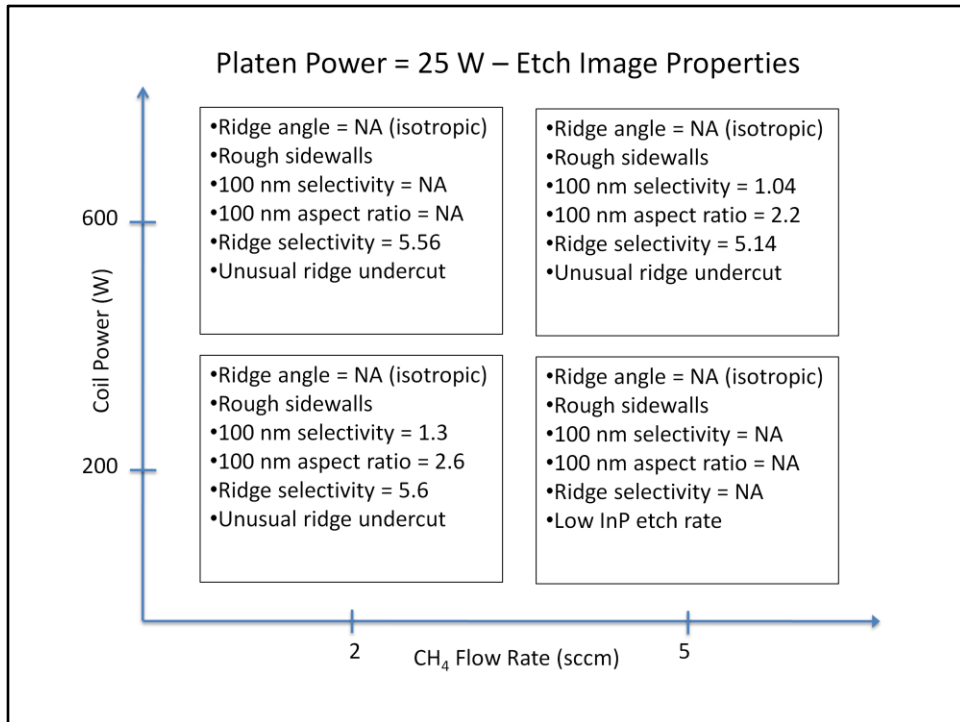
Top left hand corner – High coil power and low platen power, therefore very radical-based etch. Hence there will be a large concentration of novolatile InCl on the surface of the InP sample, resulting in rough features. Initial undercut of nanostructure may be due to increased sticking coefficient of HSQ, which would localized radicals (chemical-based etch, hence undercut) at the InP-HSQ interface.
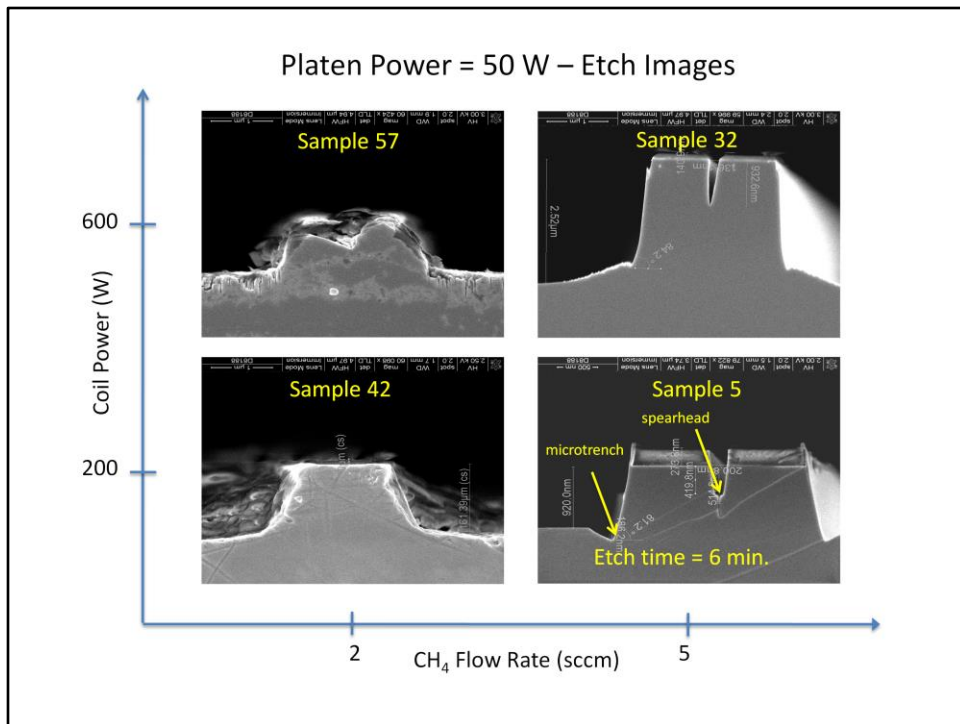Top right hand corner – over passivation due to high methane flow rate; low etch rate
Bottom left hand corner – over passivation due to low platen and coil power
Bottom right hand corner – over passivation due to high methane flow rate, low coil power, and low platen power; very low etch rate; very rough surface

Platen Power = 25 W – Etch Image Properties

Top-left quadrant (Coil Power ~600, CH₄ ~2):
- Ridge angle = NA (isotropic)
- Rough sidewalls
- 100 nm selectivity = NA
- 100 nm aspect ratio = NA
- Ridge selectivity = 5.56
- Unusual ridge undercut

Top-right quadrant (Coil Power ~600, CH₄ ~5):
- Ridge angle = NA (isotropic)
- Rough sidewalls
- 100 nm selectivity = 1.04
- 100 nm aspect ratio = 2.2
- Ridge selectivity = 5.14
- Unusual ridge undercut

Bottom-left quadrant (Coil Power ~200, CH₄ ~2):
- Ridge angle = NA (isotropic)
- Rough sidewalls
- 100 nm selectivity = 1.3
- 100 nm aspect ratio = 2.6
- Ridge selectivity = 5.6
- Unusual ridge undercut

Bottom-right quadrant (Coil Power ~200, CH₄ ~5):
- Ridge angle = NA (isotropic)
- Rough sidewalls
- 100 nm selectivity = NA
- 100 nm aspect ratio = NA
- Ridge selectivity = NA
- Low InP etch rate

Axes: Coil Power (W) vertical (200, 600); CH_4 Flow Rate (sccm) horizontal (2, 5)

Note: 100 nm selectivity refers to the selectivity within the 100 nm InP trench. Take one of these information blocks – during presentation – and describe what it means.
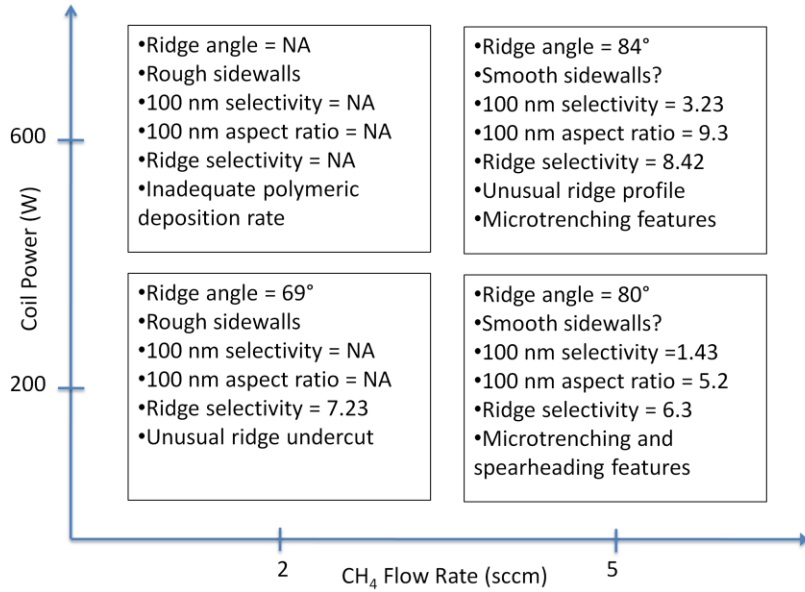
Top left hand corner – Sample was destroyed due to very high coil power, very high platen power, and low passivation rate. HSQ mask was completely removed from sample.
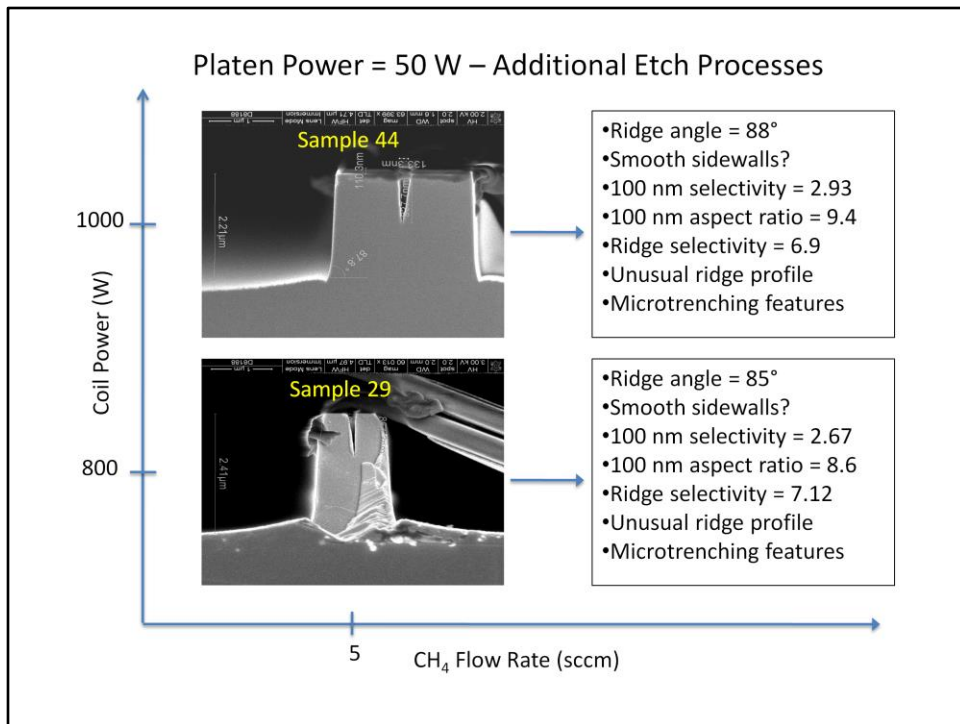
Top right hand corner – High coil and platen power balances the ion/radical ratio, resulting in smooth InP sidewalls, high degrees of anisotropy, high selectivities, and large aspect ratios. Strange vertex profile possibly due to micromasking effect.

