SUSTAINING ANOTHER DECADE OF INNOVATION IN EQUIPMENT AND PROCESS DESIGN: NEEDS AND CHALLENGES*

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http://uigelz.ece.uiuc.edu $\rightarrow$ "Presentations" link

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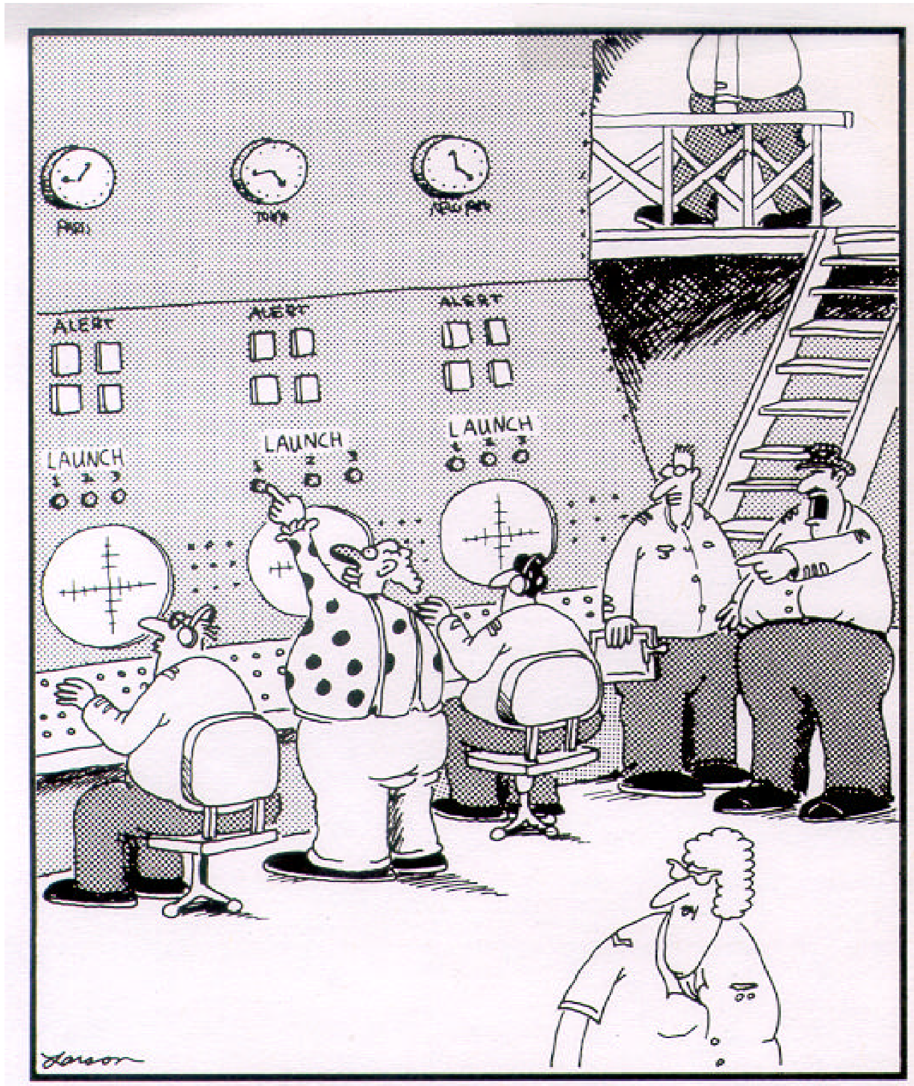
AGENDA

- Reflection on 10 years past...
- ITRS Requirements
- Knowlegebase Generation
- The "challenge": Smart, Aware and Proactive Tools
- Examples of SAP Tools
- New systems and materials
- Concluding Remarks

QUALIFICATIONS TO GIVE THIS TALK....



"Hey! What's that clown think he's doing?"

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37th AVS INTERNATIONAL SYMPOSIUM
October 1990, Toronto, Canada

Topics from papers appearing in Proceedings of 37th AVS International Symposium

Plasma Sources:

Helicon	**1**	**ECR**	**10**
RIE	**8**	**Magnetron**	**1**
ICP	**0**	**Ion Beam**	**1**

Materials:

Polymer	**2**	**SiGe**	**1**
Si_3N_4	**1**	**p-Si/c-Si**	**3**
SiO_2	**2**	**GaAs**	**1**

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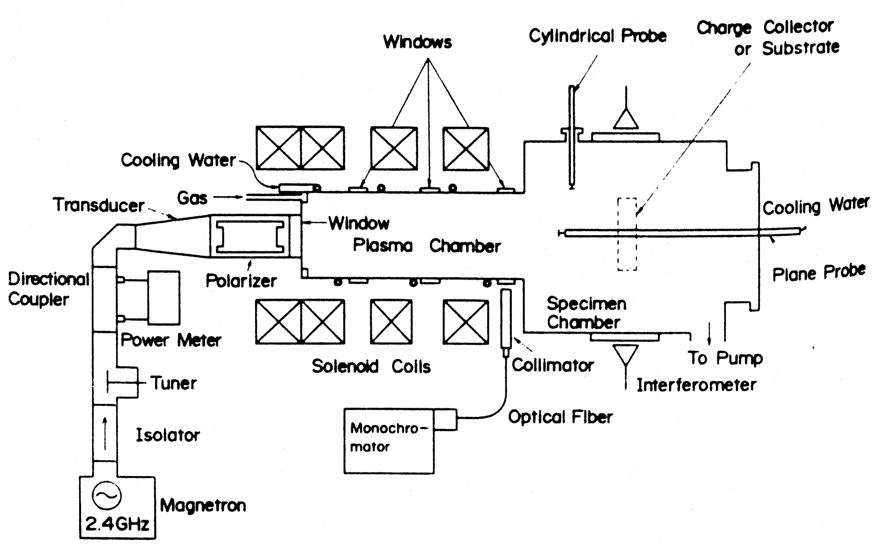
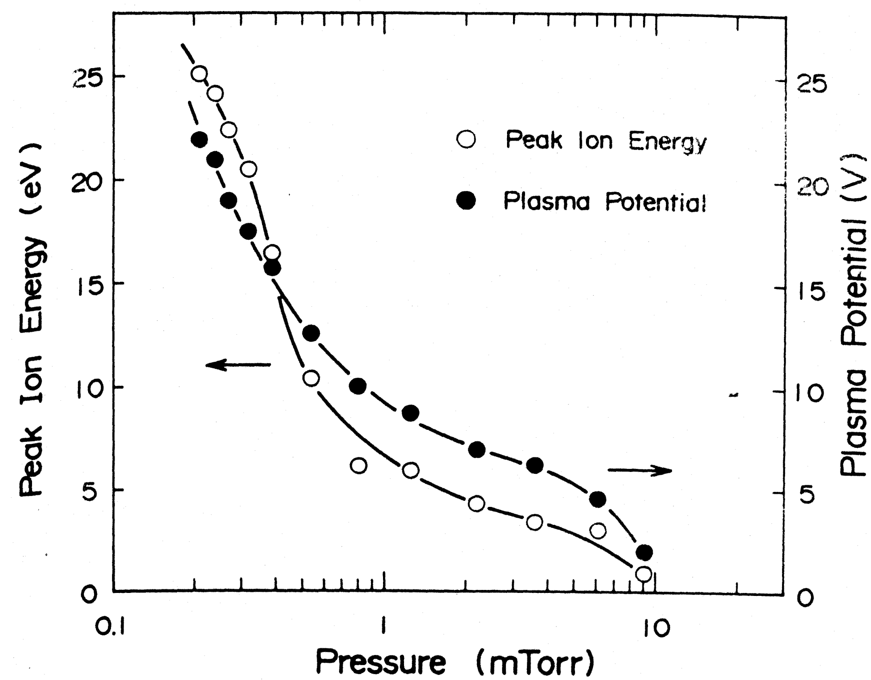
Electrical and optical measurements of electron cyclotron resonance discharges in Cl_2 and Ar

Tatsuo Oomori, Mutumi Tuda, Hiroki Ootera, and Kouichi Ono
Central Research Laboratory, Mitsubishi Electric Corporation, Tsukaguchi-Honmachi, Amagasaki, Hyogo 661, Japan

JVST A 9, 722 (1991)



- **Cl_2 plasma**

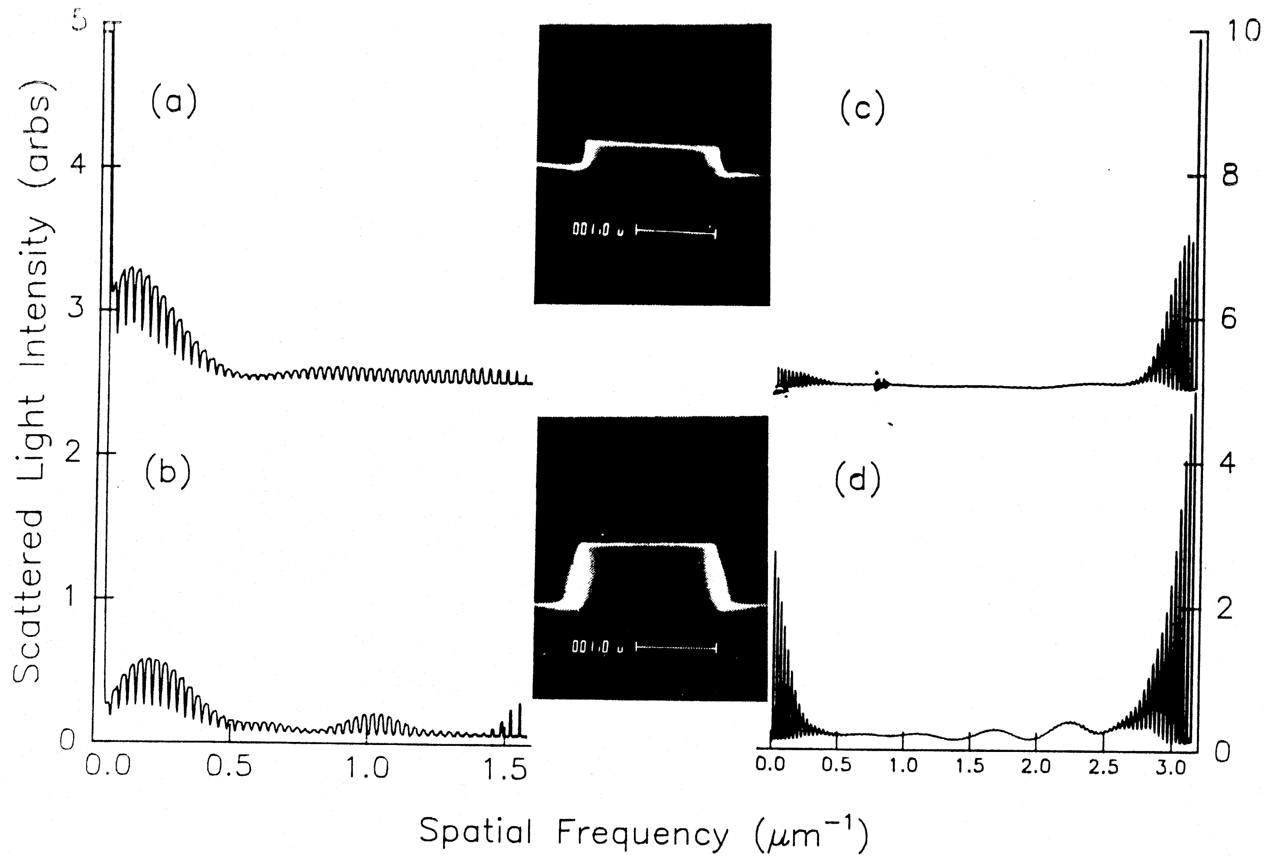


- **Measurements of ion energies arriving at the substrate correlate with peak plasma potential, indicating collisionless acceleration through (pre)sheath.**

Use of light scattering in characterizing reactively ion etched profiles

Konstantinos P. Giapis, Richard A. Gottscho,[a) Linda A. Clark, Joseph B. Kruskal, and Diane Lambert
AT&T Bell Laboratories, Murray Hill, New Jersey 07974
Avi Kornblit and Dino Sinatore
AT&T Bell Laboratories, Allentown, Pennsylvania 18103

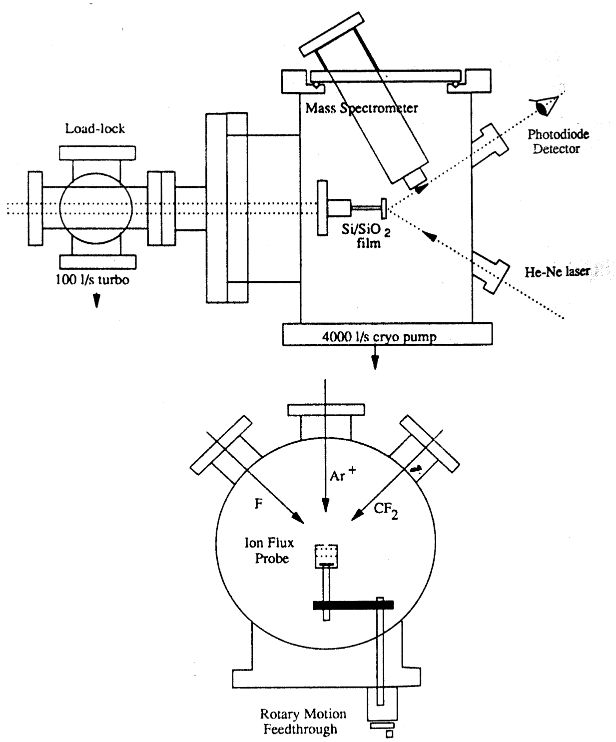
JVST A 9, 664 (1991)

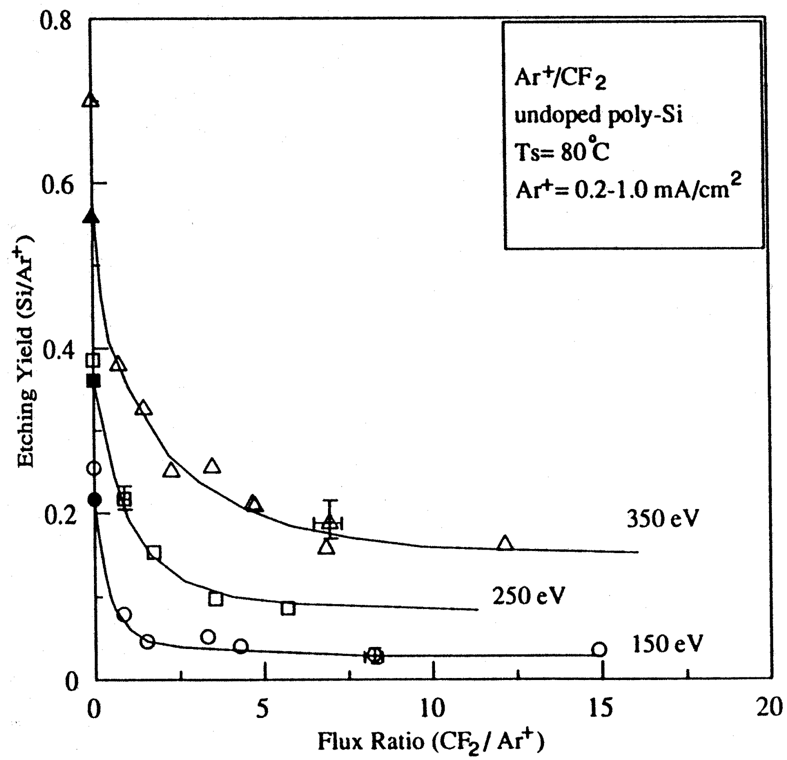


- **Laser light scattering from patterned wafers is spatially anayzed as a sensor for feature shape.**

Quantification of surface film formation effects in fluorocarbon plasma etching of polysilicon

David C. Gray and Herbert H. Sawin
Department of Chemical Engineering, MIT, Cambridge Massachusetts 02139
Jeffrey W. Butterbaugh
IBM, General Technology Division, Essex Junction, Vermont 05452 **JVST A 9, 779 (1991)**





- **Radical/ion beams synthesize the plasma tool environment and show a decrease in p-Si etching with CF_2/Ar^+ ratio due to overlying polymerization.**

CHALLENGES FOR < 100 nm BEYOND 2005

- **ITRS cites many "no known solutions" for interconnect to meet the 55 nm technology node by 2011.**

