Deep Reactive Ion Etch Process Development

for MEMS Rotary Engine Power System

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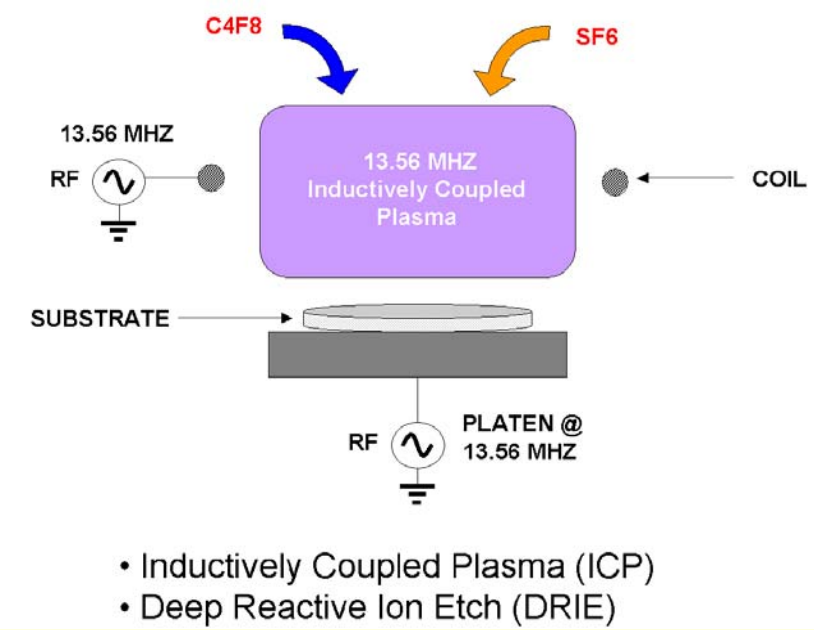
Outline of the presentation

- **Background Information**
  - DRIE process
  - MEMS Rotary Engine Power System (REPS)
    - Purpose of the Project
    - Problems encountered
    - Possible Causes
  - Strategy to approach the challenges
- **Taguchi Design of Experiment**
  - Parameters of Interest
  - Data
- **Results**
- **Future Works**

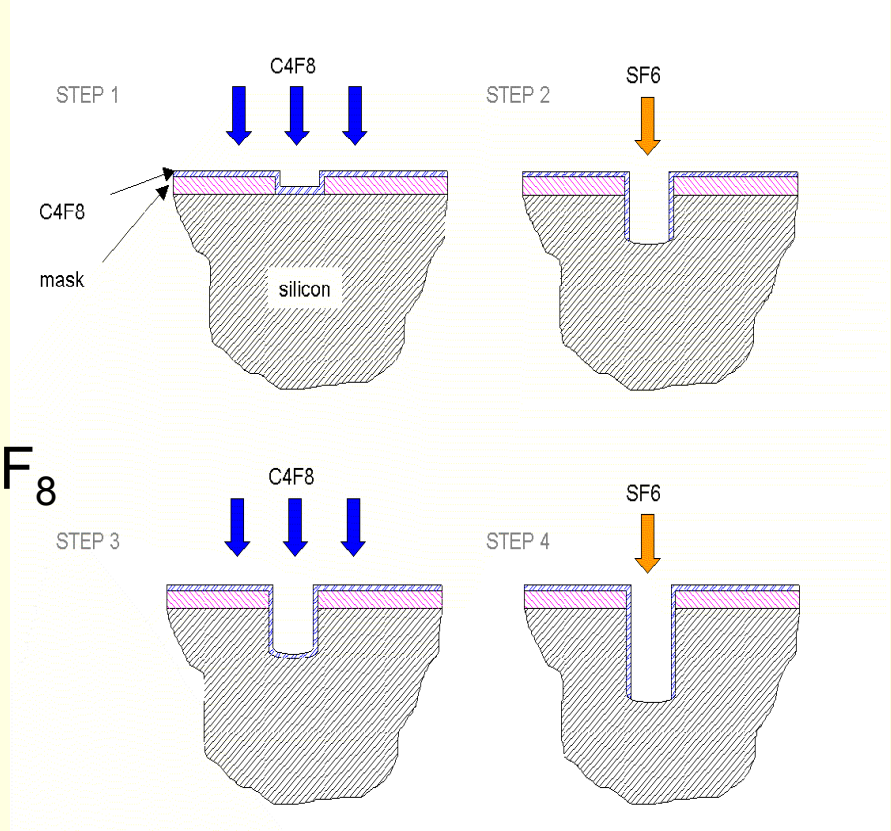
DRIE Equipment Used



- Surface Technology Systems multiplex ICP
- 2 RF power generators
- Electrostatic wafer clamping

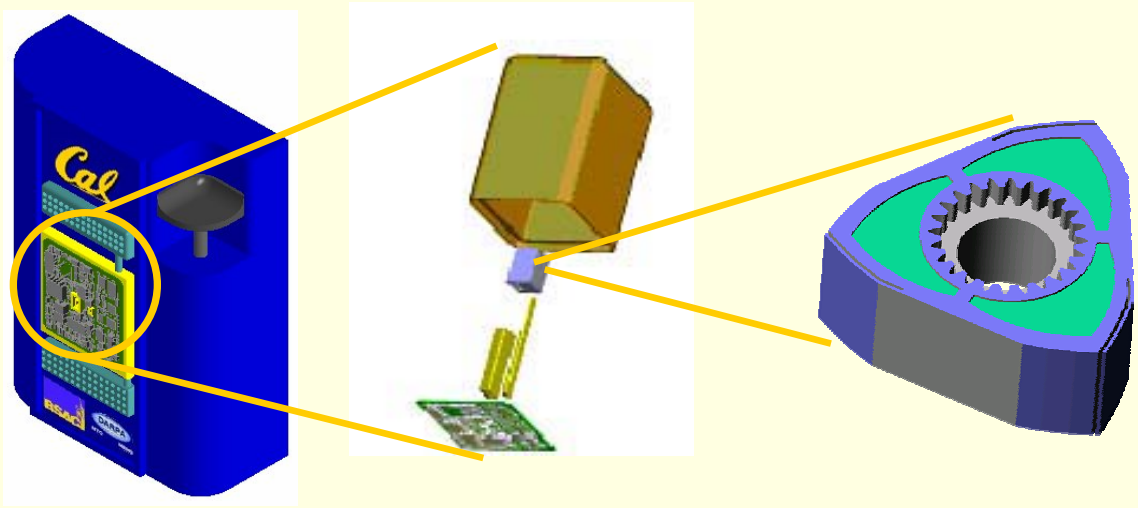
DRIE Process

- **Switched gas process (aka "Bosch" Process)**
  - Switching between etching and passivation cycle
- **Passivation mechanism**:
  - Conformal deposition of C_4F_8
- **Etching Mechanism**:
  - Disassociation
  - Bombardment
  - Reaction