Bottom left hand corner – Strongly ionic based etch due to low coil power; ions damage sample surface.

Bottom right hand corner – Strongly ionic-based etch due to low coil power, resulting in microtrenching and spearheading features.

Platen Power = 50 W – Etch Image Properties

Coil Power (W)

600

- Ridge angle = NA
- Rough sidewalls
- 100 nm selectivity = NA
- 100 nm aspect ratio = NA
- Ridge selectivity = NA
- Inadequate polymeric deposition rate

- Ridge angle = 84°
- Smooth sidewalls?
- 100 nm selectivity = 3.23
- 100 nm aspect ratio = 9.3
- Ridge selectivity = 8.42
- Unusual ridge profile
- Microtrenching features

200

- Ridge angle = 69°
- Rough sidewalls
- 100 nm selectivity = NA
- 100 nm aspect ratio = NA
- Ridge selectivity = 7.23
- Unusual ridge undercut

- Ridge angle = 80°
- Smooth sidewalls?
- 100 nm selectivity =1.43
- 100 nm aspect ratio = 5.2
- Ridge selectivity = 6.3
- Microtrenching and spearheading features

2 CH_4 Flow Rate (sccm) **5**

Platen Power = 50 W – Additional Etch Processes

Coil Power (W)

1000

800

Sample 44

- Ridge angle = 88°
- Smooth sidewalls?
- 100 nm selectivity = 2.93
- 100 nm aspect ratio = 9.4
- Ridge selectivity = 6.9
- Unusual ridge profile
- Microtrenching features

Sample 29

- Ridge angle = 85°
- Smooth sidewalls?
- 100 nm selectivity = 2.67
- 100 nm aspect ratio = 8.6
- Ridge selectivity = 7.12
- Unusual ridge profile
- Microtrenching features

5   CH_4 Flow Rate (sccm)

Top - High coil and platen power balances the ion/radical ratio, resulting in smooth InP sidewalls, high degrees of anisotropy, high selectivities, and large aspect ratios. Strange vertex profile possibly due to micromasking effect.

Bottom - High coil and platen power balances the ion/radical ratio, resulting in smooth InP sidewalls, high degrees of anisotropy, high selectivities, and large aspect ratios. Strange vertex profile possibly due to micromasking effect.

Conclusions

1. Low platen power – poor etch results

2. Low CH_4 flow rate – poor etch results

3. High platen power & high methane flow rate – superior etch results

Where "poor etch result" indicates that the desired InP nanostructures features listed in the slide "Primary Objectives" have not been satisfactorily attained.

Conclusions

4. High coil power – reduced microtrenching

5. InP etch profile – major dependence upon CH_4 flow rate & platen power; minor dependence upon coil power

Note: Conclusion 5 refers to the observation that, should un-optimized platen power and methane flow rates be utilized, the resulting profile will not contain the desired nanostructures. Should un-optimized coil power be used, it is still possible to obtain the desired indium phosphide nanostructure profile.

Further Testing
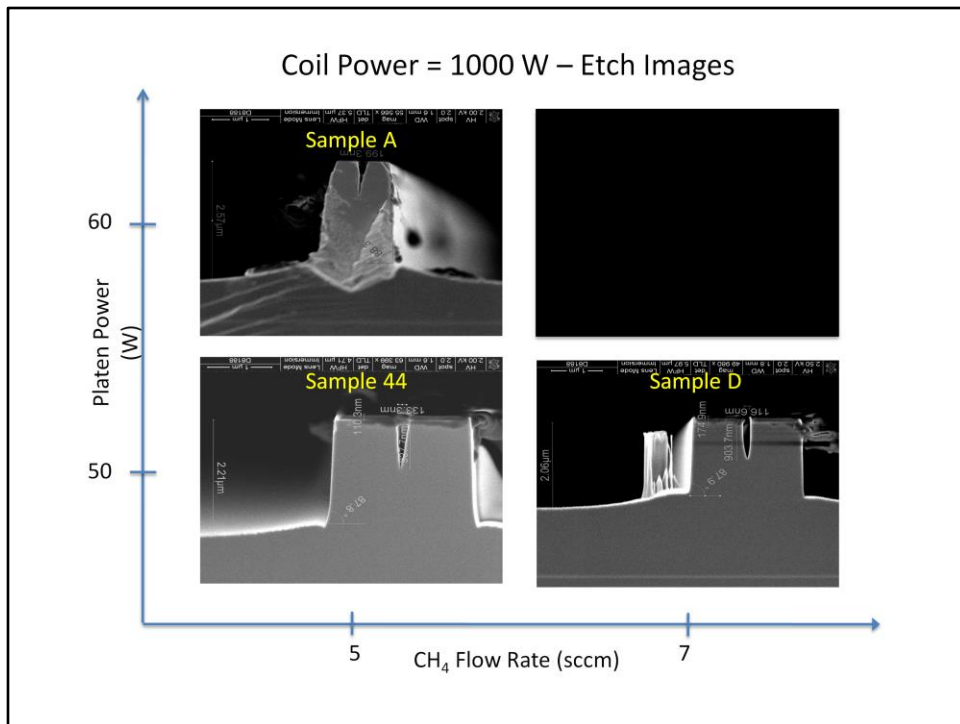
Sample A – Increased platen power to 60 W results in minimal etch differences relative to those obtained from InP sample 44. The trench grating anisotropy appears to worsen, possibly due to scattering effects. Additionally, mask erosion appears to occur. This may be due to mask charging occurring predominantly at the HSQ/InP apexes (which would occur since ions impinging upon the HSQ would try to become grounded by traveling to the InP), which would result in distorted ionic bombardment trajectories. Consequently, mask erosion occurs.

Sample D – Increased passivation (by increasing the methane flow rate) results in a lower InP etch rate, as expected. However, the anisotropy of the 100 nm trench grating significantly increases. This may be due to the increased quantity of methyl radicals molecules formed during the process. These radicals react with the InP, producing $In(CH_3)_x$ molecules, which are much more volatile than $InCl_x$ molecules. Hence increasing the methane flow rate results in a much more chemically (radical)-based etch. Hence, the trench grating profile of InP sample D differs from the triangular profile obtained from the highly ionic-based etch of InP sample 44 due to superior balance between chemical and ionic based etching.