YEAR TECHNOLOGY NODE	2008 70 nm	2011 50 nm	2014 35 nm
MPU ½ pitch	80	55	40
MPU gate length (nm)	45	32	22
Number of metal levels	9	9–10	10
Number of optional levels – ground planes/capacitors	3	4	4
Jmax (A/cm^2)—wire (at 105°C)	2.1E6	3.7E6	4.6E6
Imax (mA)—via (at 105°C)	0.18	0.16	0.11
Local wiring pitch (nm)	185	130	95
Local A/R (for Cu)	1.9	2.1	2.3
Cu local dishing (nm), 5% × height	9	7	5
Intermediate wiring pitch (nm)	240	165	115
Intermediate wiring dual damascene A/R (Cu wire/via)	2.5/2.3	2.7/2.4	2.9/2.5
Cu intermediate wiring dishing (nm), 15 micron wide wire, 10% × height	30	22	17
Dielectric erosion (nm), intermediate wiring	0	0	0
Minimum global wiring pitch (nm)	390	275	190
Global wiring dual damascene A/R (Cu wire/via)	2.8/2.9	2.9/3.0	3.0/3.1
Cu global wiring dishing (nm), 15 micron wide wire, 10% × height	55	38	29
Conductor effective resistivity (μΩ-cm) Cu wiring	1.8	<1.8	<1.8
Barrier/cladding thickness (nm)	0	0	0
Interlevel metal insulator—effective dielectric constant (κ)	1.5	<1.5	<1.5

Solutions Exist (white) *Solutions Being Pursued* (yellow) *No Known Solutions* (red)

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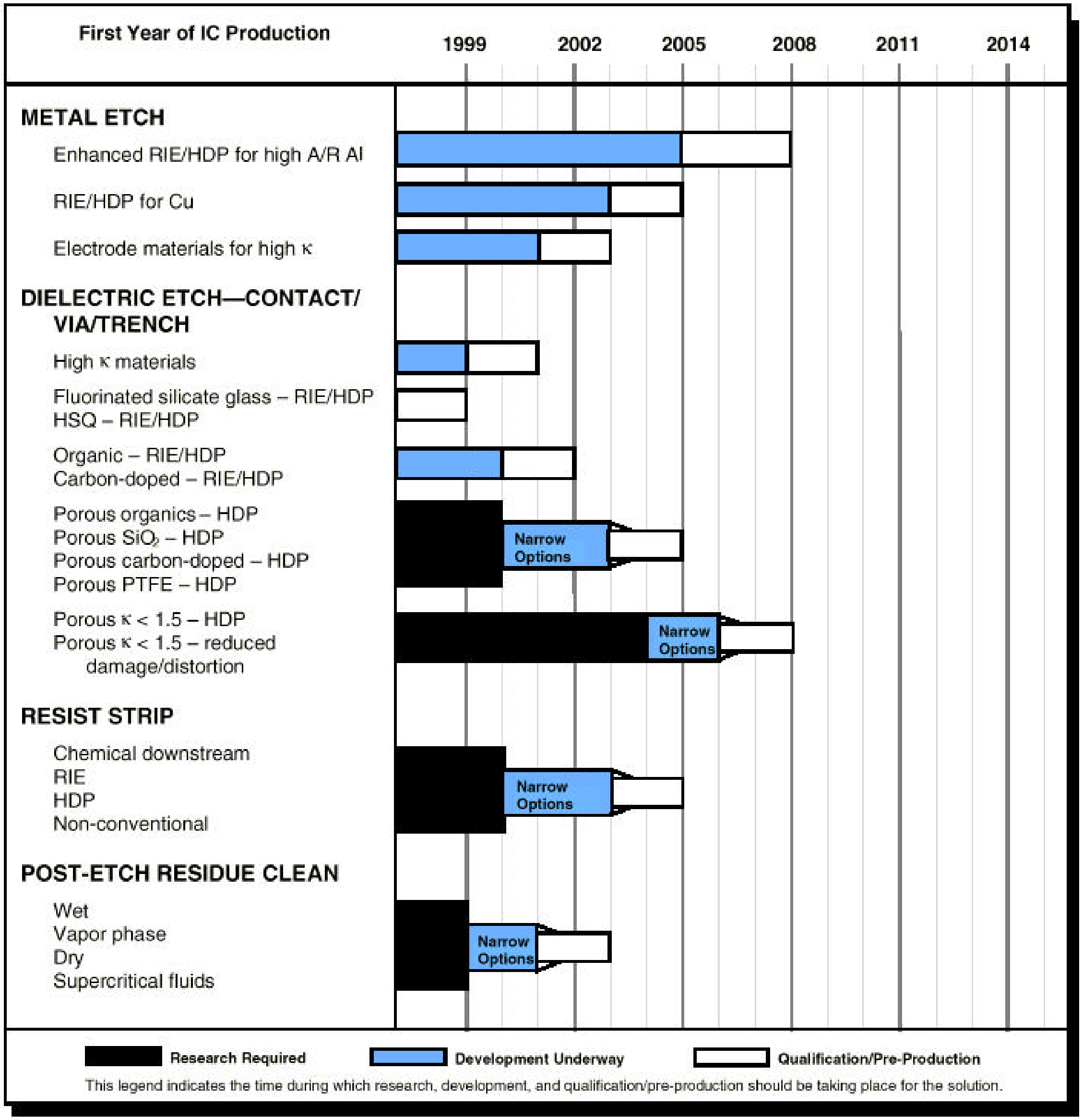
CHALLENGES FOR < 100 nm BEYOND 2005

- **The challenges cited to meet the ITRS goals focus on new materials and structures.**

Five Difficult Challenges <100 nm / Beyond 2005	*Summary of Issues*
Dimensional control and metrology	Multi-dimensional control and metrology of interconnect features is necessary for circuit performance and reliability.
Aspect ratios for fill and etch	As features shrink, etching and filling high aspect ratio structures will be challenging, especially for DRAM. Dual damascene metal structures are also expected to be difficult.
New materials and size effects	Continued introductions of materials/processes are expected. Microstructural and quantum effects become important.
Solutions beyond copper and low κ	Material innovation with traditional scaling will no longer satisfy performance requirements. Accelerated design, packaging and unconventional interconnect innovation will be needed.
Process integration	Combinations of materials along with multiple technologies used in SoC applications are a continued challenge. Plasma damage, contamination and thermal budgets are key concerns.

Int. Tech. Roadmap Semi.: Interconnect 1999

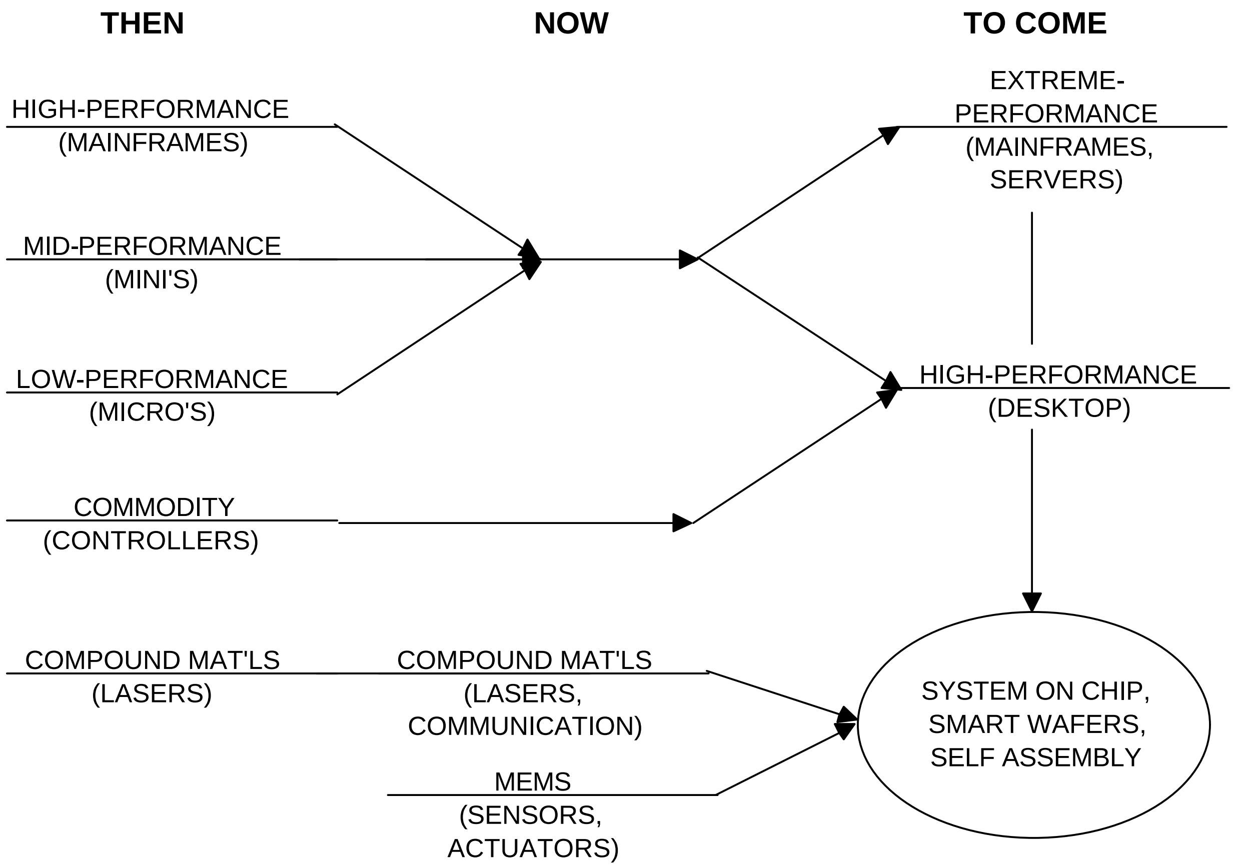
CHALLENGES FOR < 100 nm BEYOND 2005



- **Potential solutions for etch emphasize new materials, high plasma density sytems and cleans.**

MARKETS AND APPLICATIONS

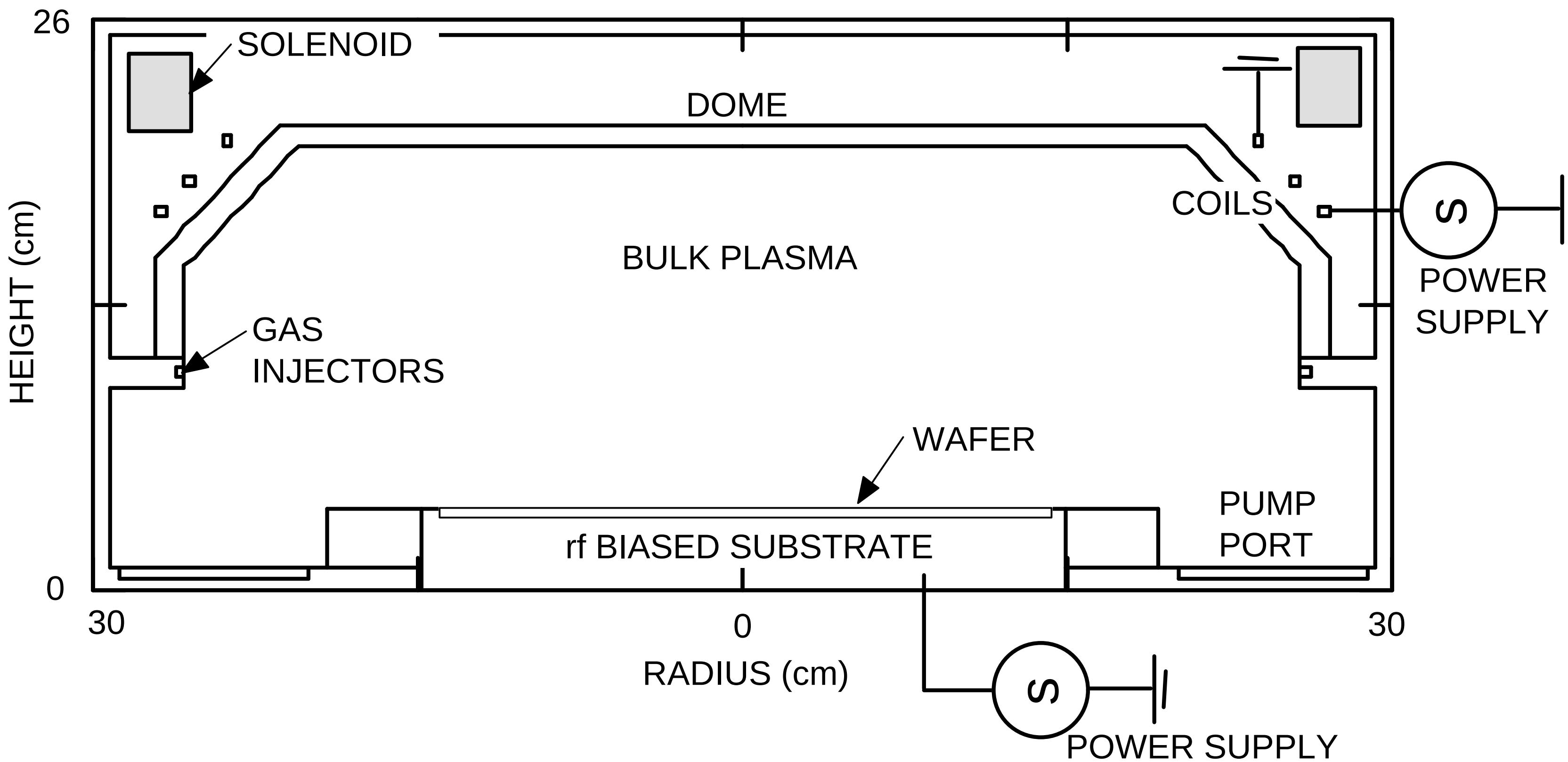
- **With the advent of high speed networks and parallel computing, past specialized markets for logic have collapsed to a single line.**
- **As processing becomes more critical (expensive) at <100 nm nodes and applications return to centralized computing, the market may bifurcate.**



- **MEMS, compound materials (e.g., Si/Ge) and organics will join "conventional" silicon in sensors, HBTs, actuators, SOC and optical interconnect.**

"GENERIC" PLASMA PROCESSING REACTOR

- **For purposes of illustration during this talk, a "generic" plasma processing reactor will be used to demonstrate principles.**



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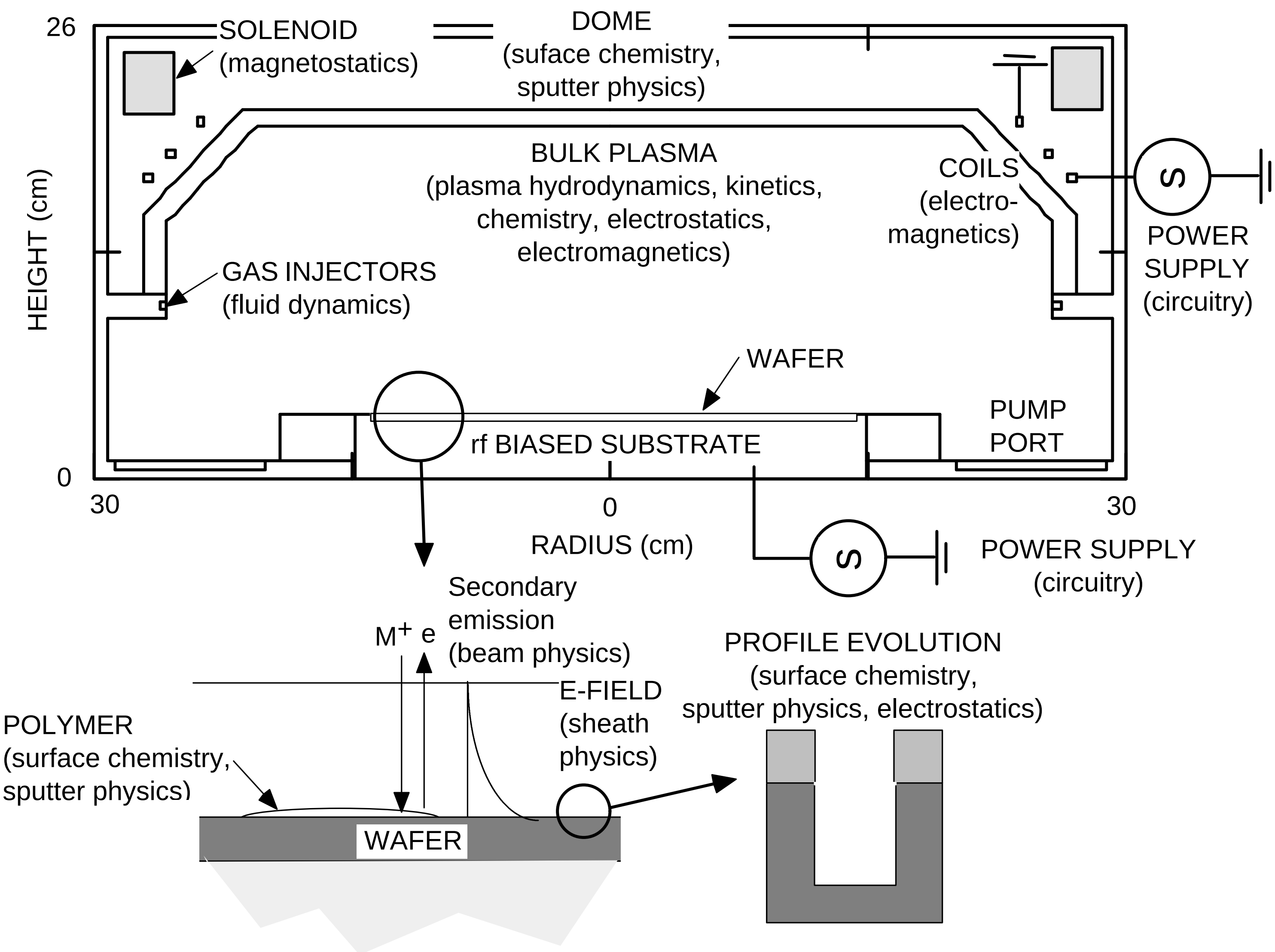
INNOVATION REQUIRES MASTERY OF THE BASICS