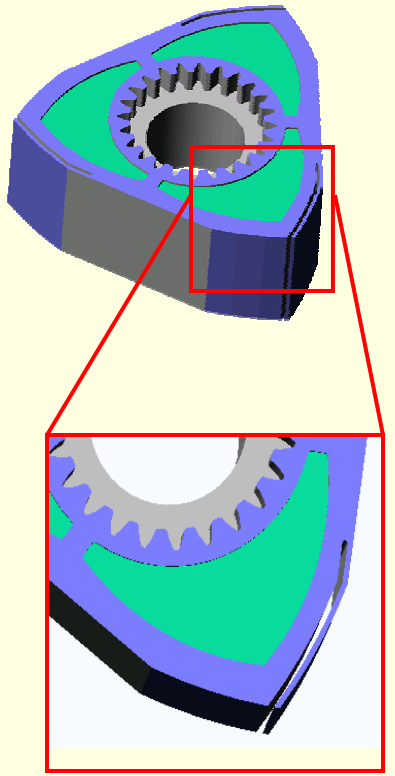
MEMS REPS

- **Rotary engine power system using MEMS technology**
  - Micro scale high compression ratio internal combustion engine to power electronic devices
  - Mechanical parts are fabricated using DRIE process.



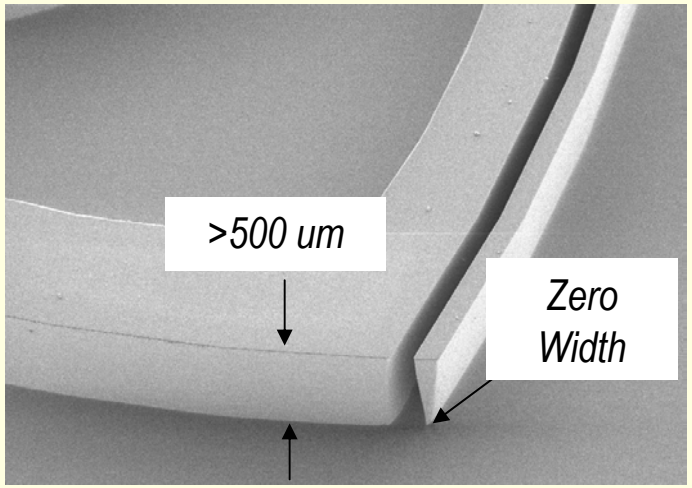
Motivation

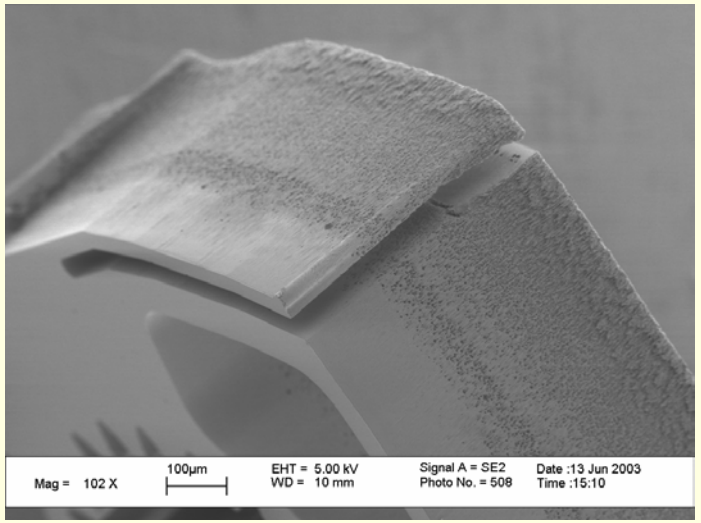
- **Develop smooth sidewall DRIE processes**
  - Through wafer etching
  - 90 degree sidewall profile
  - Maintaining good etch rate, selectivity, and uniformity
- **Optimizing mask design**
  - Sharp angle gears
  - Apex seal tip preservation for through wafer etch