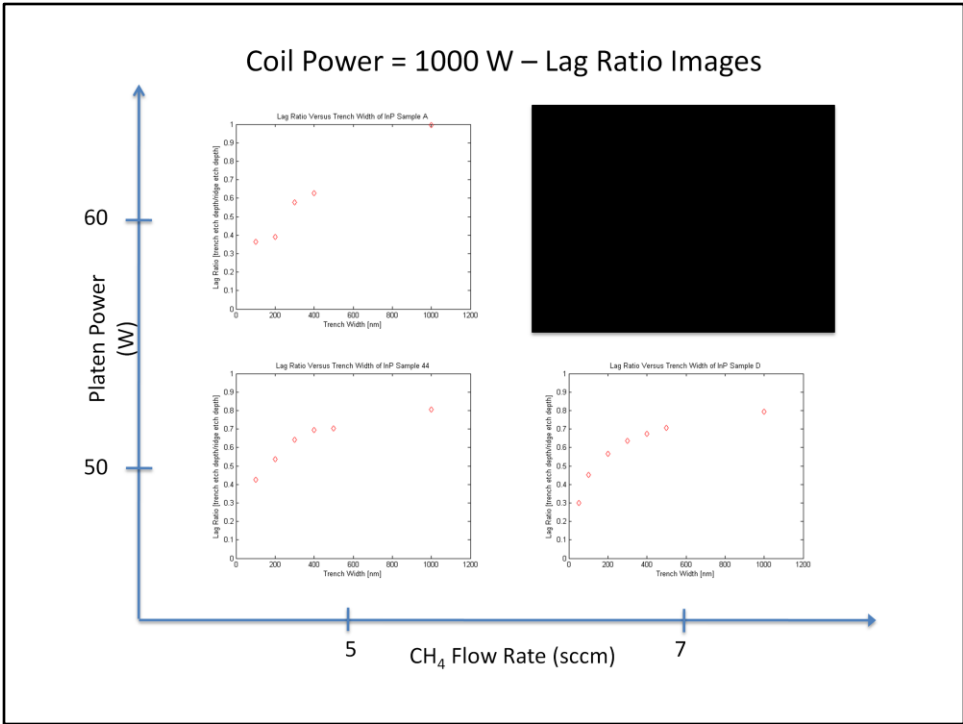Coil Power = 1000 W – Laser Interferometer Images
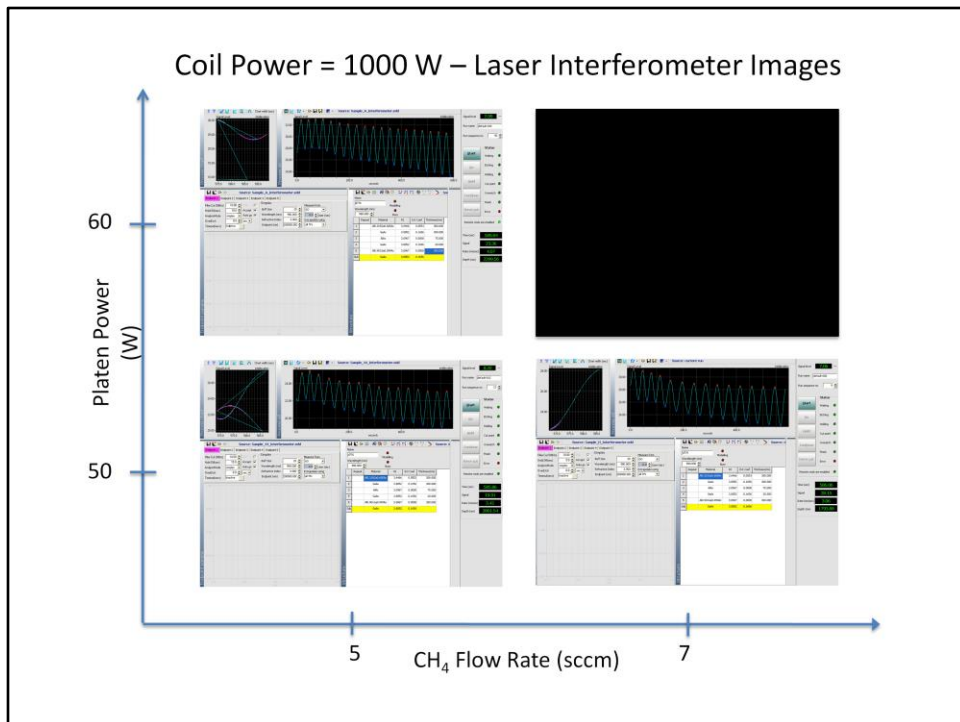
The etch rate of InP sample A is greater than that of InP sample 44 and D due to a higher coil power as well as low methane flow rate (relative to sample D).
The InP etch rate of InP sample 44 is greater than that of InP sample D due to a lower methane flow rate.
The InP etch rate of InP sample D is low due to a high methane flow rate.
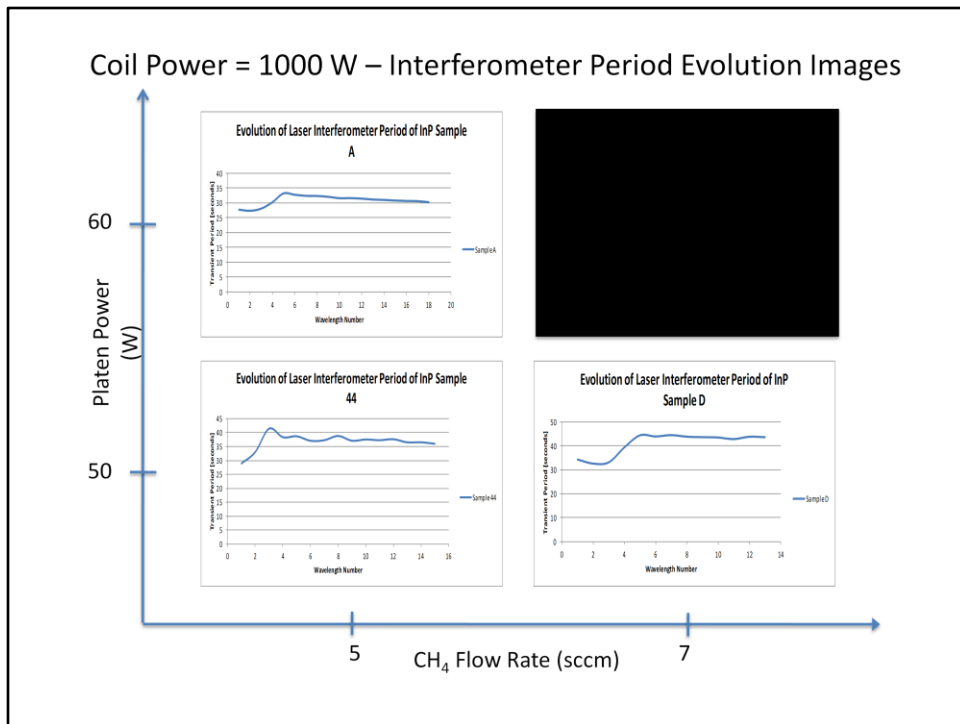
Coil Power = 1000 W – Interferometer Period Evolution Images