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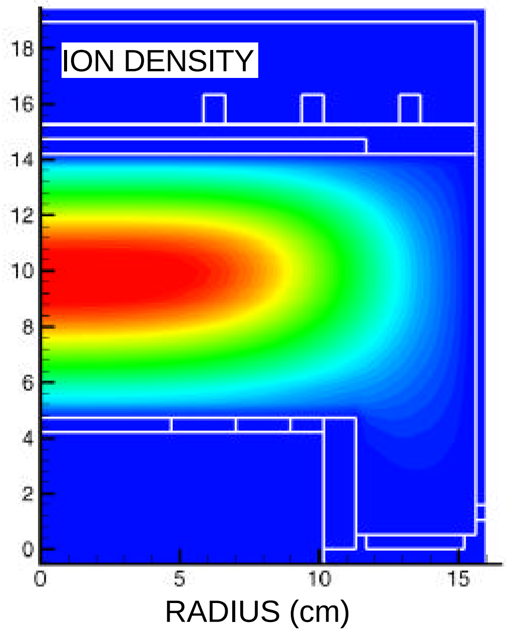
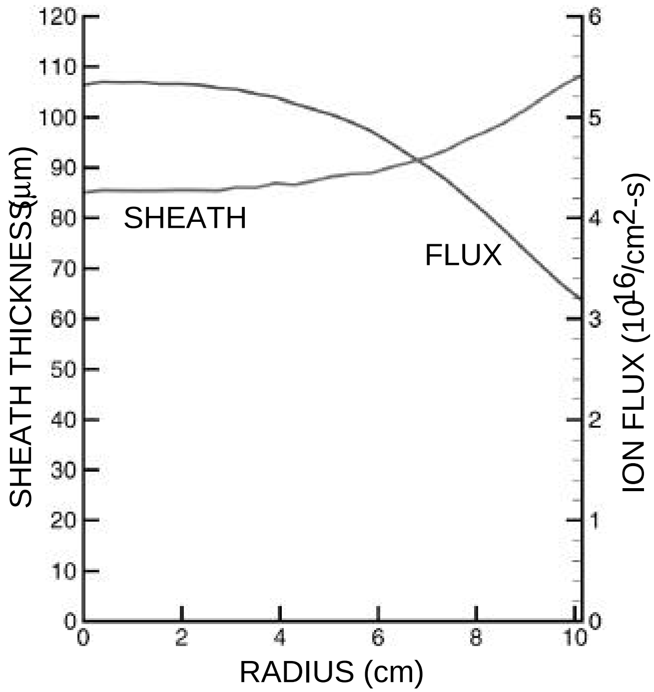
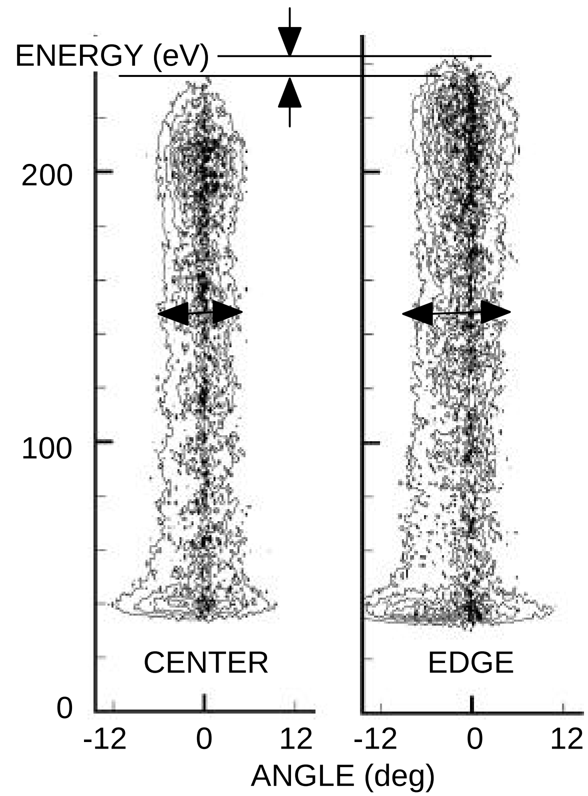
THE PROBLEM....

- **Uniformity and control of reactants becomes increasingly more difficult as wafer sizes increase and process chemistries become more complex.**
- **For example, non-uniformities in ion flux (sheath edge plasma density) across a wafer produce a change in sheath thickness and a commensurate change in ion energy-angular distributions.**







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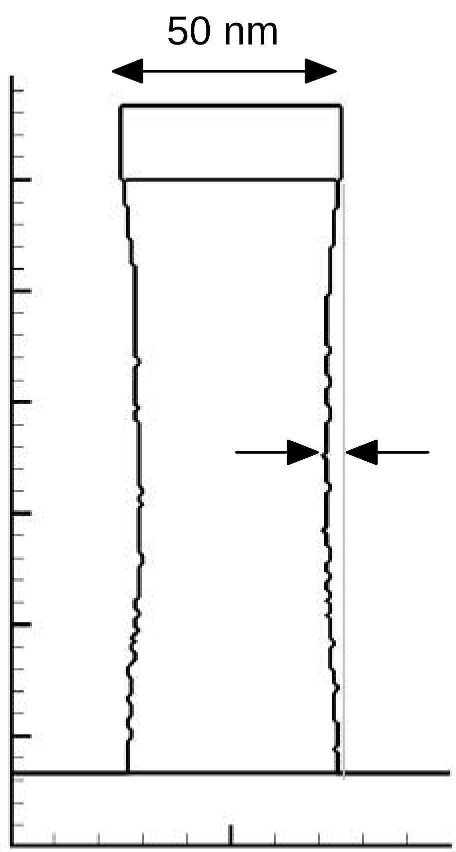
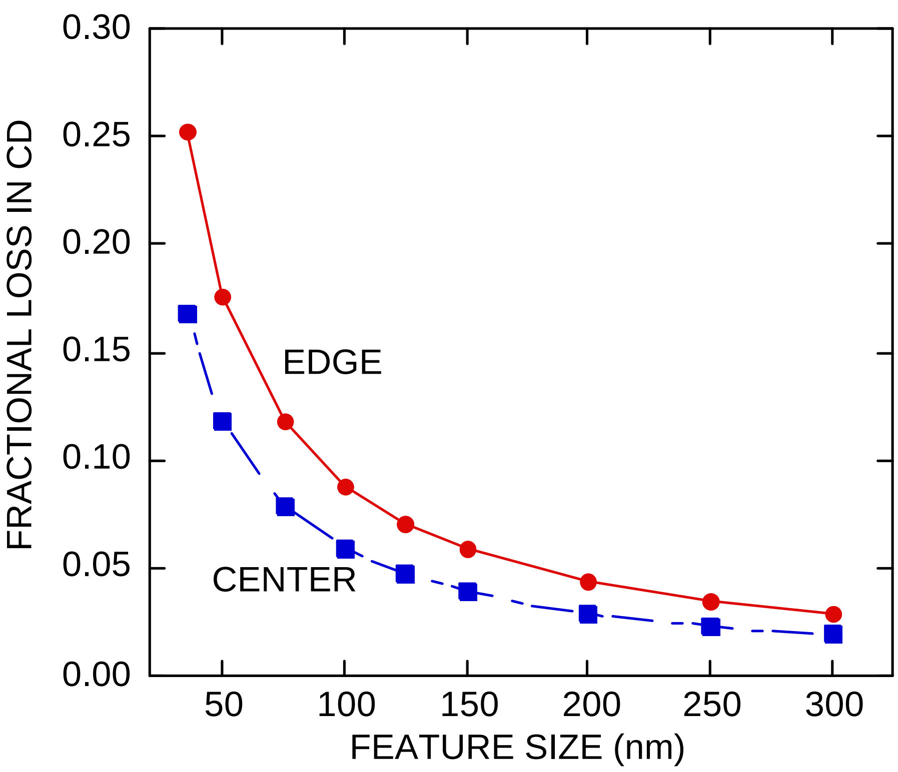
THE PROBLEM....

- **The end result is a loss in CD control (center-to-edge) which, tollerable at larger feature sizes is intolerable at smaller feature sizes.**





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SMART, AWARE AND PROACTIVE TOOLS

- In spite of tremendous progress in the design of plasma tools, most such tools are passive or, at best, reactive to their own environment.

- The case is made that continuing innovation requires Smart, Aware and Proactive (SAP) tools.

  - SMART: mentally alert, knowledgeable, shrewd

  - AWARE: having or showing realization, perception or knowledge

  - PROACTIVE: involving modification by a factor which proceeds that which is being modified.

Webster's New Collegiate Dictionary

- A SAP tool is one that:
  - Senses its internal reactive environment
  - Has access to a knowledge base which enables it to interpret these observations
  - Changes its environment to meet specifications.

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THE CASE FOR SAP TOOLS

- **The move towards foundries by even major chip producers implies that a larger variety of processes will be performed in a given tool over its lifetime; and that those processes will change more frequently.**
  - **Tools must be "reconfigurable" rapidly.**
  - **Tool memory effects may be unavoidable and unpredictable.**
- **As new materials are developed (e.g., low-k, high-k) having more stringent CDs, recipes will likely become more complex.**
  - **What is optimum for one mixture is not optimum for another.**
  - **More demanding requirements to widen process windows.**
- **As wafer sizes and die complexity increase, the value/wafer enables expenditures which now are discounted.**

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DOES The KNOWLEDGE BASE EXIST FOR SAP TOOLS (OR CAN IT BE GENERATED?)

- **Realizing SAP tools requires an intimate knowledge of the cause-and-effect relationship.**

  "If I observe A and do B, then C will result."

- **This cause-and-effect knowledge base can be generated by a range of methods ranging from empirical to a priori.**

  - **Empirical: Conventional DOE**
  - **A priori: Predict from first principles**
  - **Semi-Empirical/A priori: First principles bounded or normalized by empiricism.**

- **At present the knowledge base does not exist for SAP tools, largely because the observables A are too far removed from the outcomes C.**

- **The methodology and technologies to realize SAP tools do, however, exist or can be developed.**

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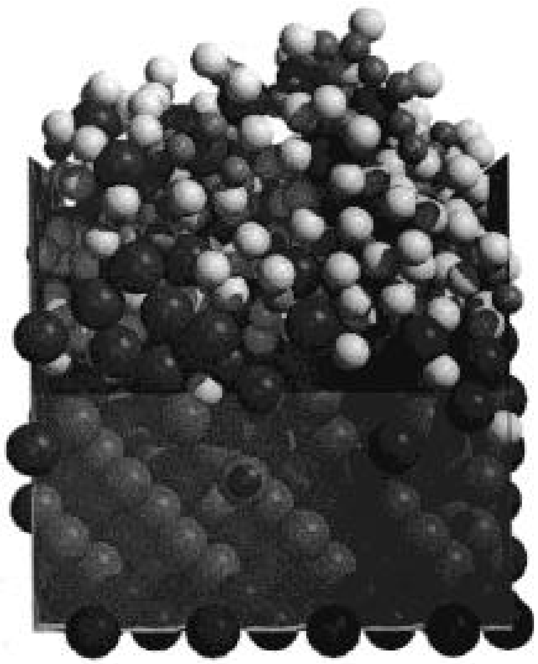
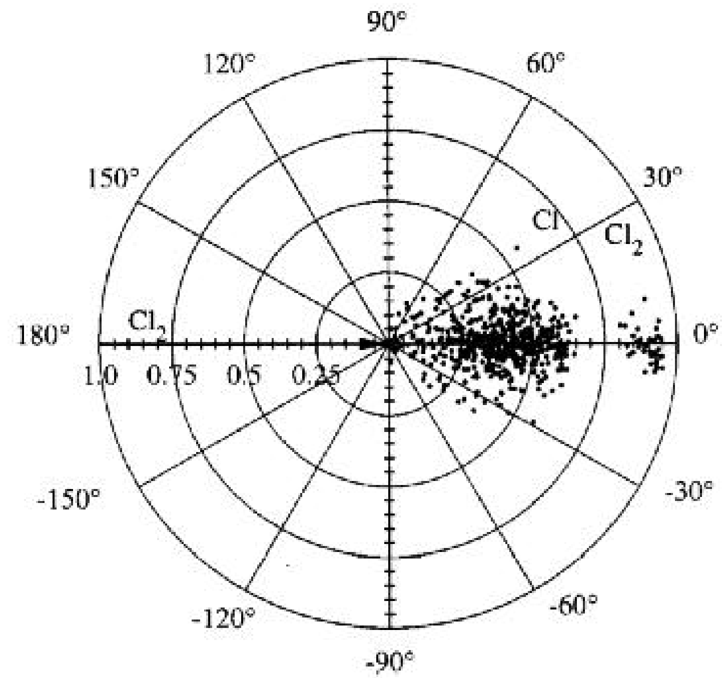
GENERATION, APPLICATION AND EXTENSION OF KNOWLEDGE BASE: FEATURE EVOLUTION (D. B. Graves)

- **Advancing the knowledge base in feature evolution has required a combination of apriori, semi-empirical and empirical calculations and measurements, supported by validating experiments.**
- **The group/collaborators of D. B. Graves demonstrate this methodology.**

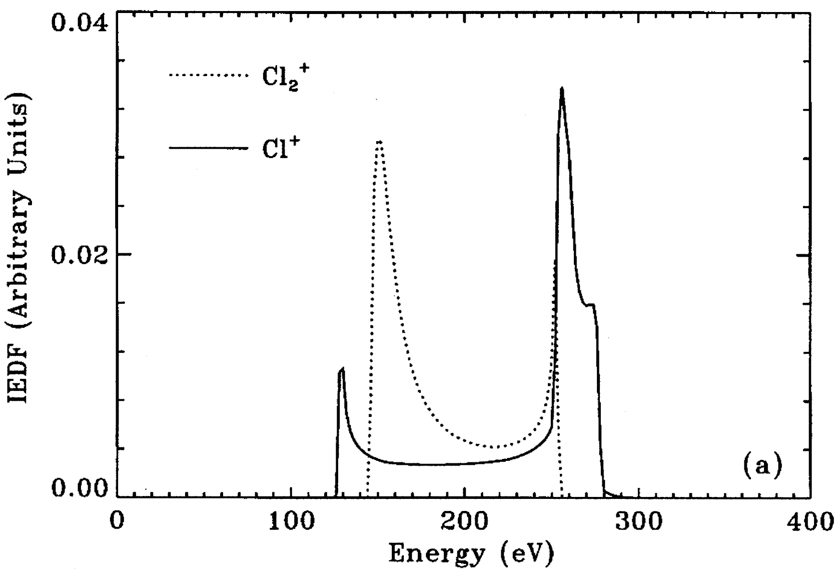


- **Sticking coefficients on evolving surfaces (CF_3^+ on Si)**

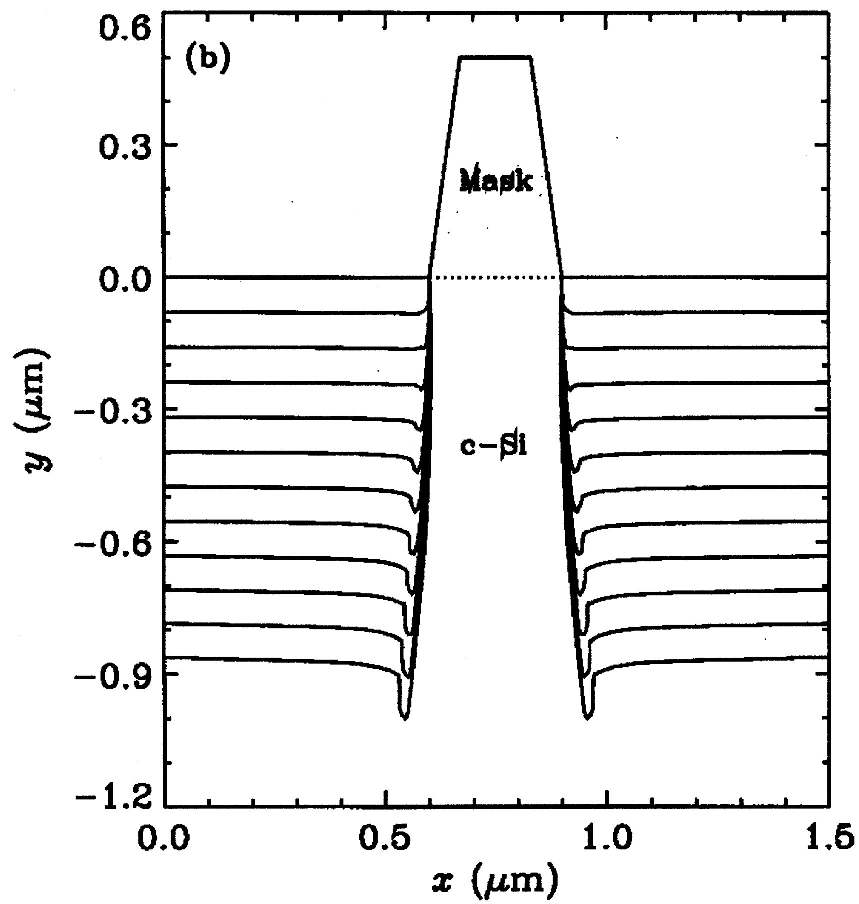


- **Reflection coefficients of ions from surfaces (Cl_2^+ on Si)**

GENERATION, APPLICATION AND EXTENSION OF KNOWLEDGE BASE: FEATURE EVOLUTION (D. B. Graves)