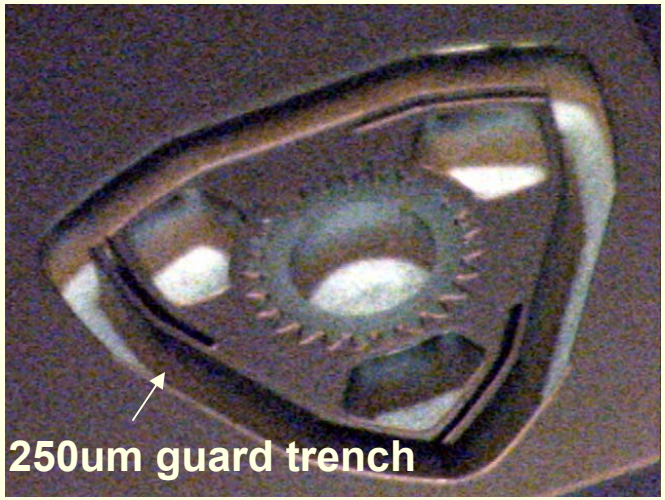
Problems and Challenges

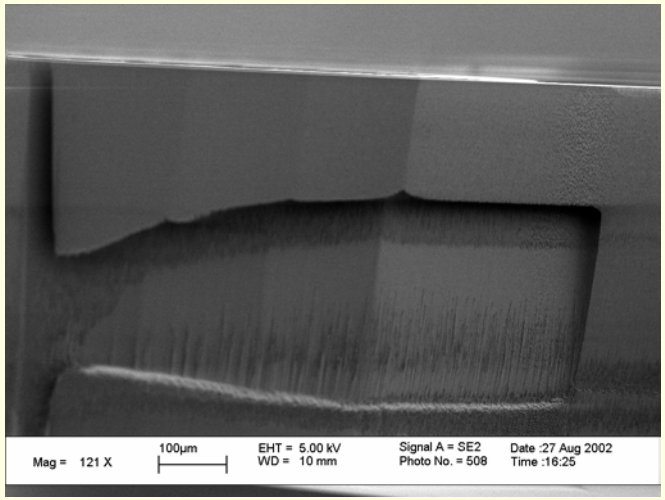
- **Apex seal tip integrity preservation**
- **Sidewall roughness**
  - Lower region has increasing striation patterns on the sidewall
- **Sidewall profile**
  - Current process has excessive negative sidewall profile





Possible Causes – Layout

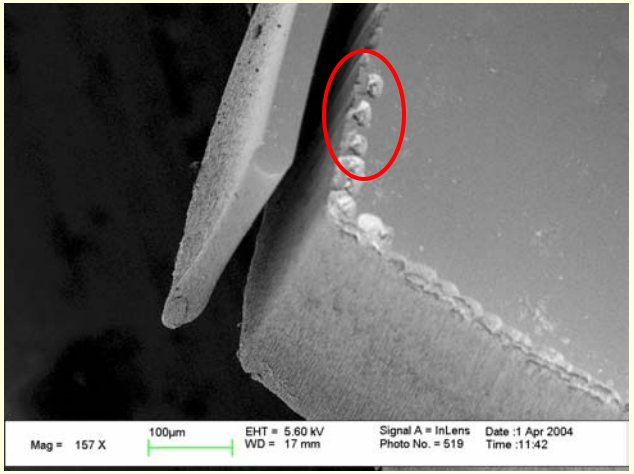




- **ARDE**
  - Large feature size variations effects the aspect ratio dependent etch rate uniformity
- **Apex Seal**
  - Large exposed area on one side of the apex seal cause asymmetrical etching
  - Apex seal blade can not be preserved

Possible Cause - Processing

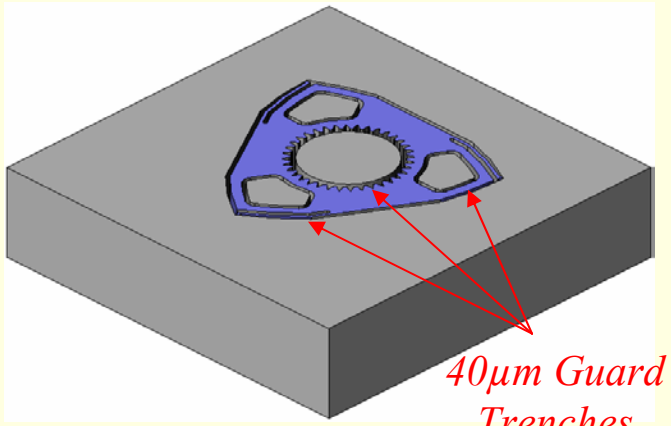
- **Micromasking**
  - Deposition of particles
    - Sputtered masking materials
    - Byproduct redeposition
- **Mask erosion**
  - Photoresist



- **DRIE processing condition is dynamic**
  - Late onset of striation pattern
  - Roughness is progressively worsen in deeper region
  - Etch rate decreases with respect to etched depth

Attack Strategies

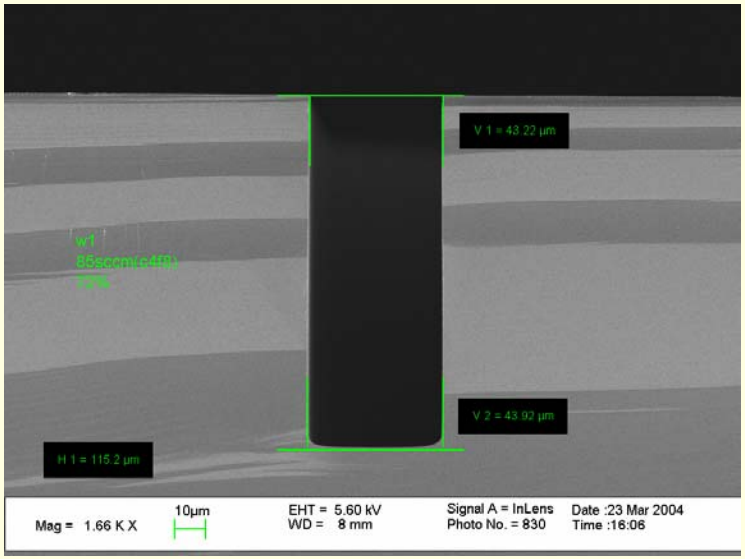
- **Better mask design**
  - Maintain a constant trench width
    - Better ARDE uniformity
    - Preservation of the apex seal
- **Process optimization**
  - Masking material
    - SiO_2 and/or SPR220 thick resist
  - Varying process parameters
    - Step wise etch (**3 recipes**) for through wafer etching
    - Optimization of each step