Analysis of the period evolutions of the laser interferometry intensity spectra of InP samples A, 44, and D reveals that the initial etch rate (at the beginning of the etch process) is substantially higher than the rates obtained during the remainder of the process. This may be due to the absence of sapphire carrier wafer preconditioning: At the commencement of the etch process, the sapphire has not been subjected to the deposition of polymeric material. As the etch progresses, polymeric material is deposited onto the sapphire sample. This organic layer is then sputtered - due to ionic bombardment - and is redeposited onto the InP sample, thus reducing its etch rate. Lastly, further inspection of the period evolutions reveals that the etch rates of all samples increases slightly as time progresses. This may be due to the gradual heating of the InP samples.
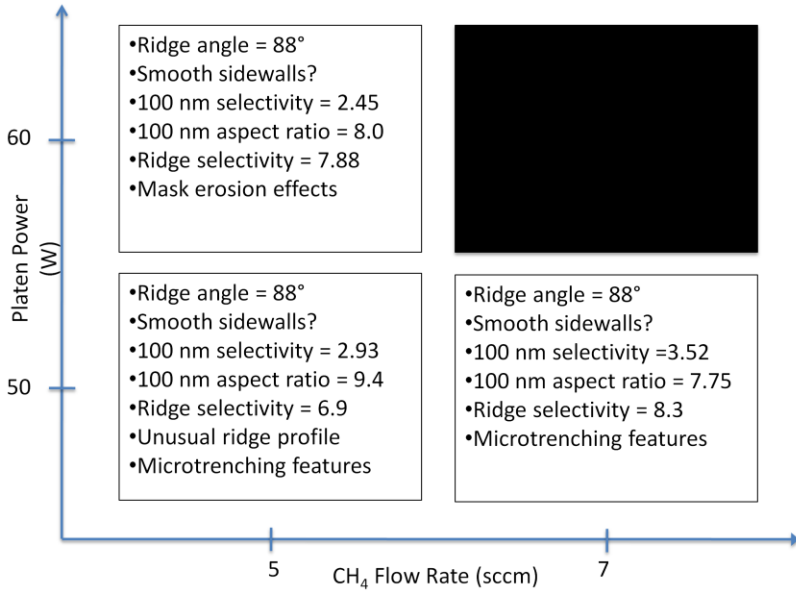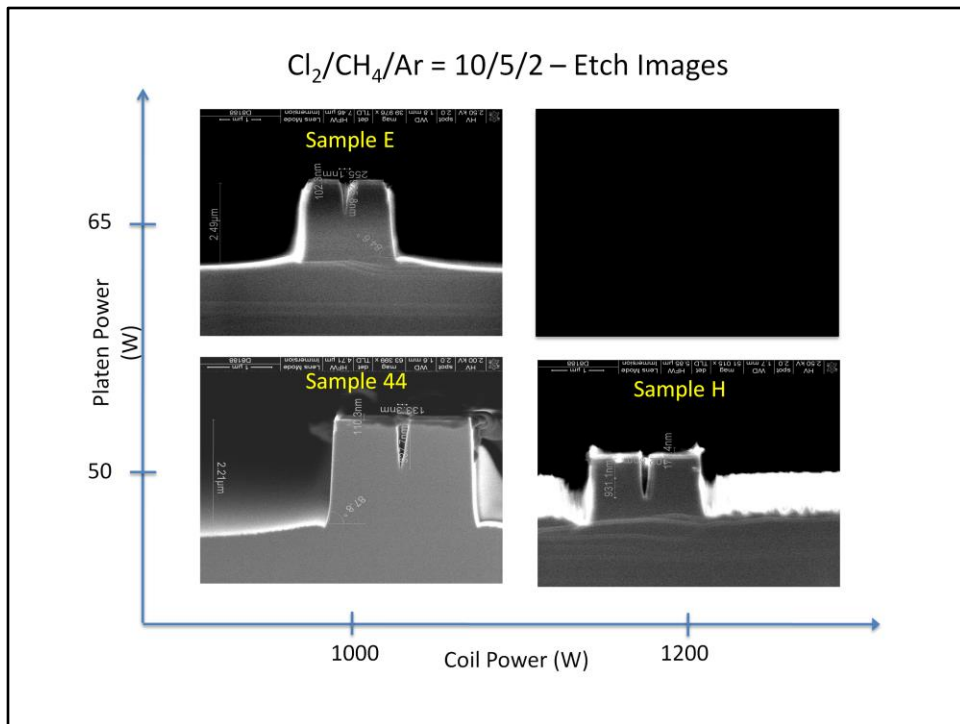
Larger lag ratios are expected for processes consisting of higher platen power (more ionic-based etches), as theoretically they attain a higher degree of anisotropy.

Coil Power = 1000 W – Aspect Ratio Images
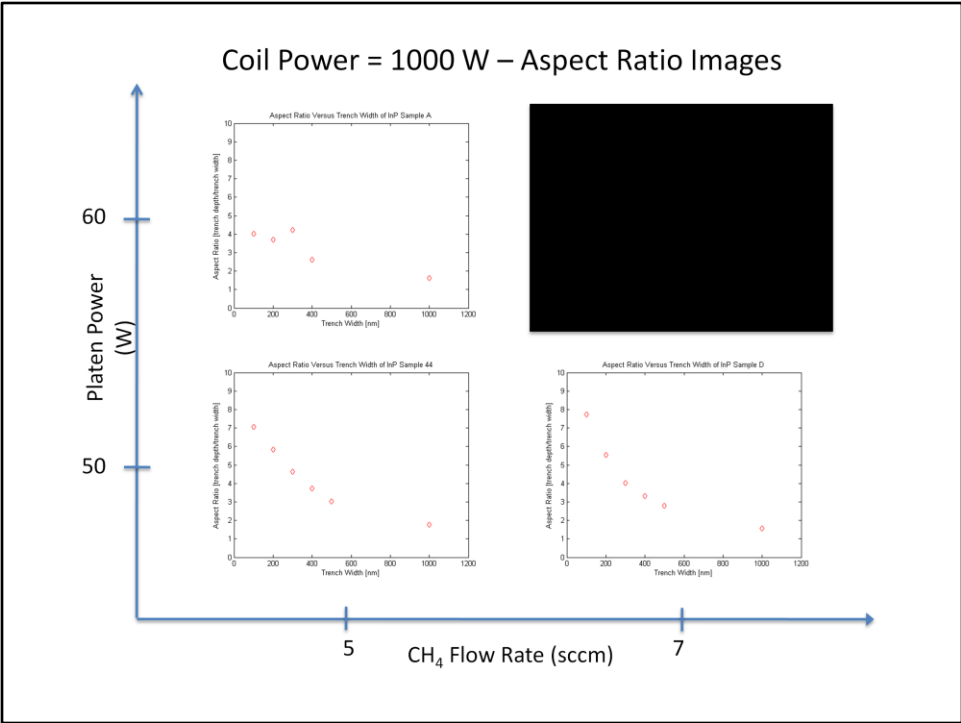
Larger lag ratios are expected for processes consisting of higher platen power (more ionic-based etches), as theoretically they attain a higher degree of anisotropy.
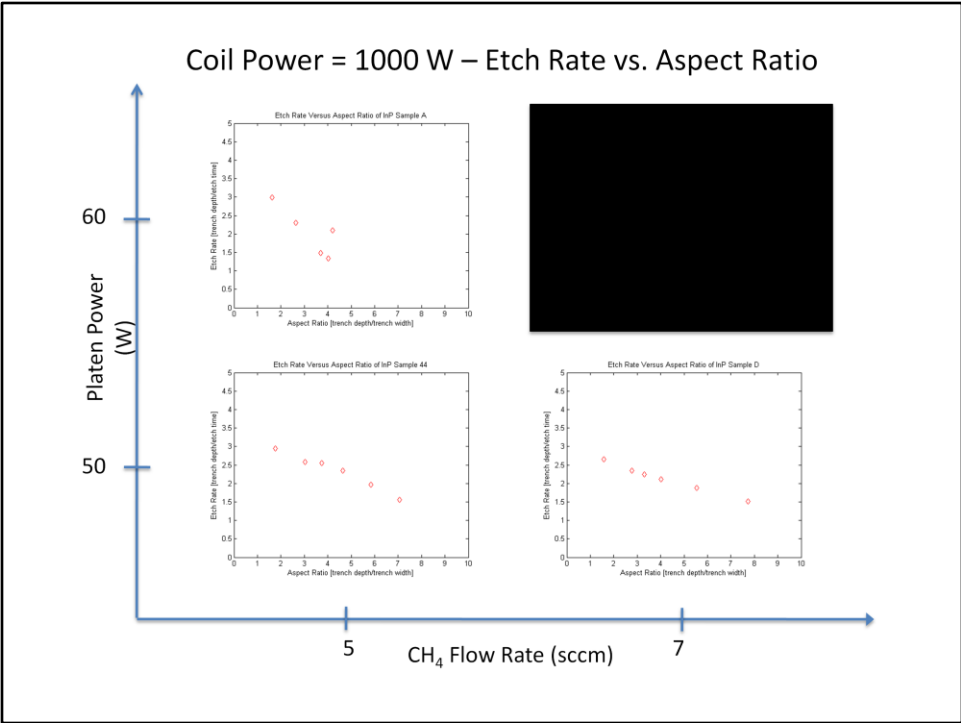
Larger lag ratios are expected for processes consisting of higher platen power (more ionic-based etches), as theoretically they attain a higher degree of anisotropy.

Coil Power = 1000 W – Etch Data

Chart with y-axis labeled "Platen Power (W)" (marked at 50 and 60) and x-axis labeled "CH$_4$ Flow Rate (sccm)" (marked at 5 and 7).

Top-left quadrant (5 sccm, 60 W):
- Ridge angle = 88°
- Smooth sidewalls?
- 100 nm selectivity = 2.45
- 100 nm aspect ratio = 8.0
- Ridge selectivity = 7.88
- Mask erosion effects

Top-right quadrant (7 sccm, 60 W): [black box, no text]

Bottom-left quadrant (5 sccm, 50 W):
- Ridge angle = 88°
- Smooth sidewalls?
- 100 nm selectivity = 2.93
- 100 nm aspect ratio = 9.4
- Ridge selectivity = 6.9
- Unusual ridge profile
- Microtrenching features

Bottom-right quadrant (7 sccm, 50 W):
- Ridge angle = 88°
- Smooth sidewalls?
- 100 nm selectivity = 3.52
- 100 nm aspect ratio = 7.75
- Ridge selectivity = 8.3
- Microtrenching features

Sample E – Increased platen power to 65 W results in minimal etch differences relative to those obtained from InP sample 44. The trench grating anisotropy appears to worsen, possibly due to scattering effects. Additionally, mask erosion appears to occur. This may be due to mask charging occurring predominantly at the HSQ/InP apexes (which would occur since ions impinging upon the HSQ would try to become grounded by traveling to the InP), which would result in distorted ionic bombardment trajectories. Consequently, mask erosion occurs.