- **Equipment Scale Modeling (Ion Energy Distributions)**



- **Feature Scale Modeling (Si etching by Cl_2/HBr)**

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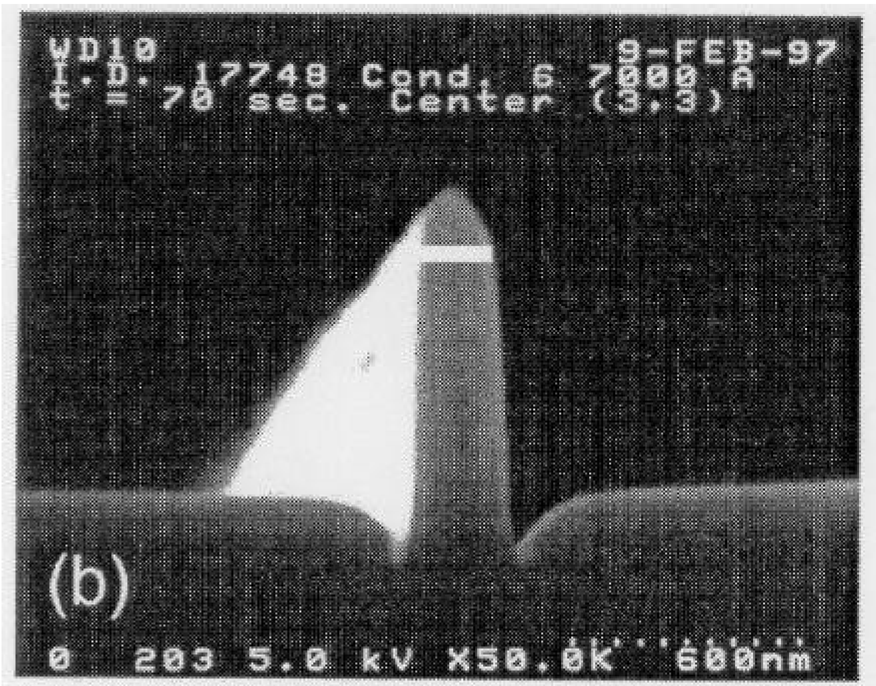
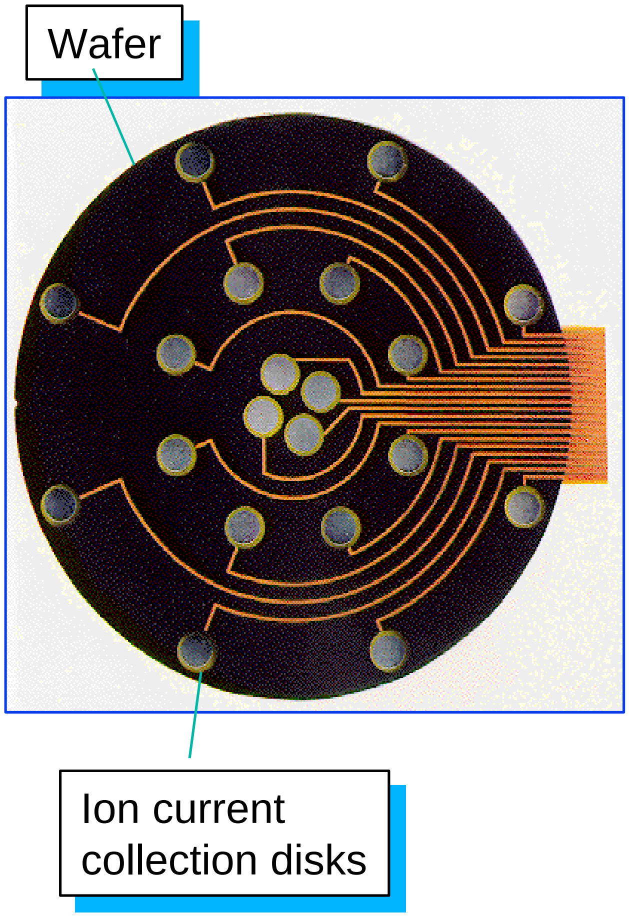
GENERATION, APPLICATION AND EXTENSION OF KNOWLEDGE BASE: FEATURE EVOLUTION (D. B. Graves)



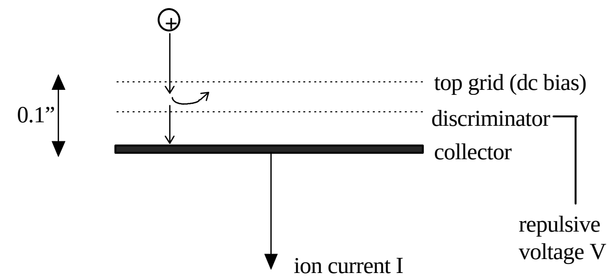
- **Validating data**

- **C.F. Abrams and D. B. Graves, JAP 86, 5938 (1999)**
- **M. Voyoda et al, JVSTB 18, 820 (2000)**
- **B. Helmer and D. B. Graves, JVSTA 17, 2759 (1999)**

Examples of Plasma Diagnostic Tools Used in Development of Etch Equipment



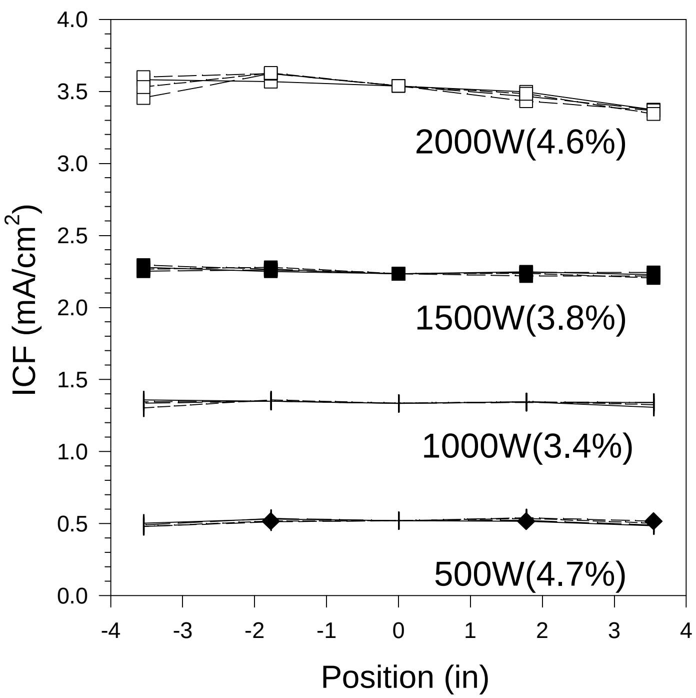
- Instrumented Wafers
  - Ion Current Flux
  - DC Bias
  - Ion Energy



Ref: Peter K. Loewenhardt

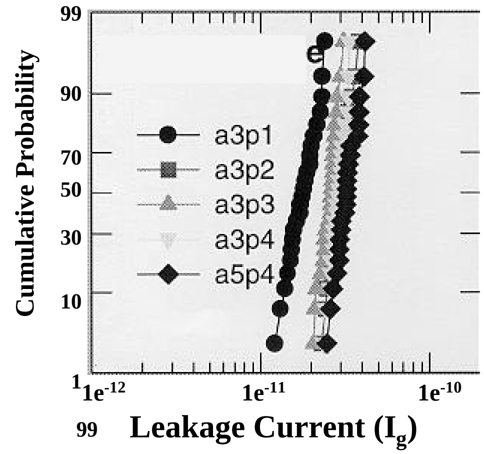
Source Power Window

ICF

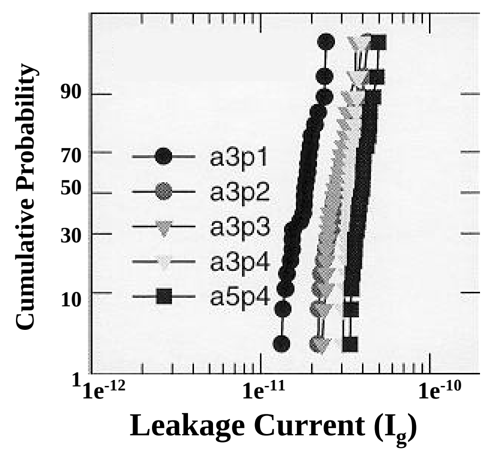


Damage

1800Watts



1000Watts

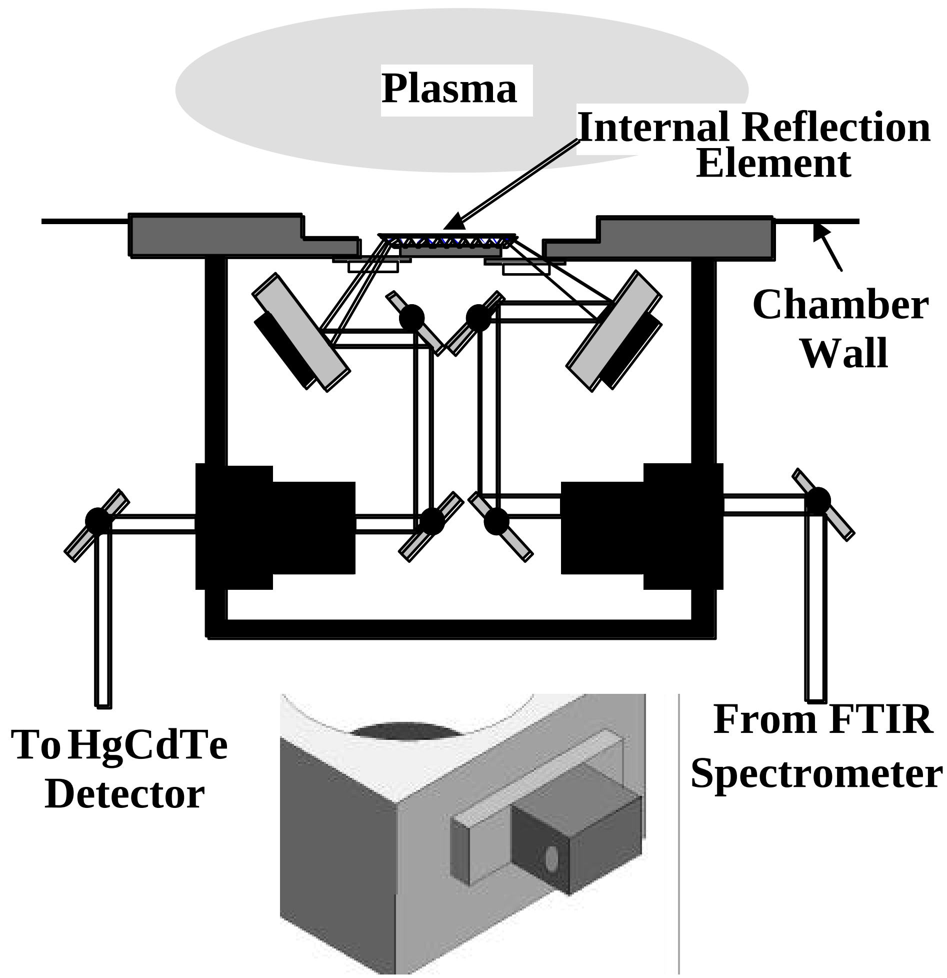


Ref: Peter K. Loewenhardt

Reference: ICF:European Semiconductor/
Damage:P_2ID

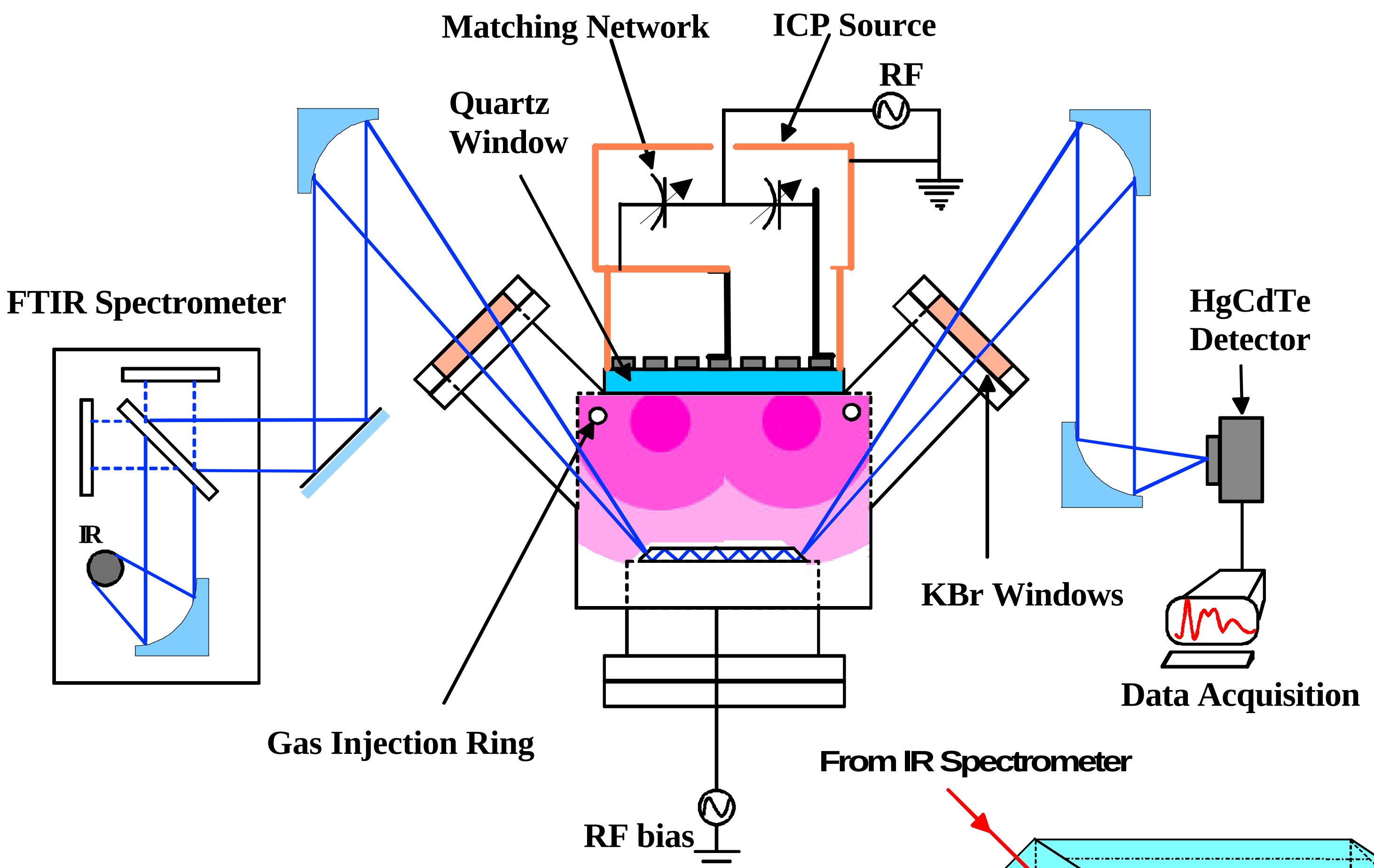
Multiple Total Internal Reflection Fourier Transform Infrared (MTIR-FTIR) surface probe

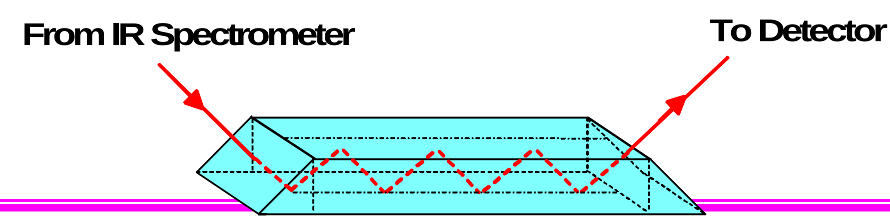
- A new diagnostic for detecting species and films formed on the reactor walls.
- What is formed on reactor walls during etching? How does it affect the plasma?
- Applications
  - Detecting Fluorocarbon films on the walls
  - SiO_xCl_y films in Si etching
  - PECVD
  - Monitoring reactor wall cleaning steps.