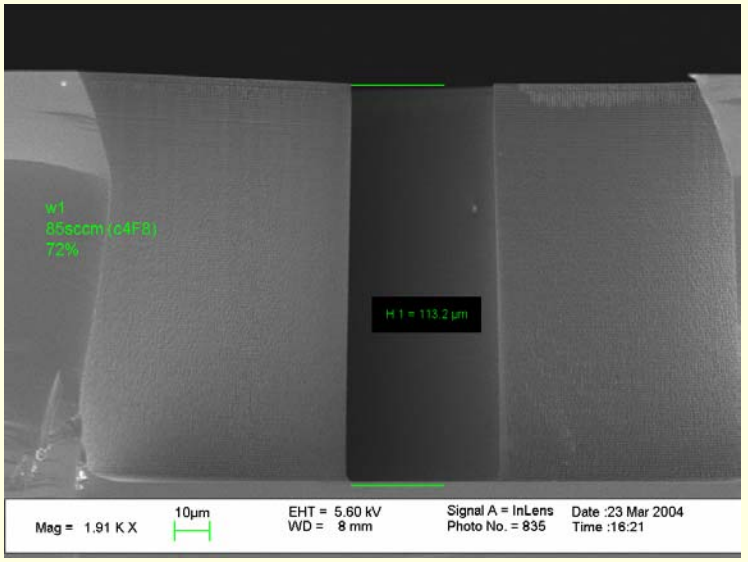


Starting Point

- **New guard trench mask design**
  - All features have 40 μm feature size
  - Attempt to eliminate ARDE non-uniformity
  - Better protection of apex seal
- **Hard mask vs. soft mask**
  - Hard mask (SiO_2) has less erosion
  - Virtually no difference with respect to sidewall roughness
  - Combination of both soft and hard mask would increase the tolerance on selectivity while minimizing mask erosion

Starting Point





1st 100 µm Process

	Time	Gas	Flow	Coil	Bias	Avg P	APC
ETCH	12	SF6	90	600	10	32	~72
PASS	7.2	C4F8	85	600	5	26	~72

Taguchi Design of Experiment

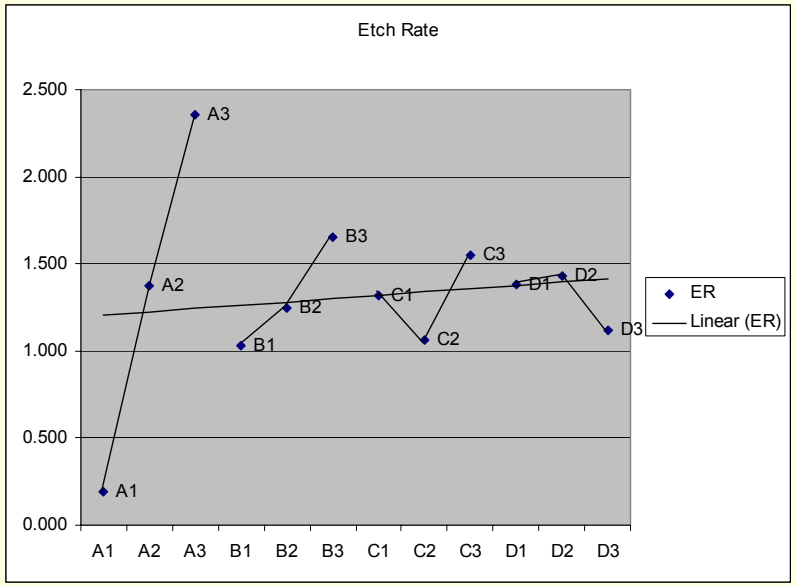
- **Goal**
  - Process optimization for 2nd recipe step
  - Gain insight on general trends of processing parameters for subsequent recipe step.
- **Variables to consider:**
  - Etching cycle time and Cycle time ratio
  - Process pressure
  - Bias power during etching cycle
  - Coil power
- **4 Factors/3 Level L9 DOE.**
  - 9 runs total.

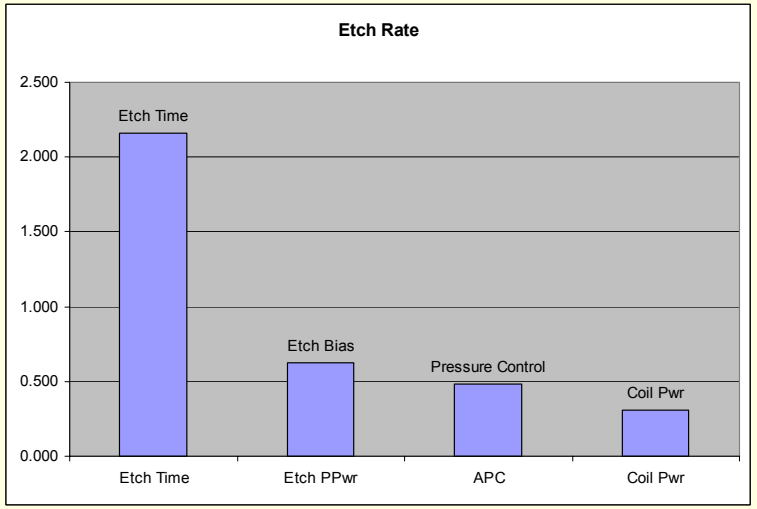
Orthogonal Design

	Etch Time	Etch PPwr	APC	Coil Pwr
1	6	8	68	600
2	6	10	70	650
3	6	12	72	700
4	8	8	70	700
5	8	10	72	600
6	8	12	68	650
7	10	8	72	650
8	10	10	68	700
9	10	12	70	600

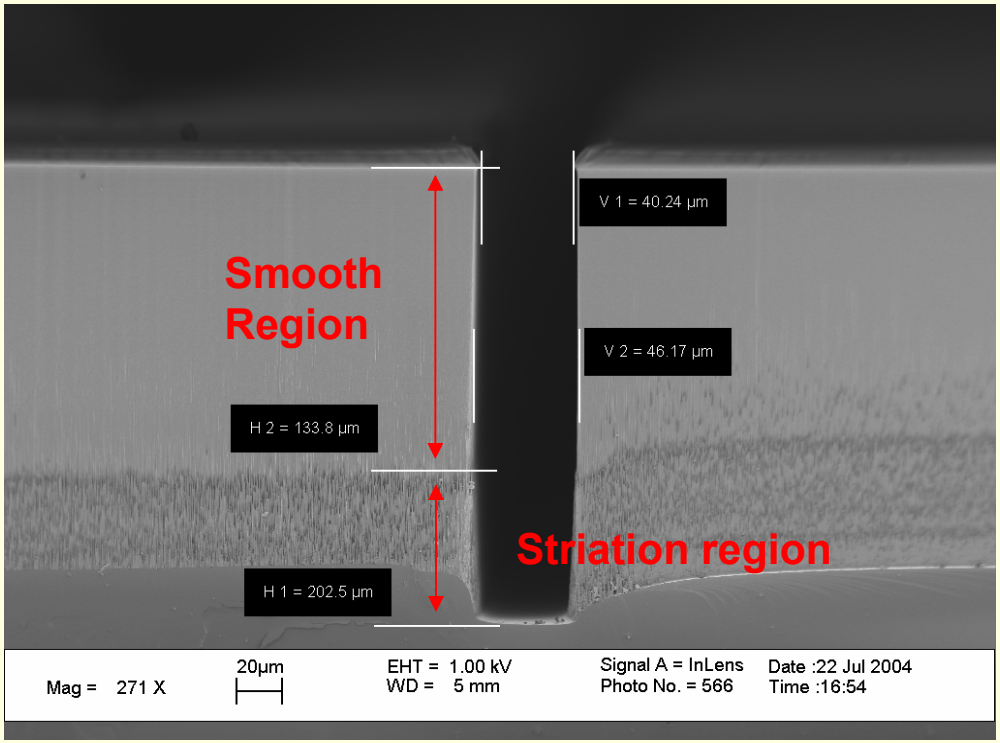
	Variable	Low	Mid	High
A	Etch Time	6	8	10
B	Etch Bias	8	10	12
C	APC Angle	68	70	72
D	Coil Power	600	650	700