Sample H – Increasing the coil power increases the chemical component of the etch, producing additional chlorine radicals. These react with InP, resulting in nonvolatile $InCl_x$ molecules. This effect should yield an increasingly rough surface, although such extreme roughness was unexpected.

Cl$_2$/CH$_4$/Ar = 10/5/2 – Laser Interferometer Images
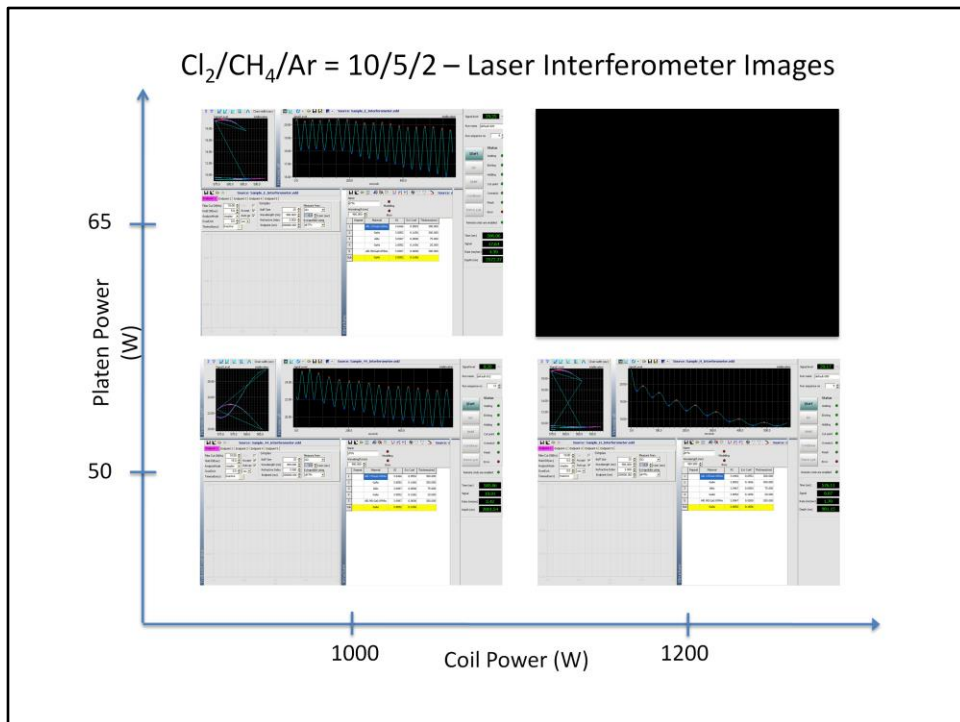
The etch rate of InP sample E is greater than that of InP sample 44 and D due to a higher coil power as well as low methane flow rate (relative to sample D).

The InP etch rate of InP sample 44 is greater than that of InP sample D due to a lower coil power, and hence fewer nonvolatile InCl$_x$ molecules present to disrupt the etch process.

The InP etch rate of InP sample D is low due to a high coil power.
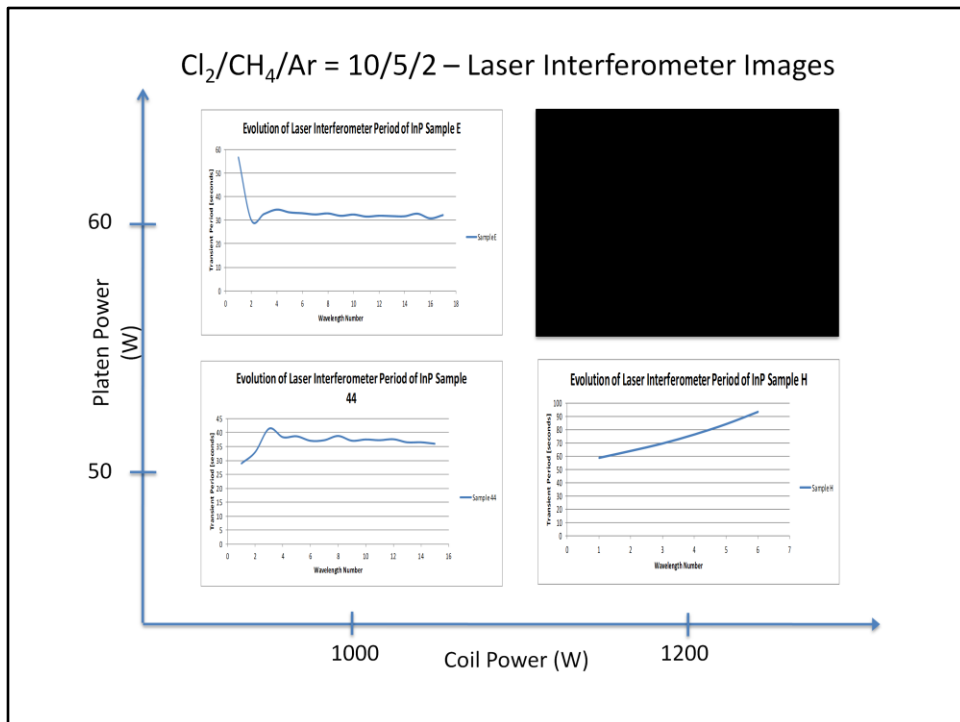
Cl$_2$/CH$_4$/Ar = 10/5/2 – Laser Interferometer Images

Analysis of the period evolutions of the laser interferometry intensity spectra of InP samples 44 and H reveals that the initial etch rate (at the beginning of the etch process) is substantially higher than the rates obtained during the remainder of the process. This may be due to the absence of sapphire carrier wafer preconditioning: At the commencement of the etch process, the sapphire has not been subjected to the deposition of polymeric material. As the etch progresses, polymeric material is deposited onto the sapphire sample. This organic layer is then sputtered - due to ionic bombardment - and is redeposited onto the InP sample, thus reducing its etch rate. Lastly, further inspection of the period evolutions reveals that the etch rates of all samples increases slightly as time progresses. This may be due to the gradual heating of the InP samples.