- Ref: Eray Aydil, UCSB, aydil@engineering.ucsb.edu

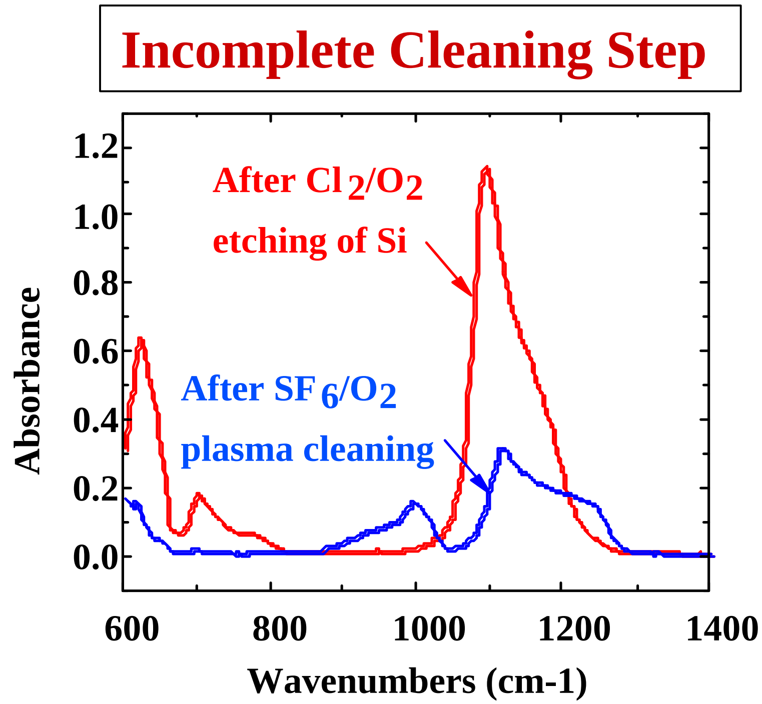
In Situ Attenuated Total Reflection Fourier Transform Infrared (ATR-FTIR) Spectroscopy

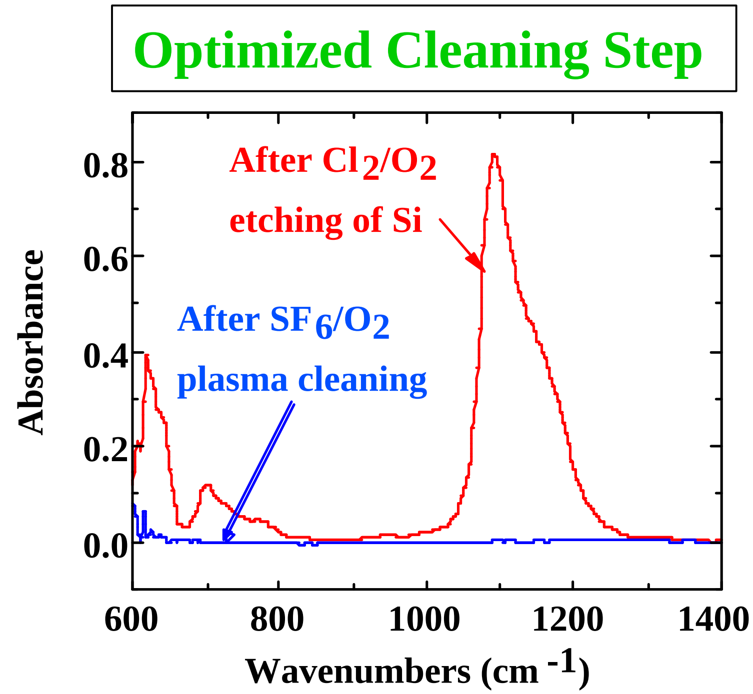




- Ref: Eray Aydil, UCSB, aydil@engineering.ucsb.edu

Application of MTIR-FTIR surface probe: reactor wall cleaning





- **During Cl_2/O_2 etching of Si, SiO_xCl_y film deposits on the reactor walls.**
- **SiO_xCl_y film must be etched from the reactor walls using F-containing plasma in between every wafer in a step referred to as Waferless Auto Clean (WAC).**
- **MTIR-FTIR probe help develop successful WAC in Lam's TCP reactor for Si STI etching and improved productivity.**

Lam RESEARCH

- **Ref: Eray Aydil, UCSB, aydil@engineering.ucsb.edu**

UCSB

MEMS (MICRO-ELECTRO-MECHANICAL SYSTEMS) MICROSENSORS FOR SMART WAFERS

- The development of MEMS technologies provide the opportunity to implement intra-tool sensors and, ultimately, on-wafer sensors resulting in the wafer analogue of the smart-tool: the *Smart Wafer*

- MEMS sensors enable measurements of, for example, reactive fluxes to be made at or near the wafer surface.

  - Provides data directly relevant to process control

  - Eliminates need to disengage complex relationships between measurements of, for example, OES and desired quantities such as flux.

- Smart Wafers may have unique sensors for individual processes, thereby eliminating the need for over-functionality to be built into the tool.

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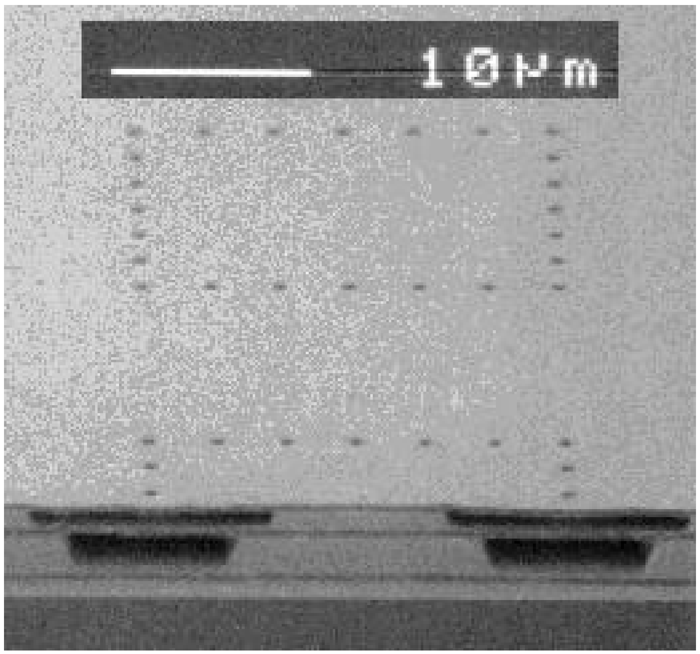
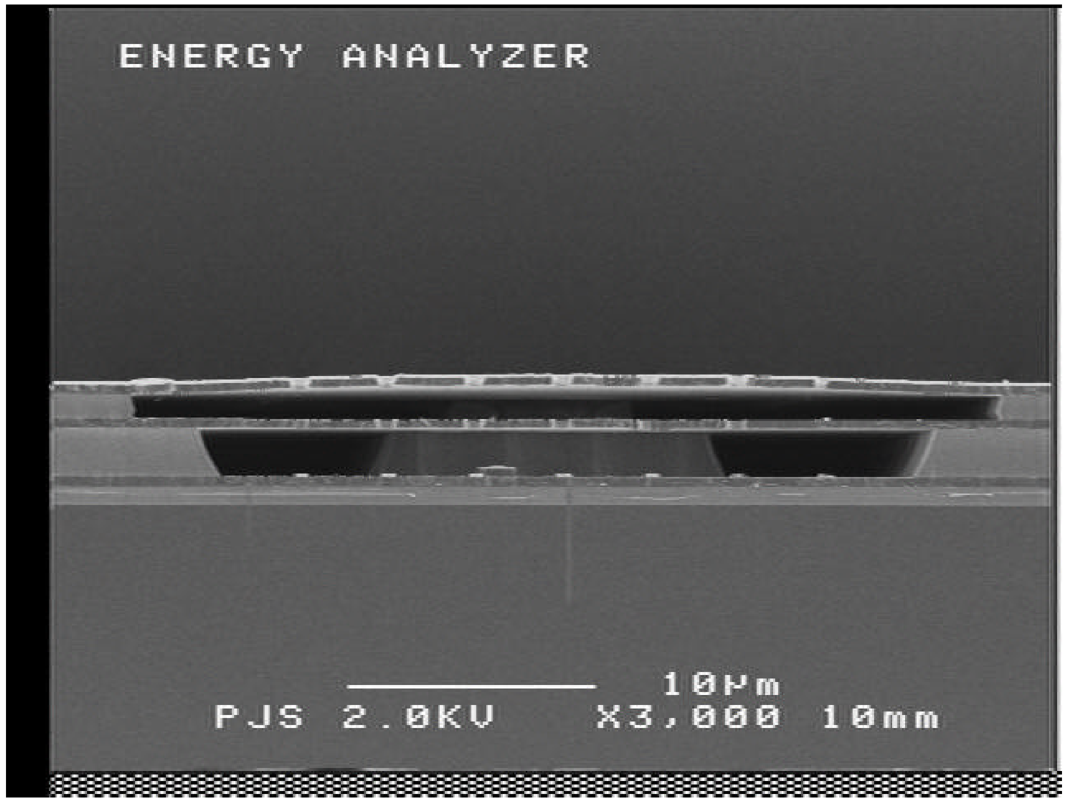
SUB-MICRON RETARDING FIELD ENERGY ANALYZER
(M. BLAIN, Sandia National Labs)

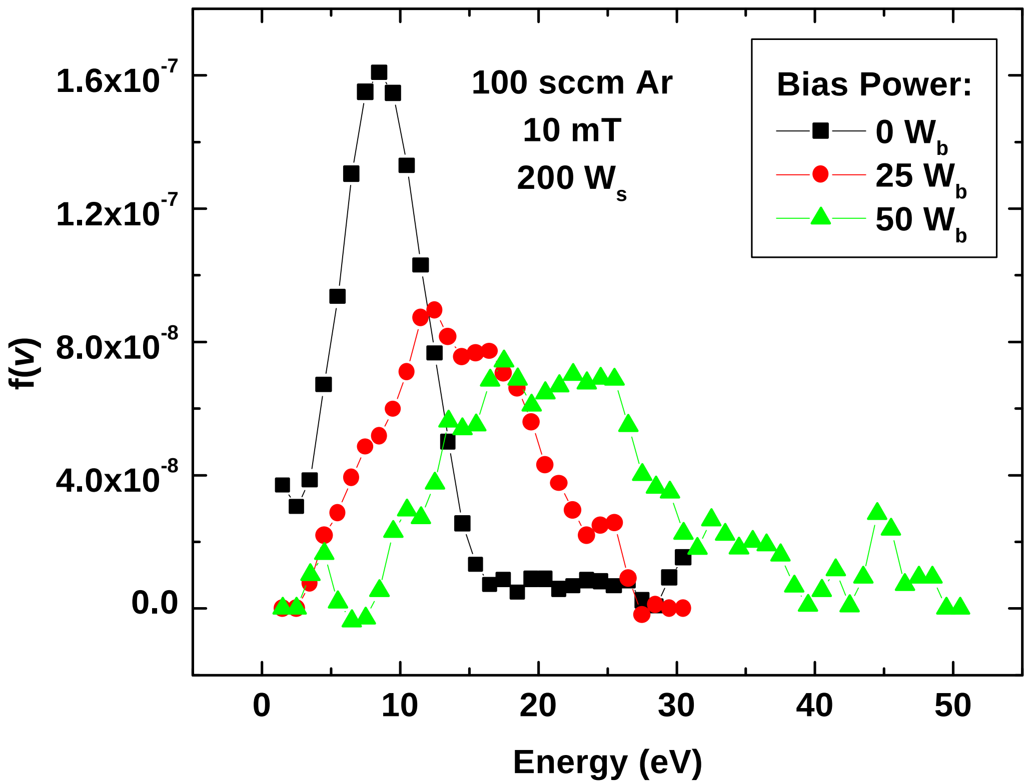
- **Leveraging MEMS technologies, Blain et al have developed sub-micron ion energy anlyzers which provide the means for non-perturbing, in-situ, on-wafer measurements.**





- **Micro-Ion Energy Analyzer fabricated using MEMS technologies**

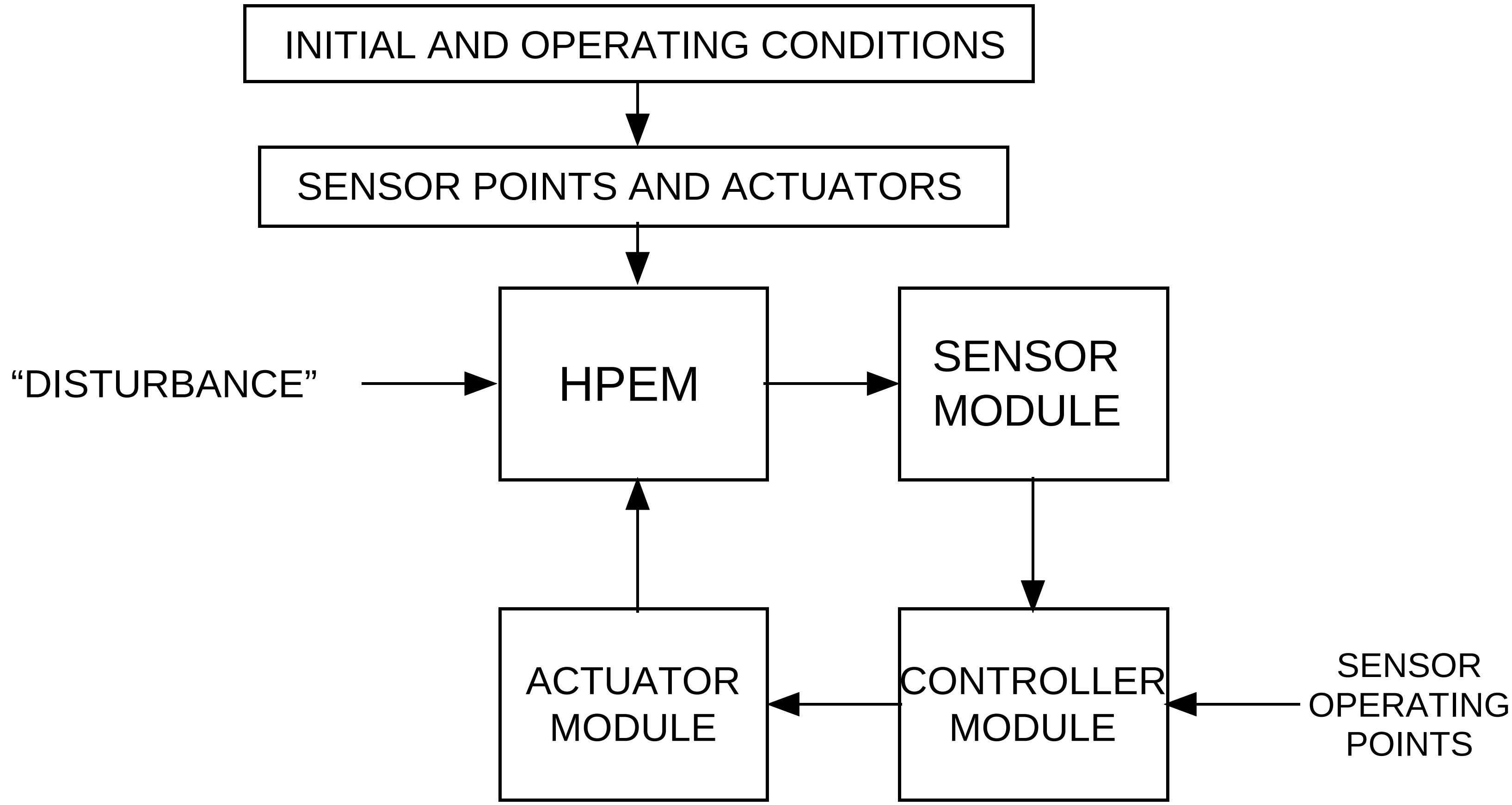
SUB-MICRON RETARDING FIELD ENERGY ANALYZER
(M. BLAIN, Sandia National Labs)



- **Ion energy distributions obtained on rf-biased substrate in ICP-GECRC**
- **With multiple sensors across wafer, real-time assessments of quality and uniformity of ion fluxes are possible.**

VIRTUAL PLASMA EQUIPMENT MODEL (VPEM)

- The Virtual Plasma Equipment Model (VPEM) is a “shell” which supplies sensors, controllers and actuators to the HPEM.