Results – Etch Rate



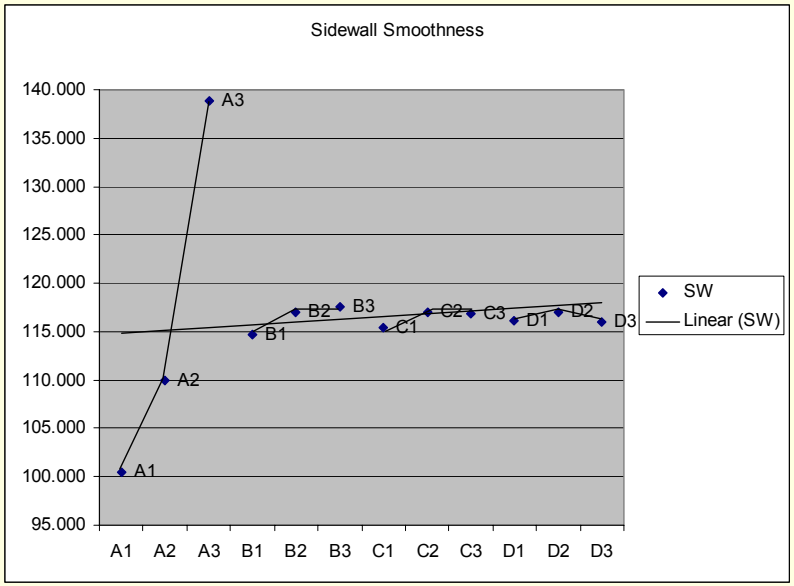


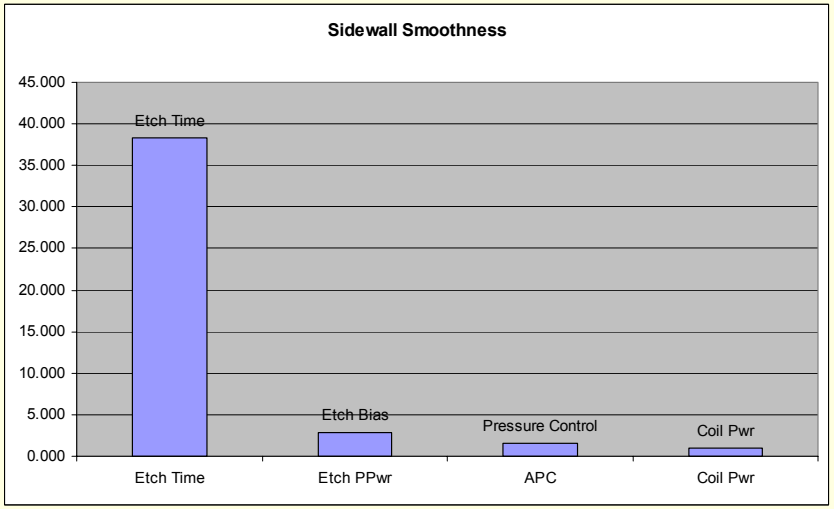
Sidewall Smoothness



Sidewall smoothness is defined as the onset of striation.