The initial, low etch rate of InP sample E may be due to inadequate thermalization; the etch rate increases as the sample temperature increases (due to ionic bombardment, surface chemical reactions, etc).
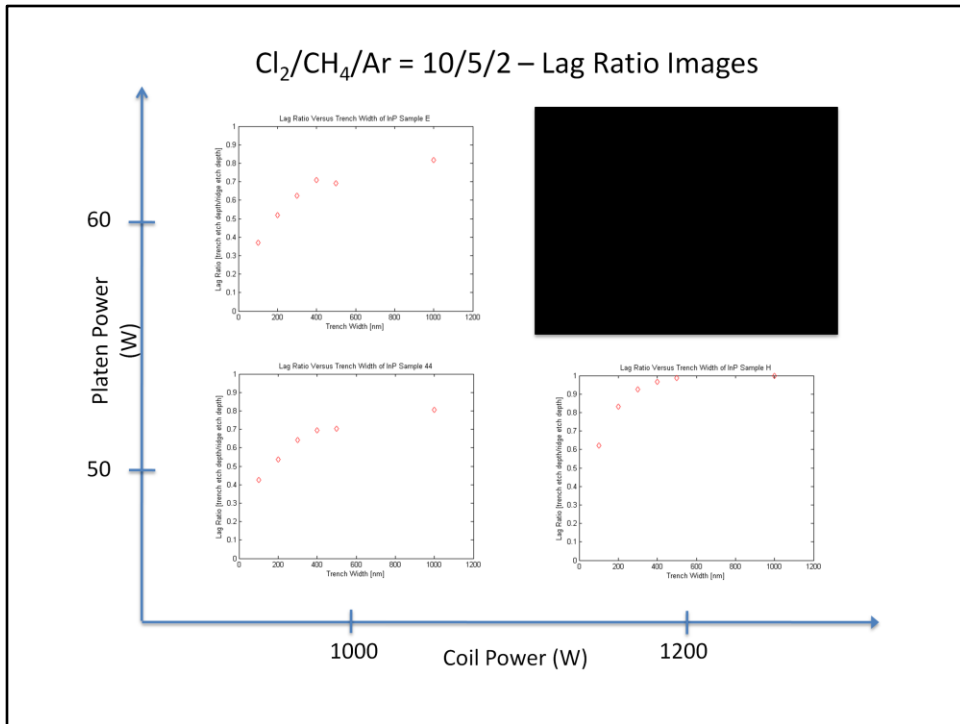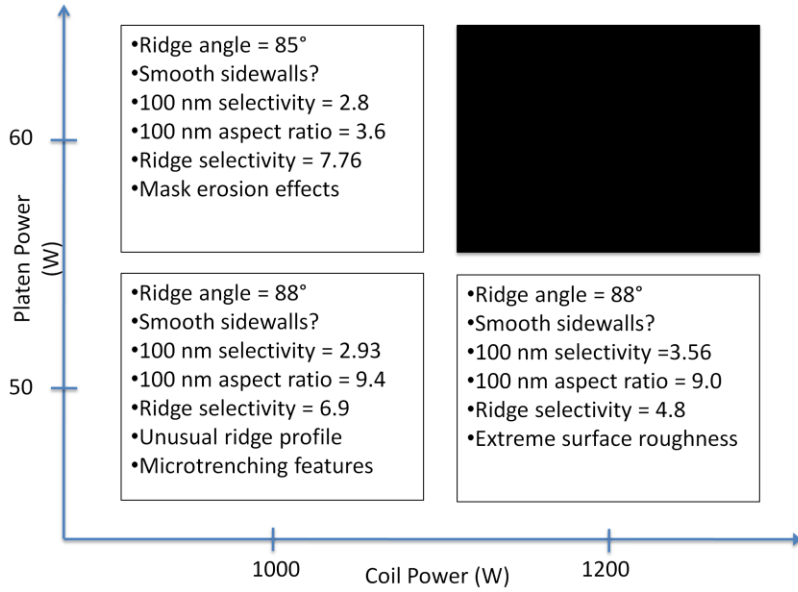
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Cl$_2$/CH$_4$/Ar = 10/5/2 – Aspect Ratio Images
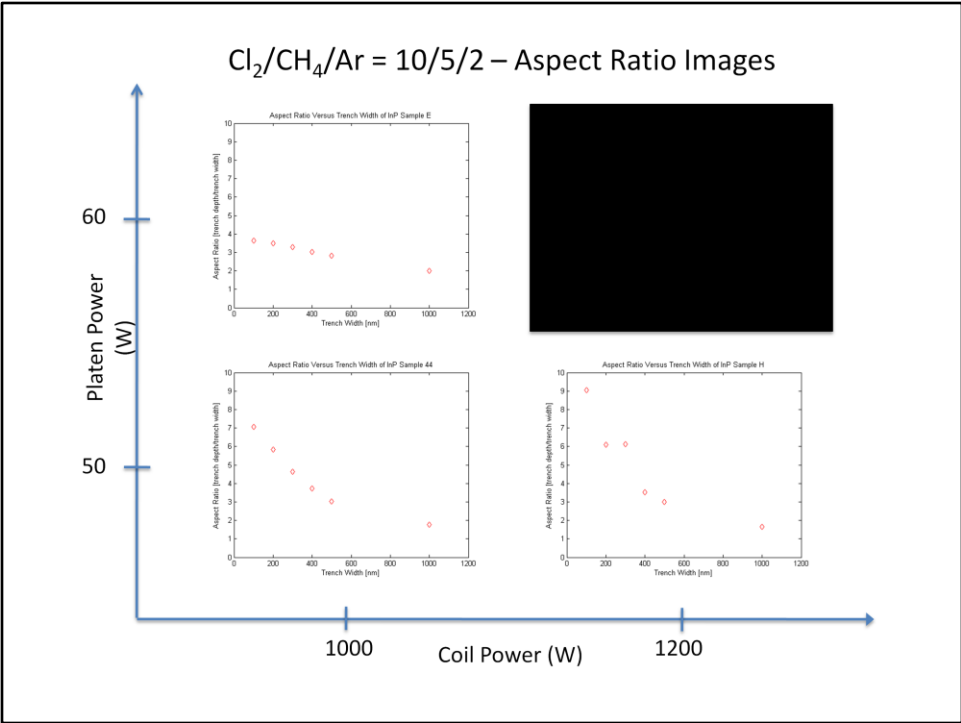
Larger lag ratios are expected for processes consisting of higher platen power (more ionic-based etches), as theoretically they attain a higher degree of anisotropy.
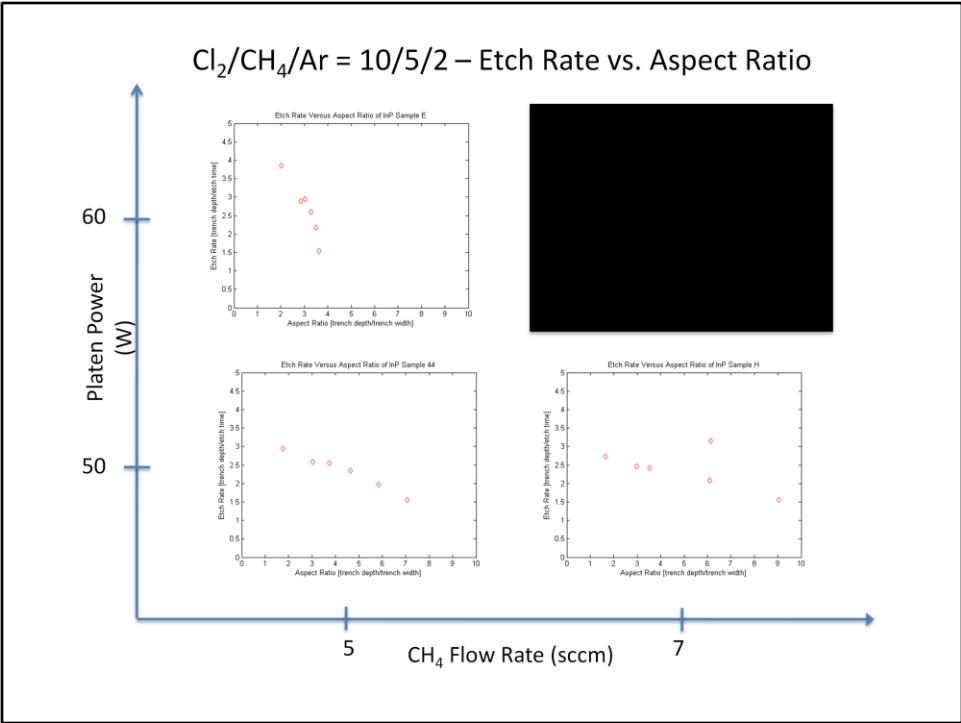
Larger lag ratios are expected for processes consisting of higher platen power (more ionic-based etches), as theoretically they attain a higher degree of anisotropy.

$Cl_2/CH_4/Ar = 10/5/2$ – Etch Data

Platen Power (W)

60

50

- Ridge angle = 85°
- Smooth sidewalls?
- 100 nm selectivity = 2.8
- 100 nm aspect ratio = 3.6
- Ridge selectivity = 7.76
- Mask erosion effects

- Ridge angle = 88°
- Smooth sidewalls?
- 100 nm selectivity = 2.93
- 100 nm aspect ratio = 9.4
- Ridge selectivity = 6.9
- Unusual ridge profile
- Microtrenching features

- Ridge angle = 88°
- Smooth sidewalls?
- 100 nm selectivity =3.56
- 100 nm aspect ratio = 9.0
- Ridge selectivity = 4.8
- Extreme surface roughness

1000   **Coil Power (W)**   **1200**

InP Sample K Etch Experiment

- Repeat Sample H Experiment
  - Unexpected extreme surface roughness
  - Verification required

- CP = 1200 W, PP = 50 W, $Cl_2/CH_4/Ar$ = 10/5/2
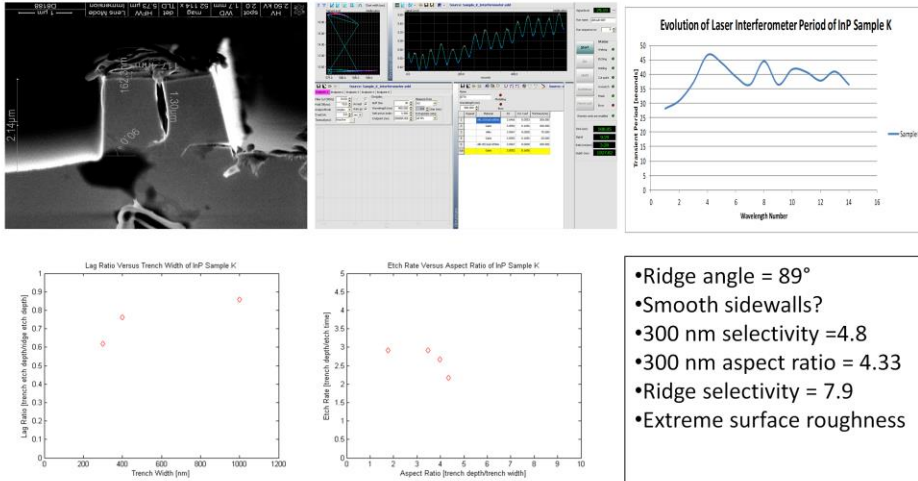
Sample K - Reduced surface roughness relative to InP sample H. Much more desirable etch profile and much more consistent period evolution profile. Experimental repeatability and consistency is therefore questionable.