PID CONTROLLER

- A Proportional-Integral-Differential (PID) controller has been implemented in the VPEM.

- Proportional:

$$\Delta A = A \cdot g \cdot \frac{\Delta S}{S}, \quad \Delta S = \left(S_o - S\right) = Error\ Signal$$

- PID

$$A = g \cdot \left(\frac{\Delta S}{S} + \frac{1}{t_i} \int \frac{\Delta S}{S} dt + t_d \left(\frac{\Delta S / S}{dt} \right) \right) + A_o$$

where:

$\Delta S, S, S_o$	Error, current value and set point of sensor	g	Gain of Controller
$\Delta A, A, A_o$	Change, current value and set point of actuator	t_d, t_i	Differential and integral time constants

PROCESS VARYING WALL CONDITIONS

- During a process recipe, deposition on reactor side walls (or changes in process conditions) results in changes in reactive-sticking coefficients, producing both intra-run and run-to-run variations in performance.

- Chamber cleans are, in large part, necessary to "reset" the reactor to "initial conditions".

- Particle formation concerns aside, the difficulty in using real-time-control to compensate for evolving wall conditions is the uncertainty in correlating observables (e.g., OES, actinometry) with fluxes to wafer surface.

- SATs and SAWs eliminate this uncertainty, by directly measuring process relevant parameters.

- Example: Cl $\rightarrow$ Cl_2 sticking coefficient increasing during process.

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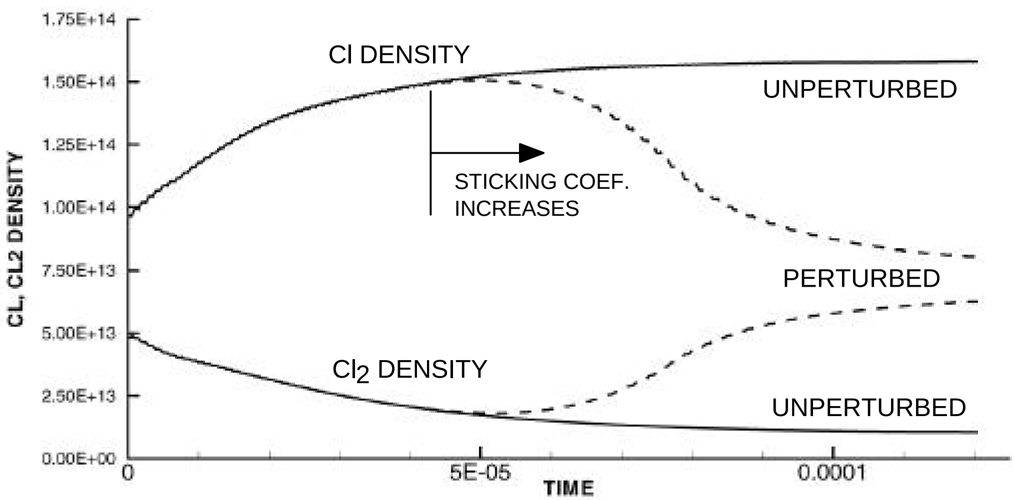
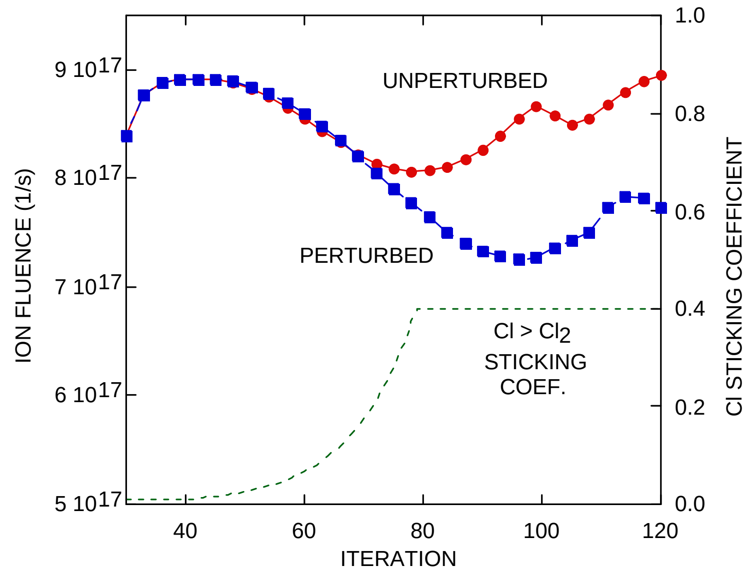
Cl → Cl_2 STICKING COEFFICIENT

- **During a process, the sticking coefficient on chamber walls increases from 0.01 to 0.4 due to deposition of etch products.**





<u>Cl, Cl_2 Densites with/without Perturbation</u> **<u>Ion Fluence, Sticking Coef.</u>**

- **Cl densities decrease, Cl_2 densities increases, resulting in a decrease in the ion flux to the on-wafer sensor.**

- **Ar/Cl_2 = 70/30, 20 mTorr, 500 W, 200 sccm**

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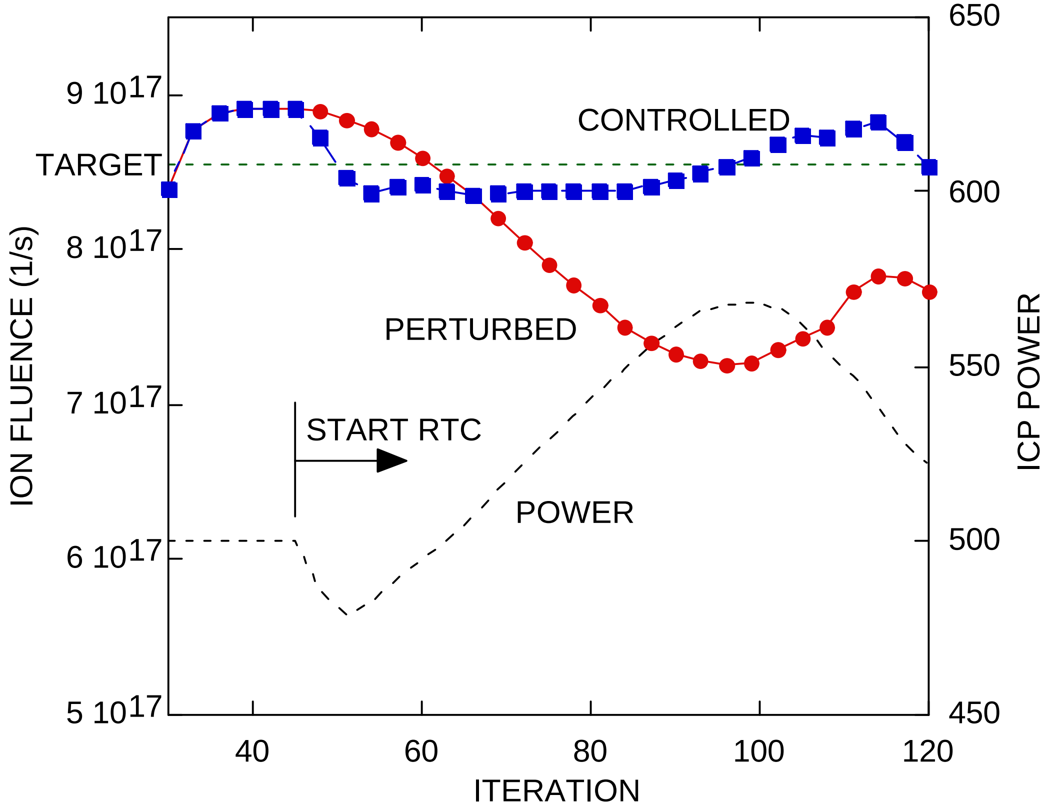
$Cl \rightarrow Cl_2$ STICKING COEFFICIENT: ION FLUENCE-POWER RTC

- **A simple proportional controller with a wafer-level ion flux sensor is used. The desired ion fluence, perturbed by the change in Cl sticking coefficient, is largely recouped.**



- **Ar/Cl_2 = 70/30, 20 mTorr, 500 W, 200 sccm**

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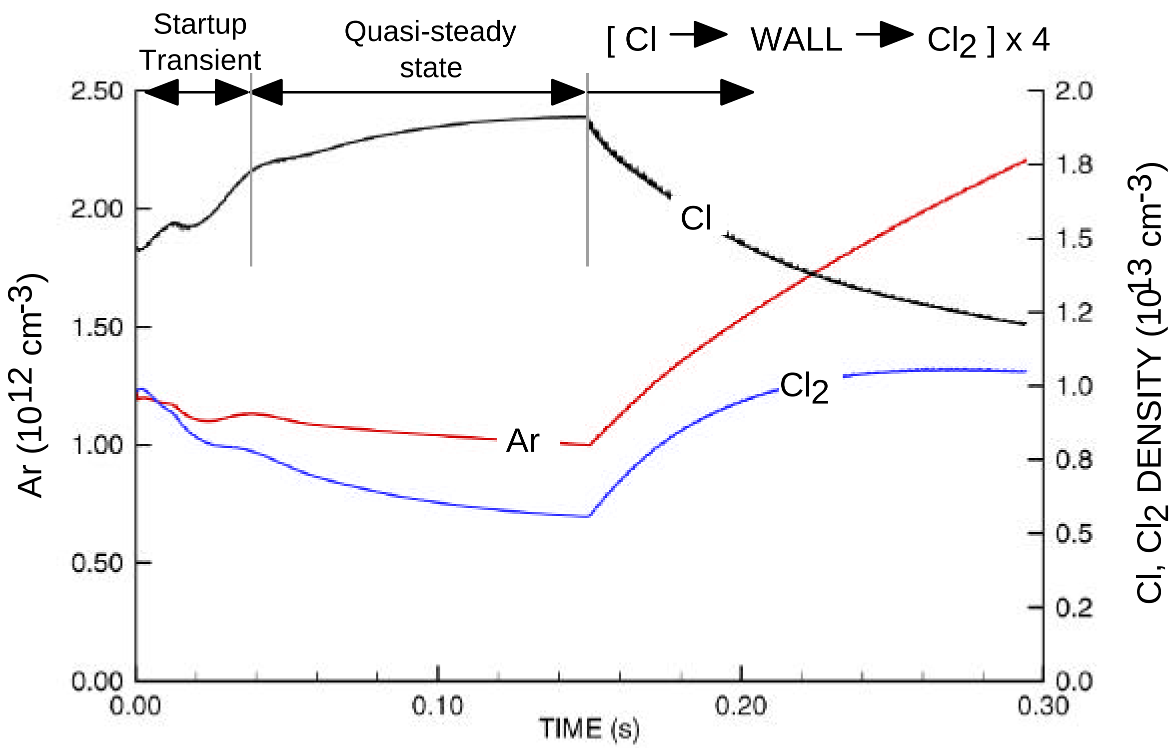
CHOICE OF SENSOR FOR TRANSIENTS: ACTINOMETRY

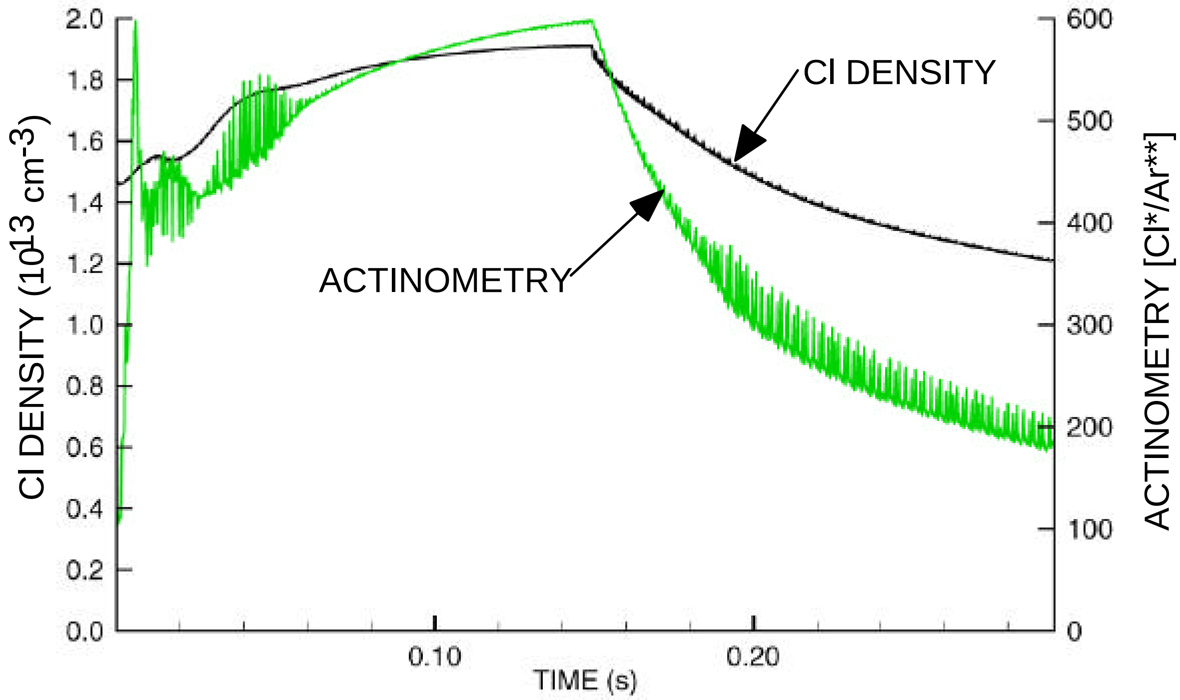
- **The proper choice of sensor is critical to controlling through transients.**
- **Sensors which are adequate for perturbations to the steady state may fail during a transient.**
- **Example: Impulsively change the coefficient for Cl ® Cl_2 on walls while keeping the input flow rate and pressure constant.**



- **Sensor: Actinometry of Cl*: S = [Cl*]/[Ar**]**
- **The decrease in outflow resulting from more recombination increases the Ar density.**
- **10 mTorr, 120 sccm, Cl_2/Ar = 95/5, 500 W**

CHOICE OF SENSOR FOR TRANSIENTS: ACTINOMETRY

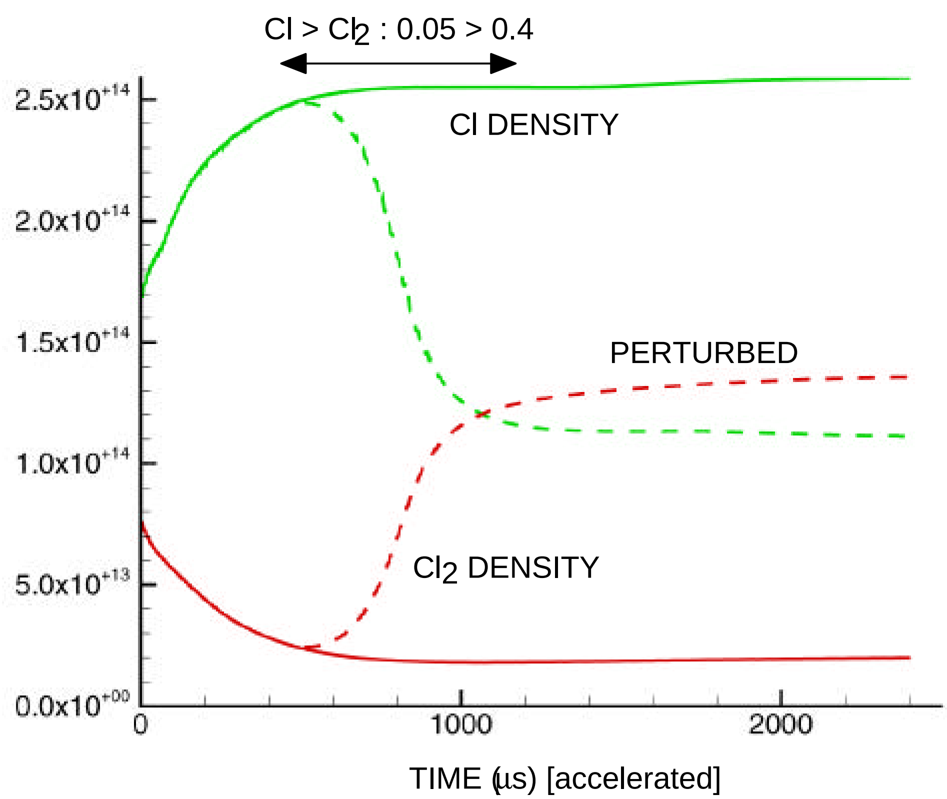
- **As a result of the absolute increase in Ar density (and Ar* signal) resulting from the change in mole fractions, the actinometry signal *decreases* relative to the actual Cl density.**