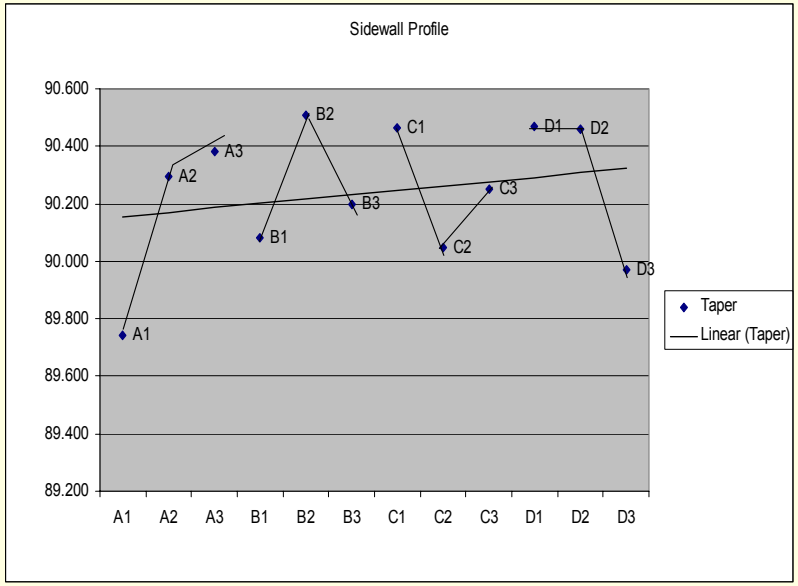
Sidewall Smoothness

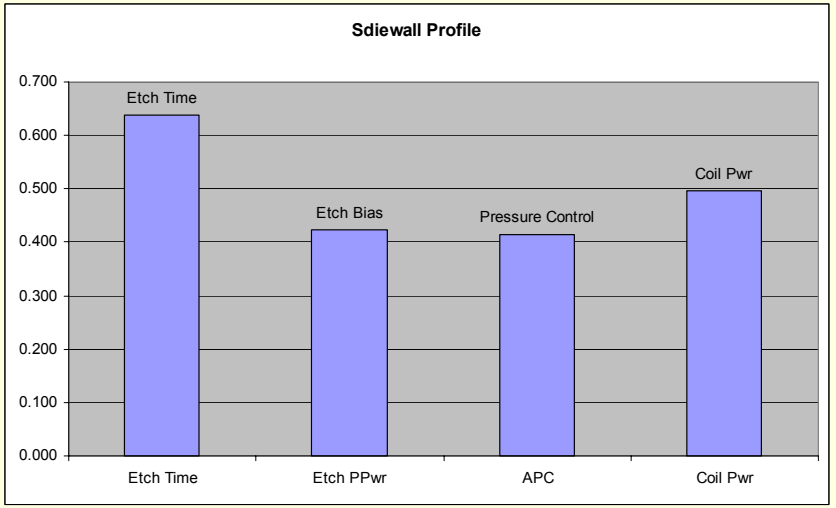




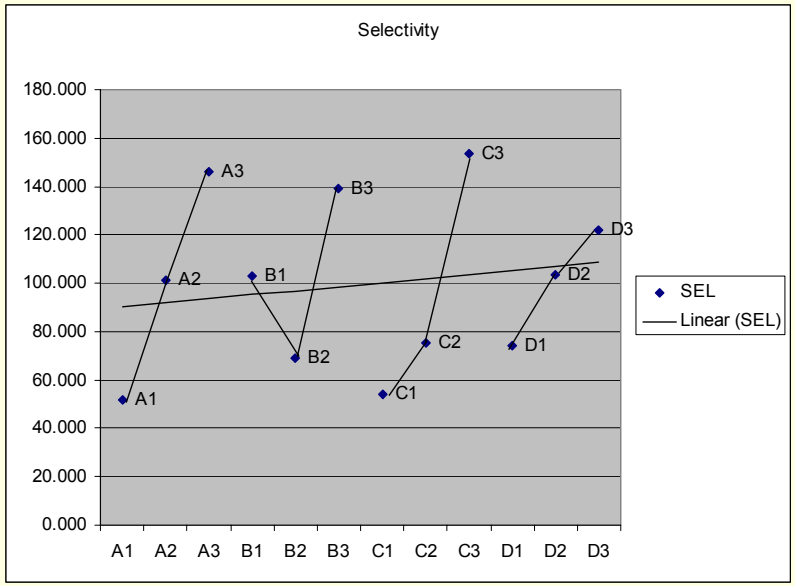
*** Pressure actually plays a more prominent role in this response than the result indicates.**