Conclusions – Further Testing

1. InP sample D – Superior etch result
   - CP = 1000 W, PP = 50 W, Cl_2/CH4/Ar = 10/7/2
   - Increased passivation = better trench anisotropy
     - Superior ionic/chemical etch ratio

2. High initial etch rate
   - Sapphire passivation/redeposition?

3. Platen power > 50 W – Mask erosion

Note: Sapphire passivation does occur, as evidenced by presence of polymeric material following the precondition stage.

KY: Adjusted CP to 1000W

Recommendations – Further Testing

1. Perform nonthermalized ICP RIE process
   - Nonthermalized/thermalized comparison

2. Additional ICP processes
   a. Repeat InP sample D experiment
      - Process time = 15 min.
   b. CP = 400 W, PP = 50 W, $Cl_2/CH_4/Ar$ = 10/5/2
   c. CP = 600W, PP = 50 W, $HBr/CH_4/Ar$ = 10/5/2

Repeat InP sample D as it is the best etch result obtained this far.
Perform additional process with CP of 400 W, as ideally the InP etch would be ion-based in order to attain a reduced lag effect. As can be seen from previous experimental results (samples 5, 32, 29, 44), as the coil power decreases, the etch becomes increasingly ionic.
Perform etch experiment substituting HBr for Cl, as HBr has a lower vapour pressure and is thus much more volatile than Cl.

Recommendations – Further Testing

4. Reduce ICP pressure to 0.1 mT
   - Assistance from Jonas

5. Reorganize slide data for pattern recognition

6. Sample 16 H_2O treatment

7. Sidewall roughness evaluation (SEM Zeiss)

Repeat InP sample D as it is the best etch result obtained this far.
Perform additional process with CP of 400 W, as ideally the InP etch would be ion-based in order to attain a reduced lag effect.
Perform etch experiment substituting HBr for Cl, as HBr has a lower vapour pressure and is thus much more volatile than Cl.

Non-Thermalized Experiment

- InP sample G

- CP = 600W, PP = 50 W, $Cl_2/CH_4/Ar$ = 10/5/2

- Non-thermalized
  - Absence of crystalbond 590
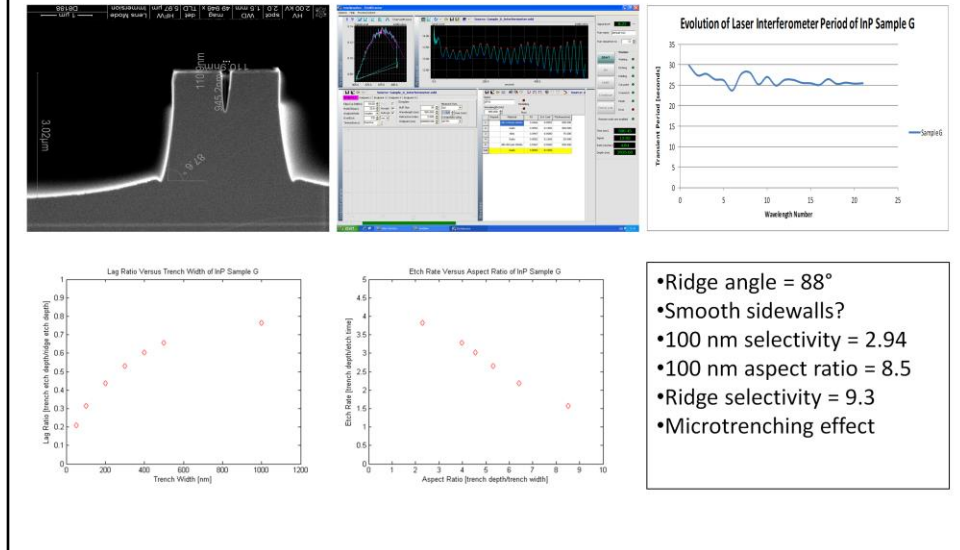
Sample G - Very similar to thermalized experiment. The etch rate during this experiment was higher than that of InP sample 32, likely due to significant sample heating. However, the etch rate was expected to increase during this process as the sample temperature increased; upon analysis of the period evolution of the laser interferometer signal, it can be concluded that this phenomenon did not occur. This observation suggests that significant sample heating did not occur during this etch process.

Thermalized Experiment

- InP sample 32

- CP = 600 W, PP = 50 W, $Cl_2/CH_4/Ar$ = 10/5/2

- Thermalized
  - Application of crystalbond 590

Thermalized Experiment
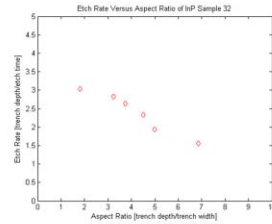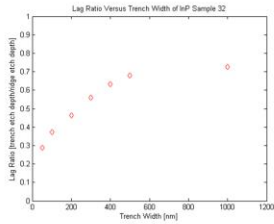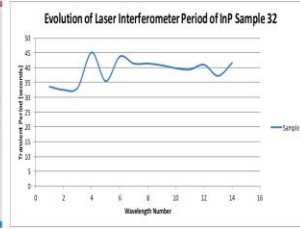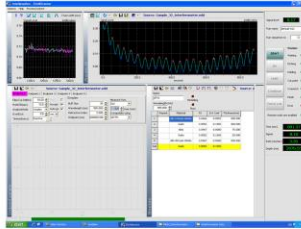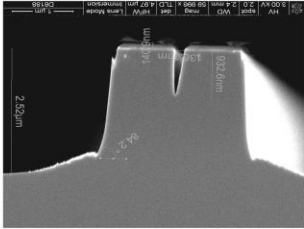
- Ridge angle = 84°
- Smooth sidewalls?
- 100 nm selectivity = 3.23
- 100 nm aspect ratio = 9.3
- Ridge selectivity = 8.42
- Unusual ridge profile
- Microtrenching features
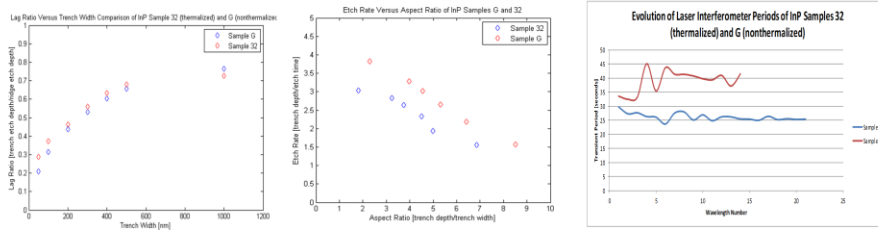
Analysis of the lag ratios of InP samples G and 32 reveals minimal difference. This suggests that sample heating does not significantly alter the lag ratio of the InP nanostructures.

Analysis of the aspect ratios of InP samples G and 32 reveals a significant difference. This suggests that a particular trench of a non-thermalized will subjected to a greater etch depth than that of a thermalized sample, as expected.

Analysis of the period evolutions of InP samples G and 32 reveals a significant difference. This suggests that the etch rate of a non-thermlized sample is greater than that of a thermalized sample, as expected due to sample heating.

Additional ICP Processes - A

- Repeat InP sample D experiment
  - Process time = 15 min.