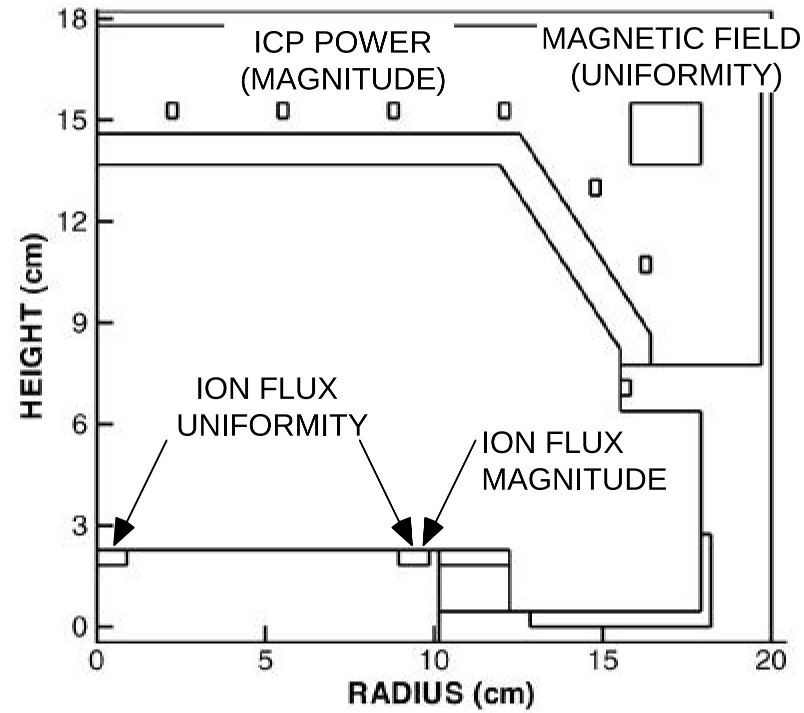


- **Transients which change the mole fraction of the reference will complicate use of actinometry.**

SMART WAFER: ION FLUX AND UNIFORMITY

- **Intra-process seasoning of walls changing reactive sticking coefficients produces changes in both magnitudes and uniformity of fluxes.**
- **Smart wafer techniques will be applied to control against changes in ion flux and uniformity following a change in sticking coefficient for Cl $\rightarrow$ Cl_2.**





- **Ar/Cl_2 = 50/50, 20 mTorr, 500 W, 200 sccm**

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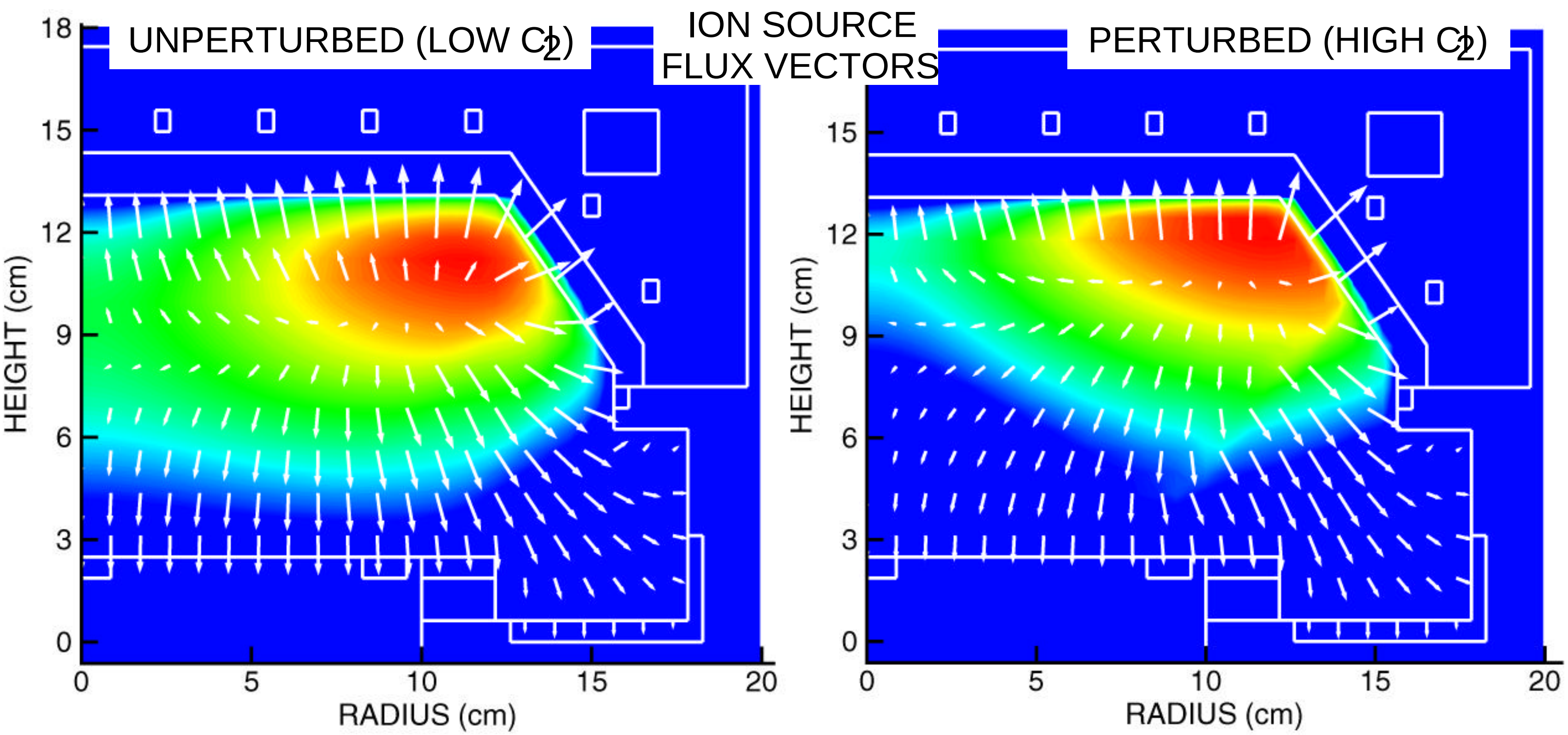
ION SOURCE AND FLUXES

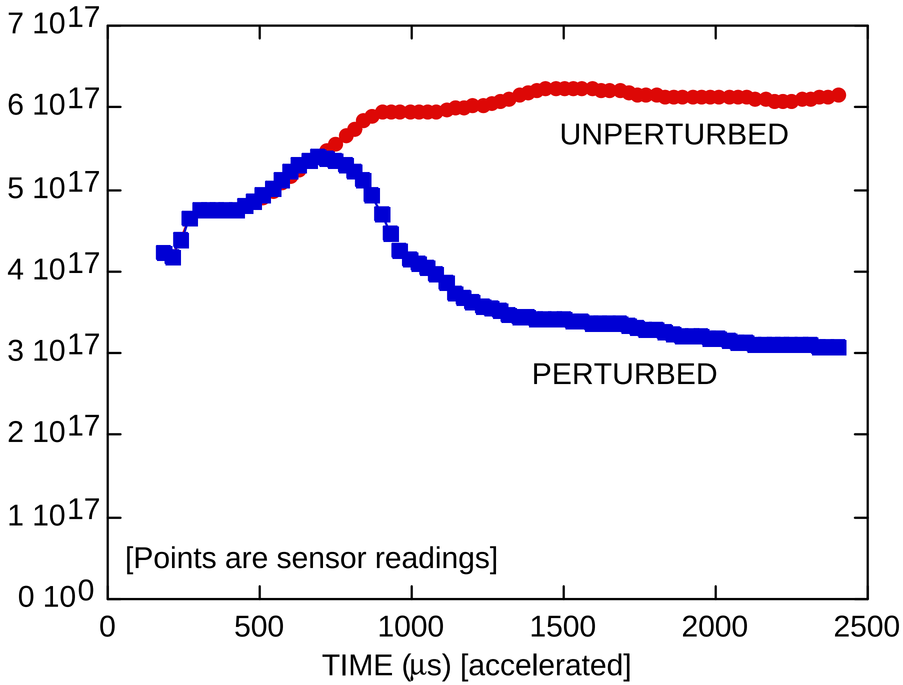
- **Due to the increase in Cl_2 resulting from the increase in Cl → Cl_2 on walls ion sources are confined closer to the coils.**
- **The ion flux decreases and becomes more edge high.**



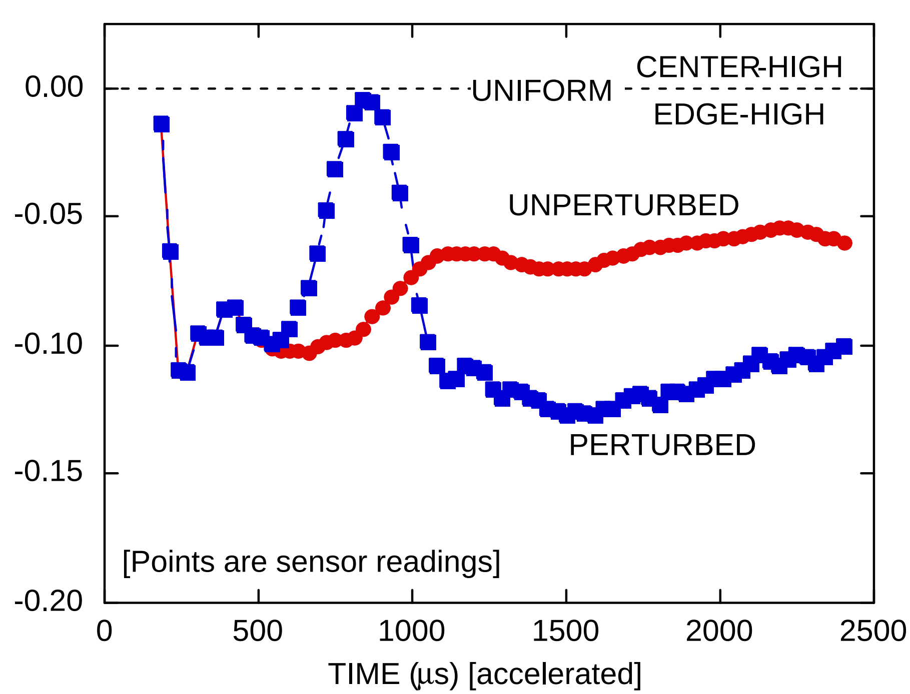
- **Ar/Cl_2 = 50/50, 20 mTorr, 500 W, 200 sccm**

ION FLUENCE MAGNITUDE AND UNIFORMITY

- **The shift in ion source to larger radius increases the ion flux at large radius thereby making uniformity more edge-high.**
- **Larger rates of attachment and higher wall losses decrease the ion flux.**
- **These trends will be corrected using ICP power and B-field as actuators.**



ION FLUENCE (1/s)



UNIFORMITY

- **Ar/Cl_2 = 50/50, 20 mTorr, 500 W, 200 sccm**

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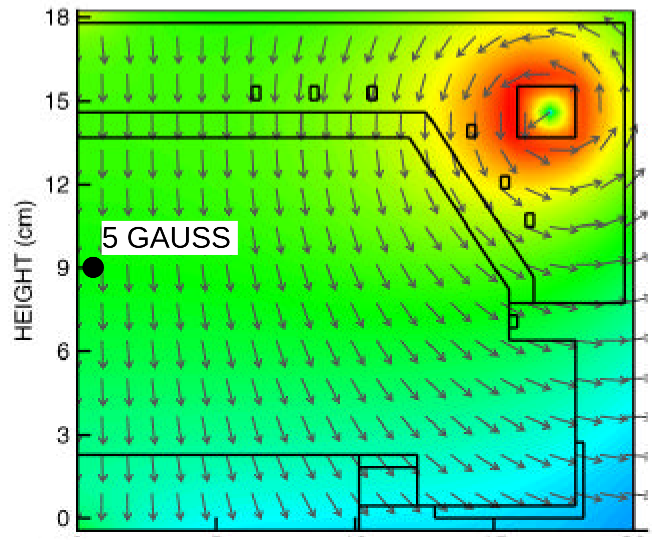
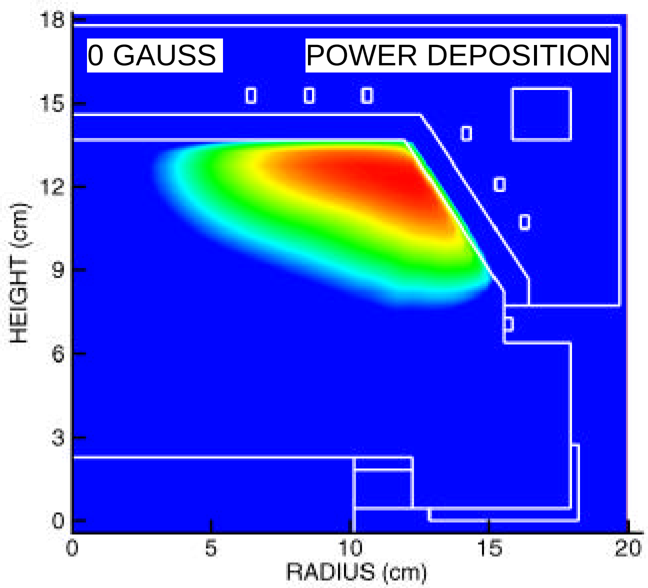
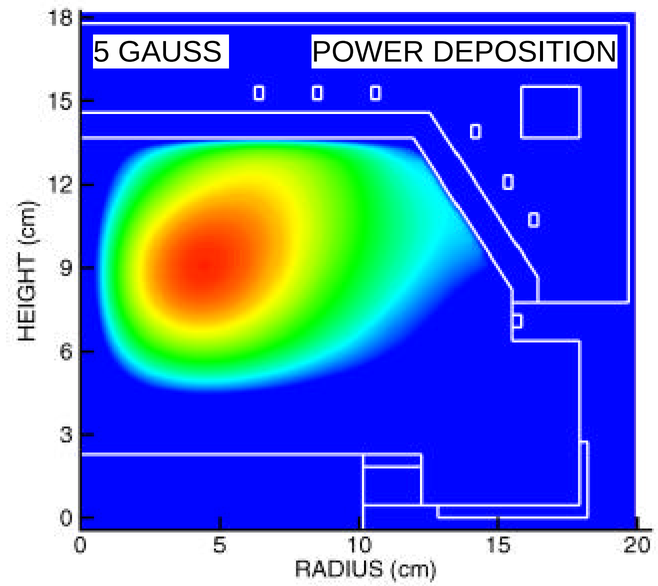
MAGNETIC FIELD AS AN ACTUATOR

- By applying moderate solenoidal magnetic fields (a few - 10s G), radial and axial components of the inductively coupled field are generated.
- This results in shifts in the power deposition, and can be used as an actuator for ion flux uniformity.
- Ar/Cl_2 = 70/30, 20 mTorr, 500 W, 200 sccm