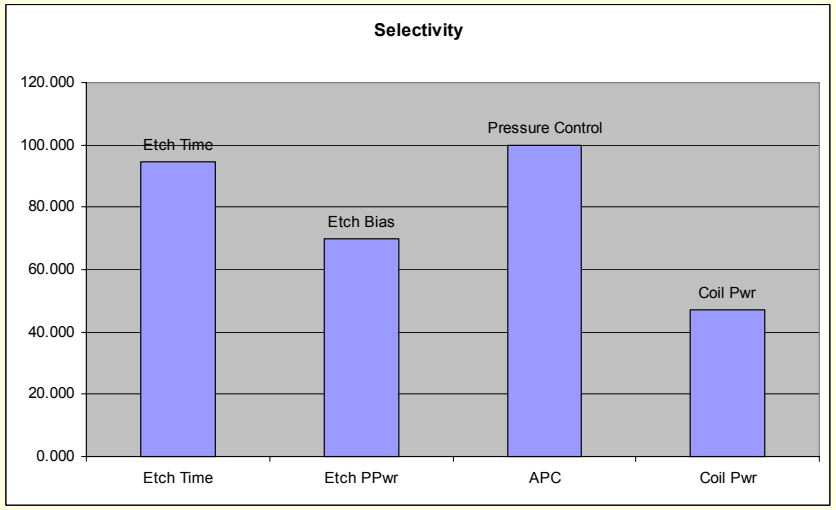
Sidewall Profile





Selectivity

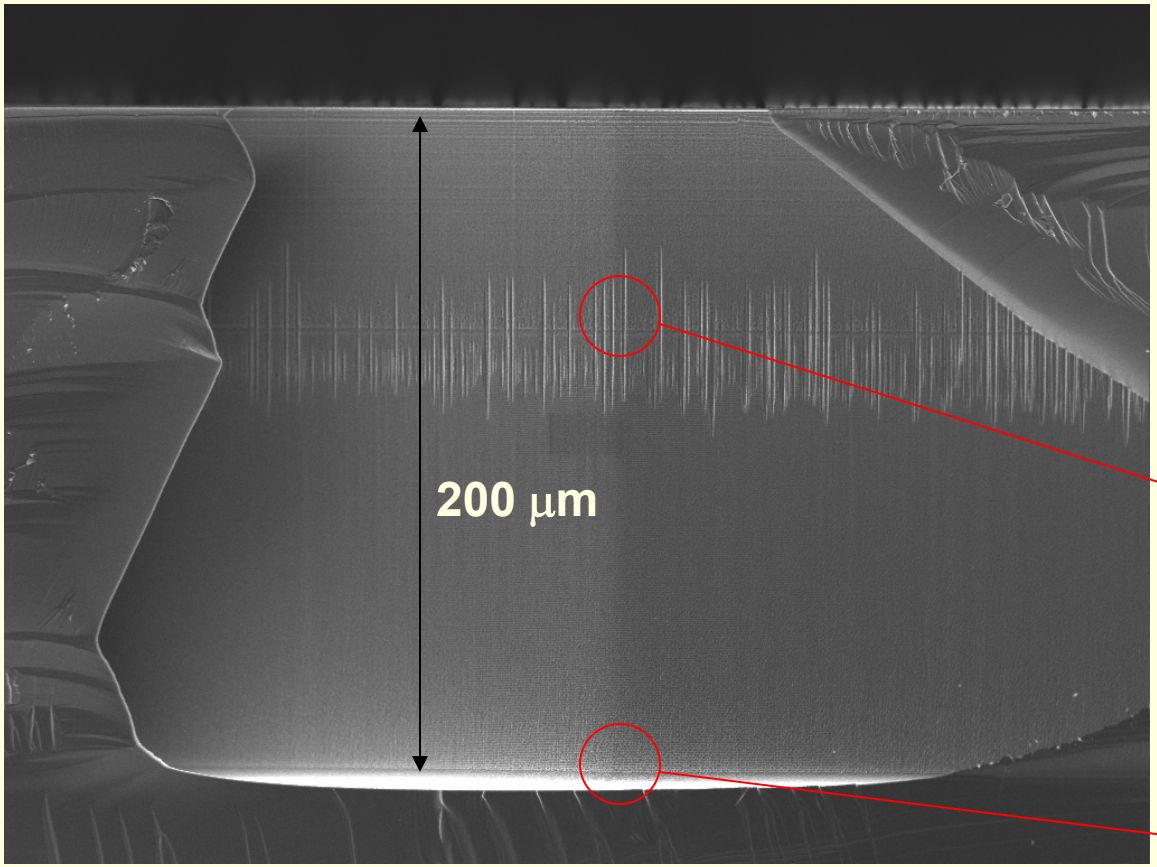


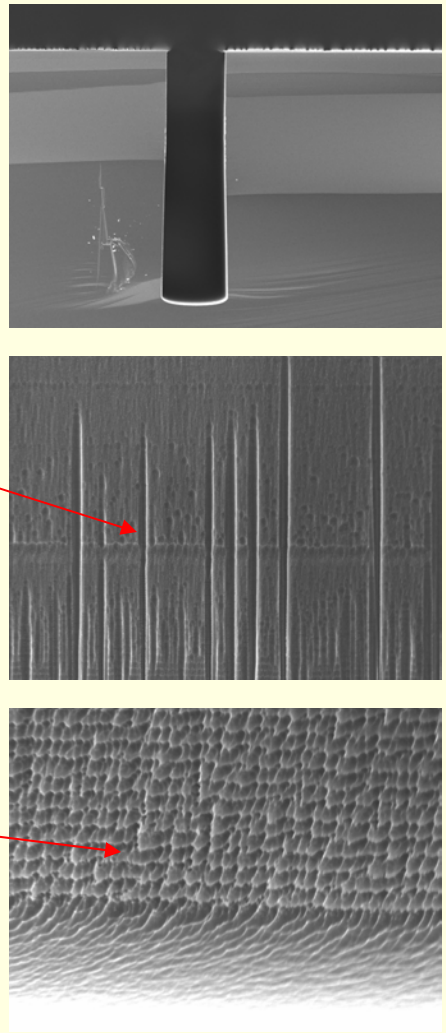


Fine Tuning of 2nd Recipe

- **Etch time:** Increase
  - Increase the etch rate, smoothness, and have a more negative profile than the DOE runs
- **Platen Power:** Increase
  - Increase directionality, and etch rate
- **Pressure:** Decrease
  - Increase mean free path, directionality
  - Decrease sidewall bombardment
  - Decrease the selectivity
- **Coil:** 600W
  - Standard coil power

2nd Recipe Results



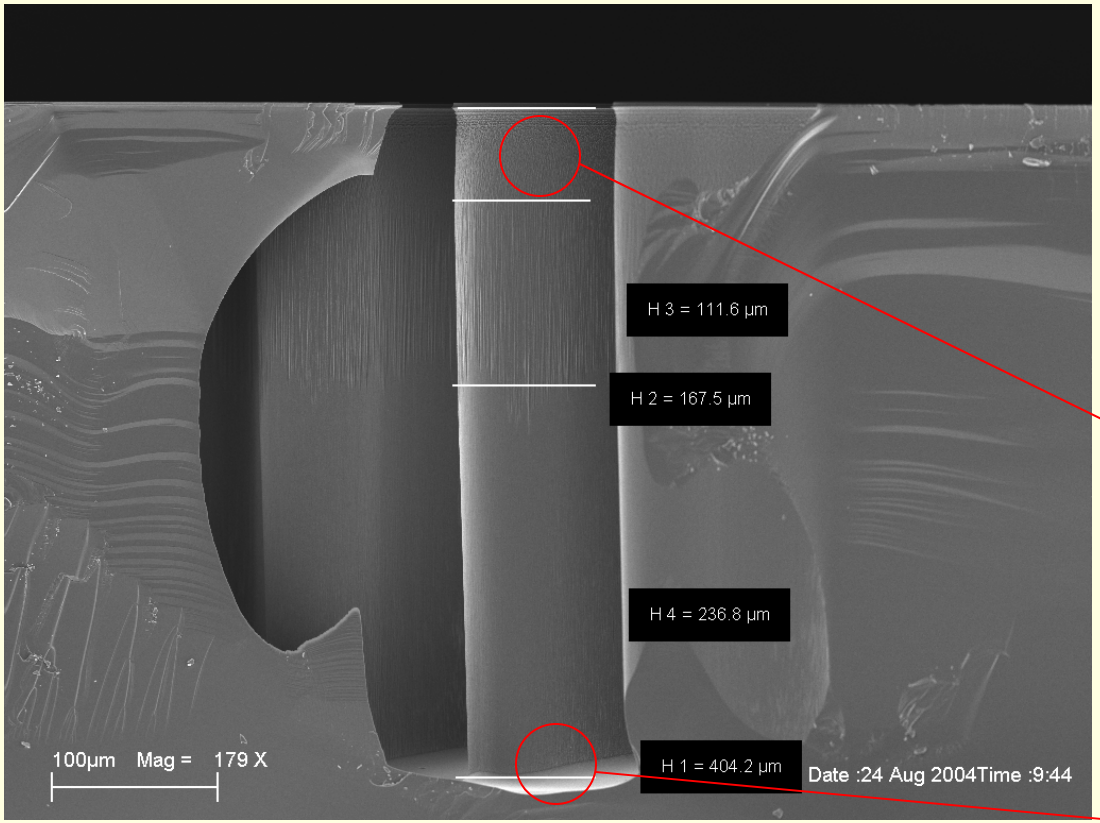


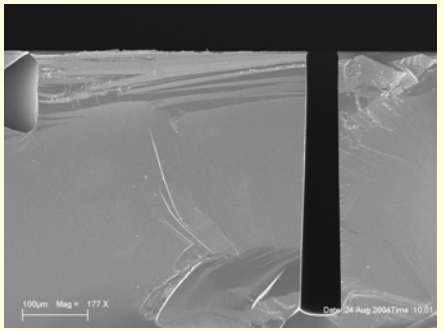
9.5/25mT/90sccm/600W/14W bias
6.0/18mT/85sccm/600W/5W bias