- CP = 1000 W, PP = 50 W, $Cl_2/CH_4/Ar$ = 10/7/2

- Purpose – Most-optimized Cl_2-based etch

Additional ICP Processes - B

- InP sample I

- PP = 50 W, CP = 400 W, $Cl_2/CH_4/Ar$ = 10/5/2

- Purpose – Ionic-dominant etch desired
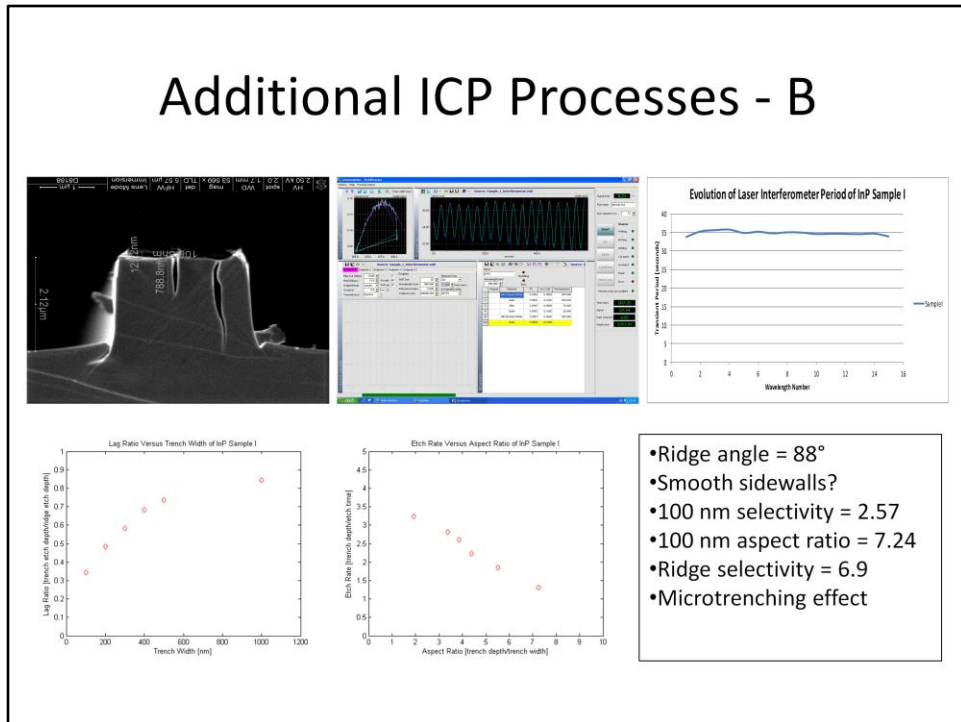
Sample I – Very anisotropic profile (although significant cracking occurred within this particular trench; this phenomenon was not observed in other trenches, such as 200 nm). Microtrenching effects occurred, likely due to the reduced coil power, resulting in a ion-dominated etch. Additionally, analysis of the period evolution data pertaining to the laser interferometer indicates the sample heating did not occur; this again may be attributable to a reduced coil power

Additional ICP Processes - C

- InP sample J

- PP = 50 W, CP = 600 W, HBr/CH$_4$/Ar = 10/5/2

- Purpose – HBr volatility >> Cl$_2$ volatility
  - Smoother InP sidewalls

Note: The above ICP parameters were selected for this experiment as they have yielded decent etch results utilizing Cl$_2$-based chemistry.
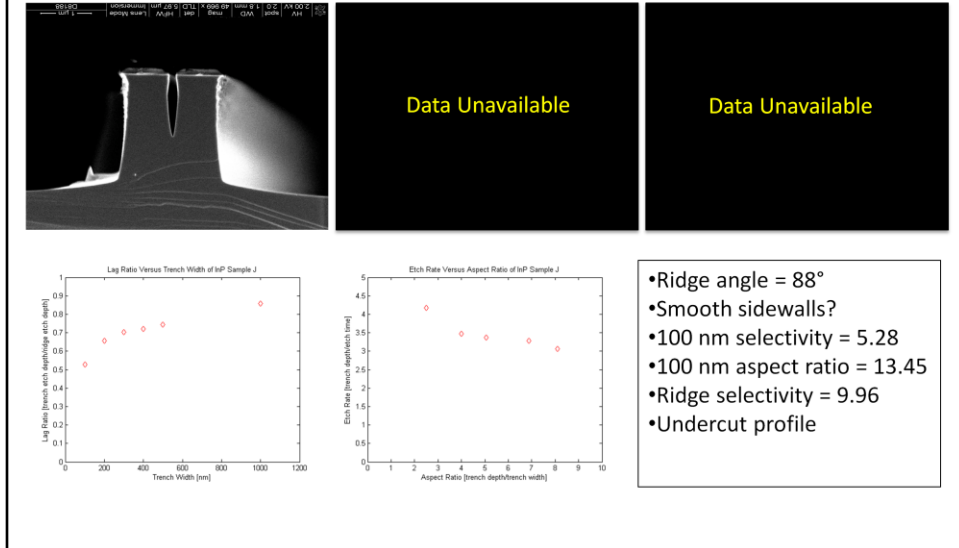
Sample J – HBr/CH4/Ar-based ICP reactive ion etch has yielded very promising results with regards to anisotropy, selectivity, aspect ratio, and lag ratio, and a smooth etch profile. However, a significant and undesirable undercut profile is observed on the exterior and interior of the trench. In order to reduce this effect, the methane flow rate could be increased (resulting in superior surface and sidewall passivation) or the coil power could be reduced (resulting and a more ion-dominant etch and thus reducing the isotropic etch component).

Conclusions

1. Nonthermalized etch rate > thermalized
   - Cause: Sample heating

2. Lowering coil power reduces chemical etch component

3. Promising etch results: HBr/CH4/Ar ICP RIE

Recommendations

1. HBr/CH_4/Ar ICP RIE process
   – CP = 600 W, PP = 50 W, HBr/CH_4/Ar = 10/7/2
   – Increased passivation = reduced etch undercut

2. HBr/CH_4/Ar ICP RIE process
   – CP = 200 W, PP = 50 W, HBr/CH_4/Ar = 10/7/2
   – Reduced CP = ion/anisotropic-dominated etch

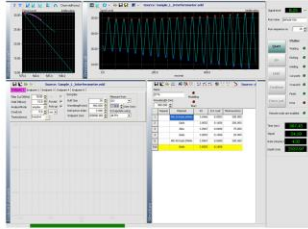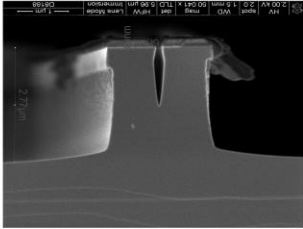3. Evaluate lag & aspect ratios vs. coil power
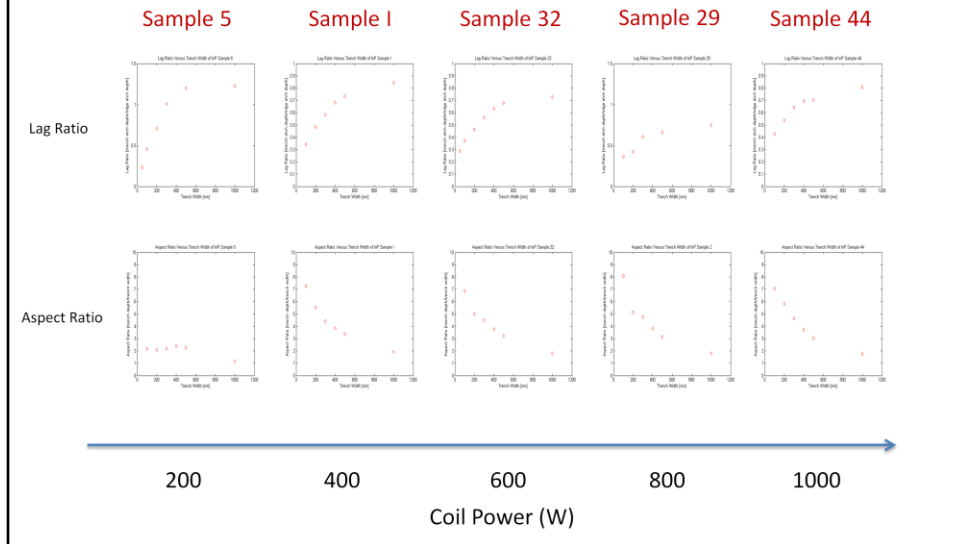
It appears that no discernable relationships exist between aspect and lag ratios as functions of coil power (with Cl2/CH4/Ar = 10/5/2, platen power = 50 W).

InP Sample N

- PP = 50 W, CP = 600 W, HBr/CH$_4$/Ar = 10/7/2

- Purpose – Increased passivation = reduced etch undercut
  - Smoother InP sidewalls

InP Sample N
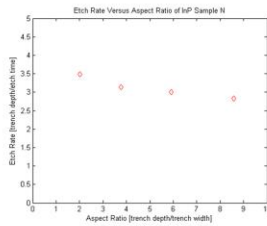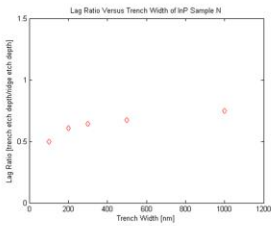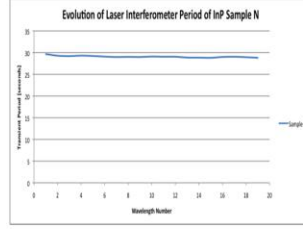
- Ridge angle = NA
- Rough sidewalls
- 100 nm selectivity = 6.48
- 100 nm aspect ratio = 11.96
- Ridge selectivity = 9.96
- Undercut profile