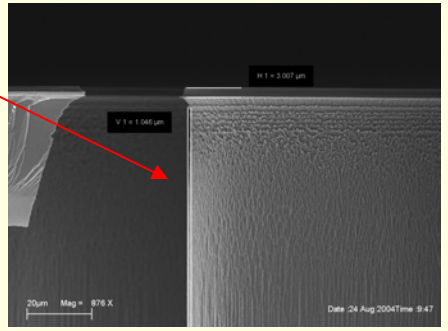
Development of 3rd Recipe

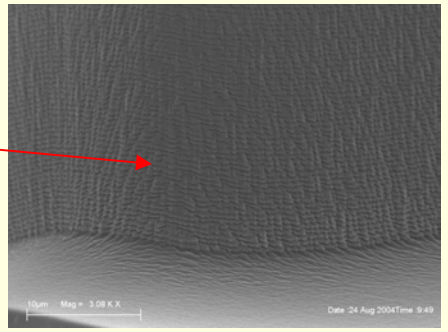
- **Pressure:** decrease
  - Maintain the striation free sidewall wall surface via increase the MFP.
- **Cycle time ratio:** decrease
  - correct the sidewall profile
- **Total cycle time:** Increase
  - to maintain a good etch rate
- **Platen power:** decrease
  - to correct the sidewall profile.

3rd Recipe Results







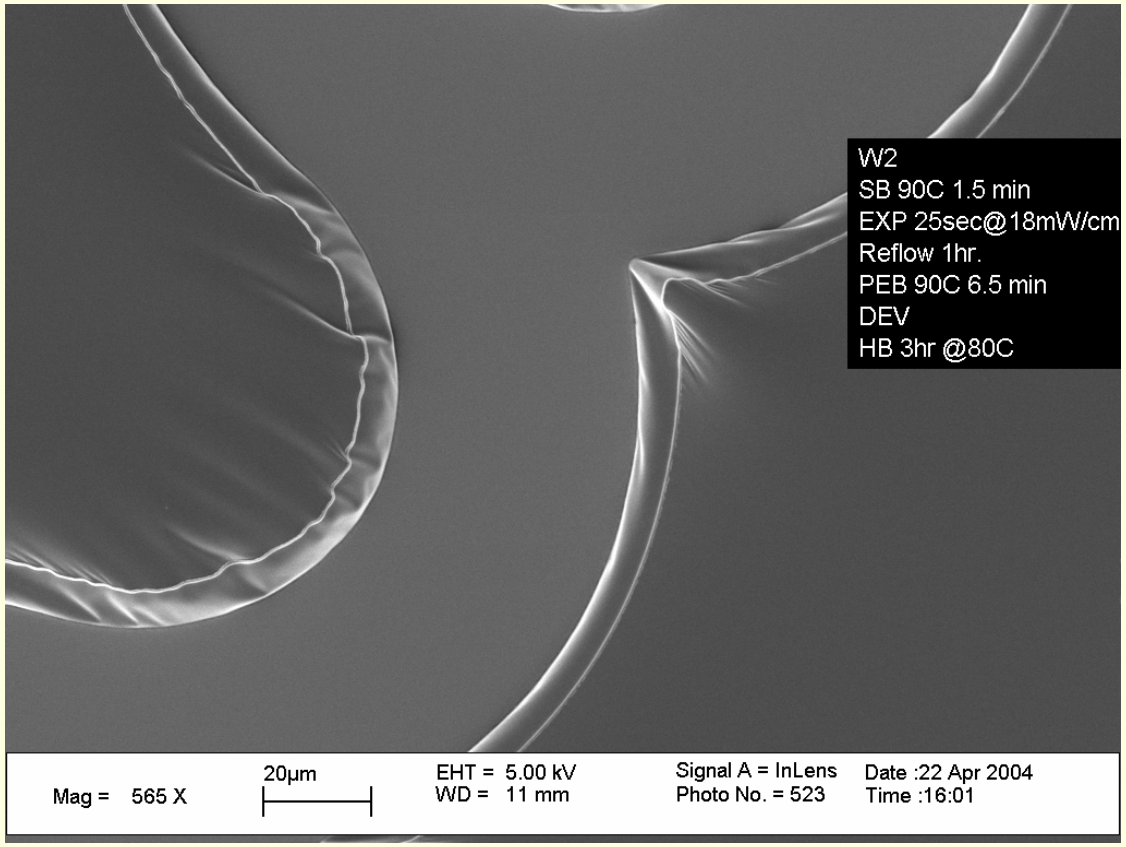


Total depth: 400um

Conclusion

- **Proposed cause of striation pattern**
  - High pressure
    - Decrease mean free path
    - Increase the ion bombardment to the sidewall
    - Increase difficulties in byproduct removal
  - Micro masking
    - Possibly induced by high pressure
- **Maintaining profile, etch rate.**
  - Cycle time ratio, total cycle time, and platen power.
- **Future works**
  - Continue to increase striation free etch depth.
  - Fine tune the sidewall profile
  - Develop a complete etch through process

SPR220


W2
SB 90C 1.5 min
EXP 25sec@18mW/cm
Reflow 1hr.
PEB 90C 6.5 min
DEV
HB 3hr @80C
Mag = 565 X
20µm
EHT = 5.00 kV
WD = 11 mm
Signal A = InLens
Photo No. = 523
Date :22 Apr 2004
Time :16:01