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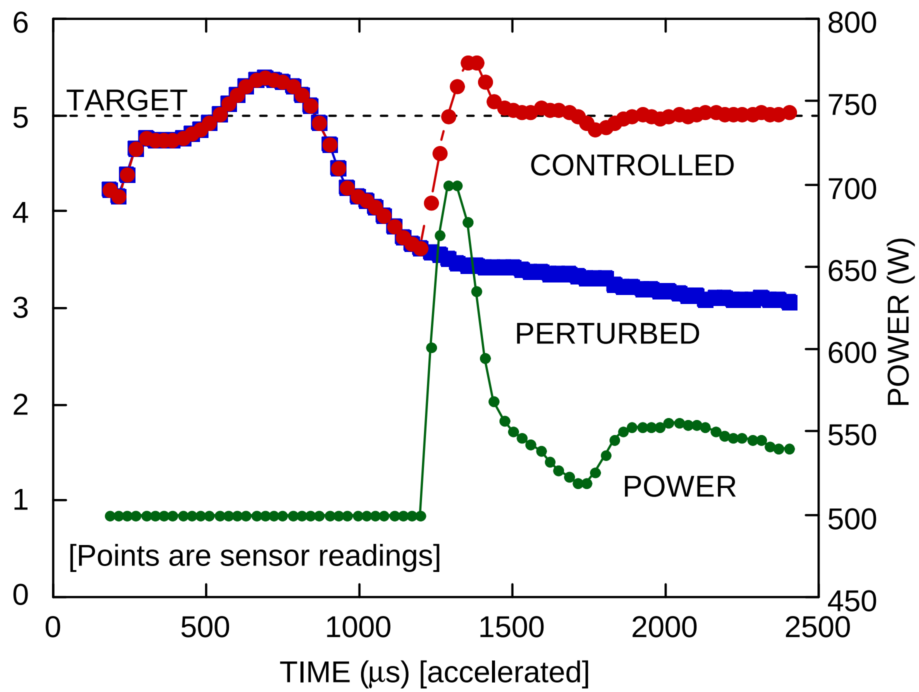
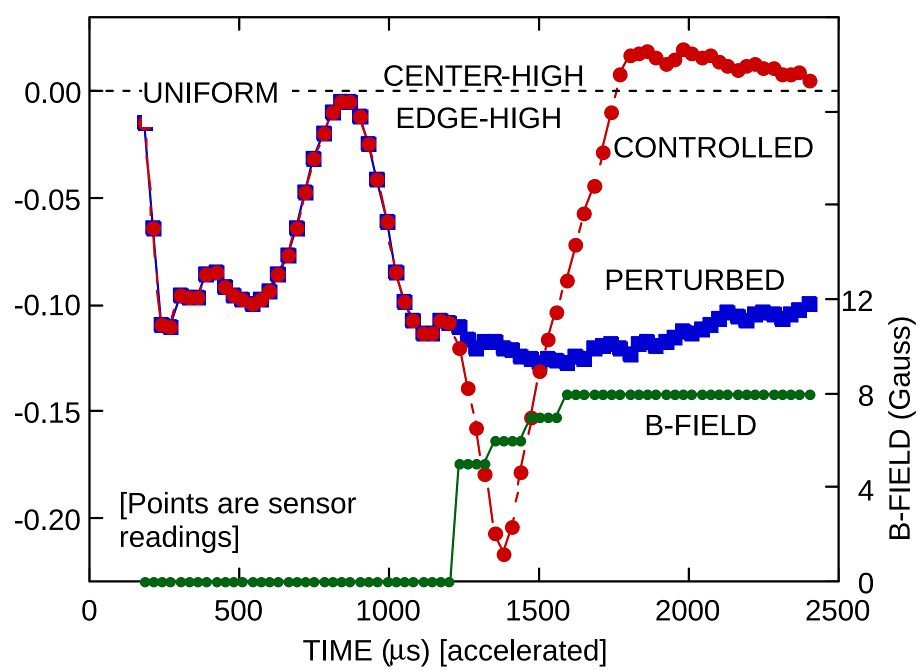
CONTROLLED ION FLUX MAGNITUDE AND UNIFORMITY

- **Using proportional controllers with moderately high gain (0.5), uniformity and ion flux are restored to their target values.**
- **The use of on-wafer sensors insures target values directly correlate with desired reactant properties.**



ION FLUENCE (10^{17}/s)



UNIFORMITY

- **Ar/Cl_2 = 50/50, 20 mTorr, 500 W, 200 sccm**

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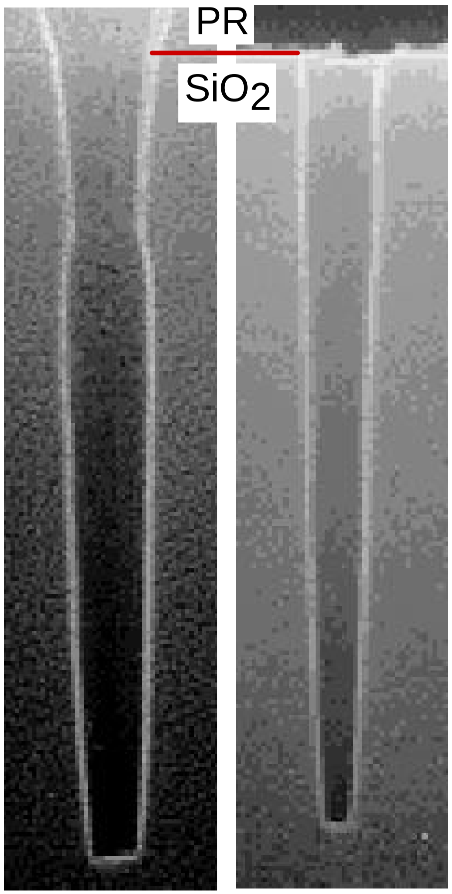
TAPERING AND BOWING OF PROFILES

- **Feature profiles in fluorocarbon plasma etching of SiO_2 often have bowed or tapered profiles.**



C Cui (AMAT)

- **Control of profile CD (and selectivity) ultimately depends on control of not only uniformity and magnitude of reactants, but also flux composition.**
- **For example, bowing and tapering have been correlated with the ratio of polymerizing radical fluxes to ion fluxes.**
- **On wafer measurements of species resolved, neutral and ion resolved fluxes are beyond the state of the art.**
- **However, innovating such sensors may be the key to maintaining CDs to 0.08 nm and beyond.**

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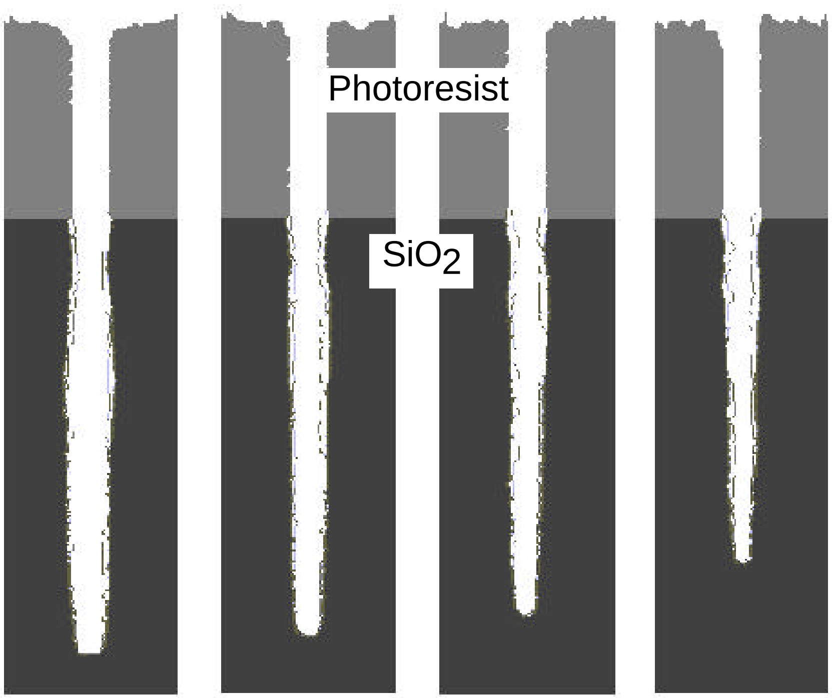
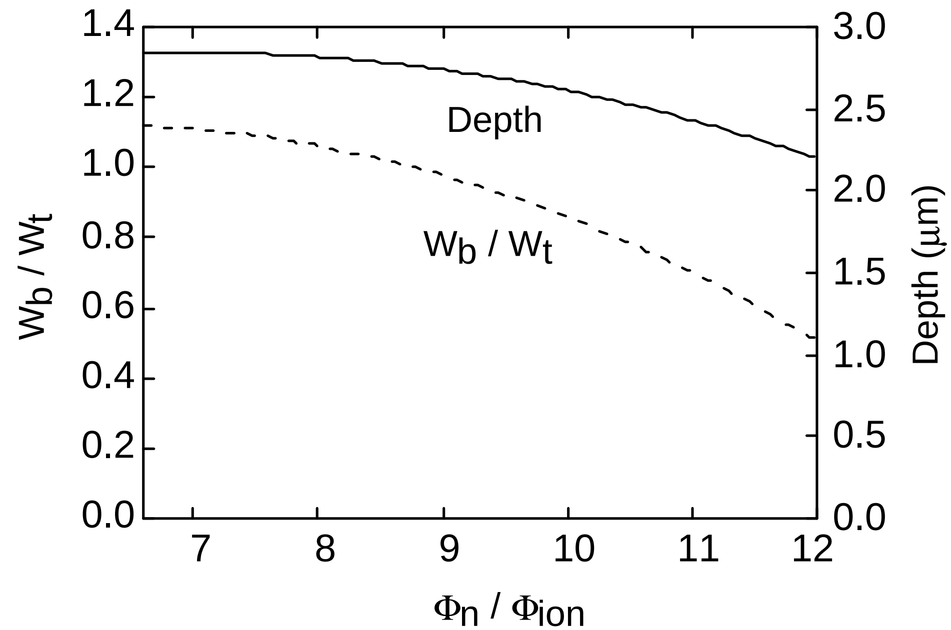
CORRELATION OF PROFILE WITH REACTANT FLUX RATIOS

- **Results from integrated plasma equipment and feature profile modeling have shown that SiO_2 feature profiles can be correlated with the ratio of the passivating neutral flux to the ion flux.**



Φ_n/Φ_{ion} = 6 8.4 10.2 12

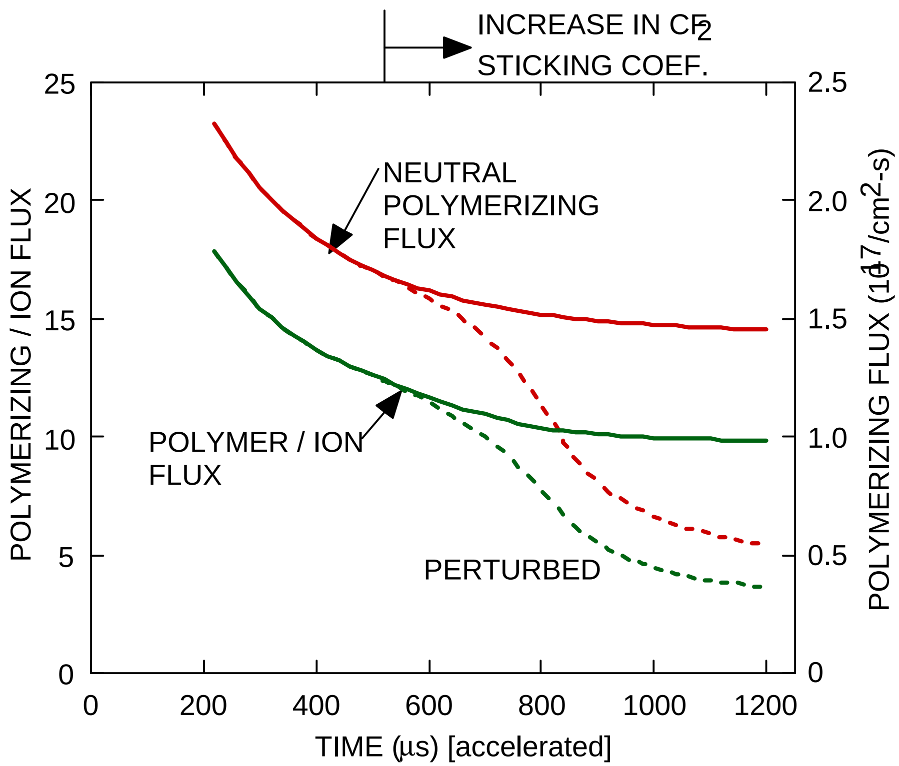


$\Phi_n\Phi/_{ion}$: Passivating Neutral/Ion flux **W_b/W_t: Bottom Width / Top Width**

- **Quantitative knowledge of these trends, coupled with measurement of composition of reactive flux, provide the means ot control profile CD.**

SMART WAFER: ION FLUX AND ION/NEUTRAL RATIO

- Intra-process seasoning of walls changing reactive sticking coefficients produces changes in both magnitudes and ratio of fluxes.
- Smart wafer techniques will be used to control changes in ion flux and neutral/ion flux ratio following a change in sticking coefficient for CF_2.

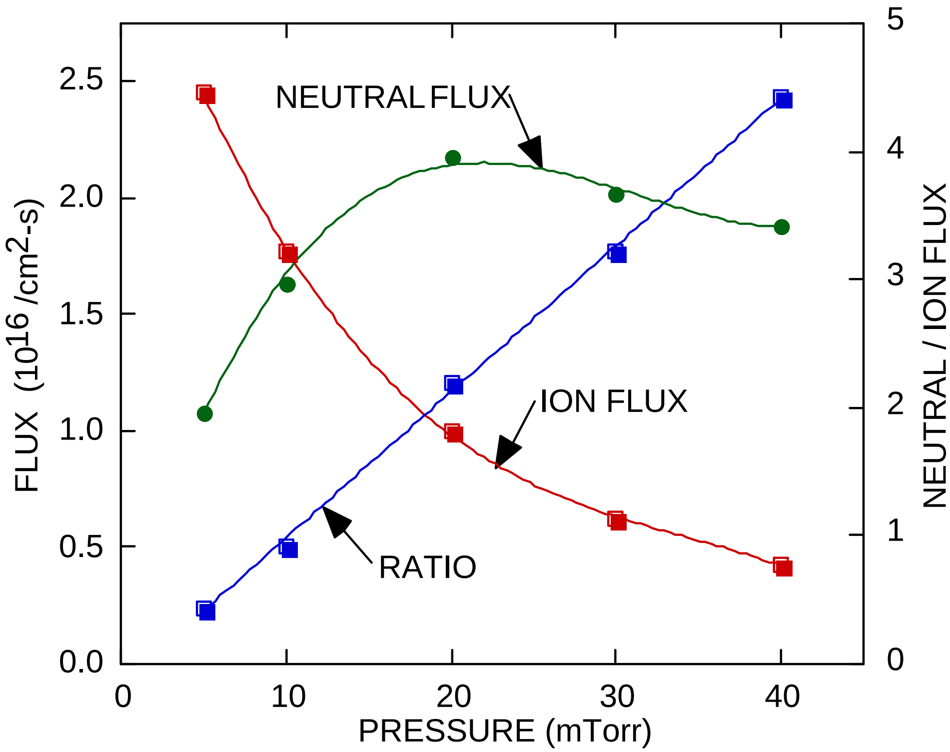


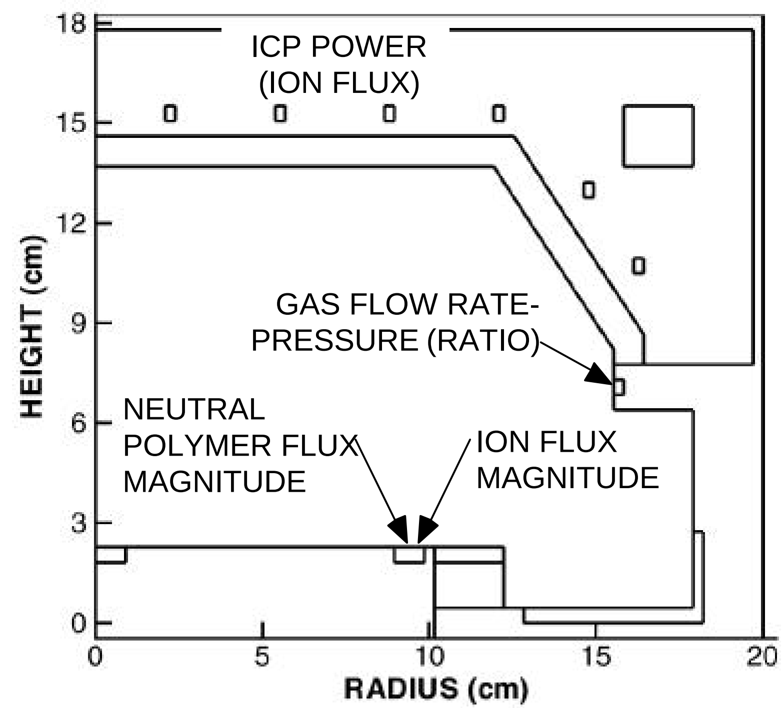
- An increase in CF_2 sticking coefficient on walls decreases the polymerizing flux (mostly CF_2 and CF).
- The ion flux remains nearly constant, producing a large decrease in the neutral/ion flux ratio.

- Ar/C_2F_6= 60/40, 15 mTorr, 500 W, 200 sccm

Ar/C_2F_6 ION FLUX AND NEUTRAL/ION RATIO vs PRESSURE

- **To determine process variables to control, computational (or experimental) DOEs are performed.**
- **Power (to control ion flux) and pressure (to control ineutral/ion flux ratio) are chosen.**





- **Ar/C_2F_6= 60/40, 500 W, 200 sccm**

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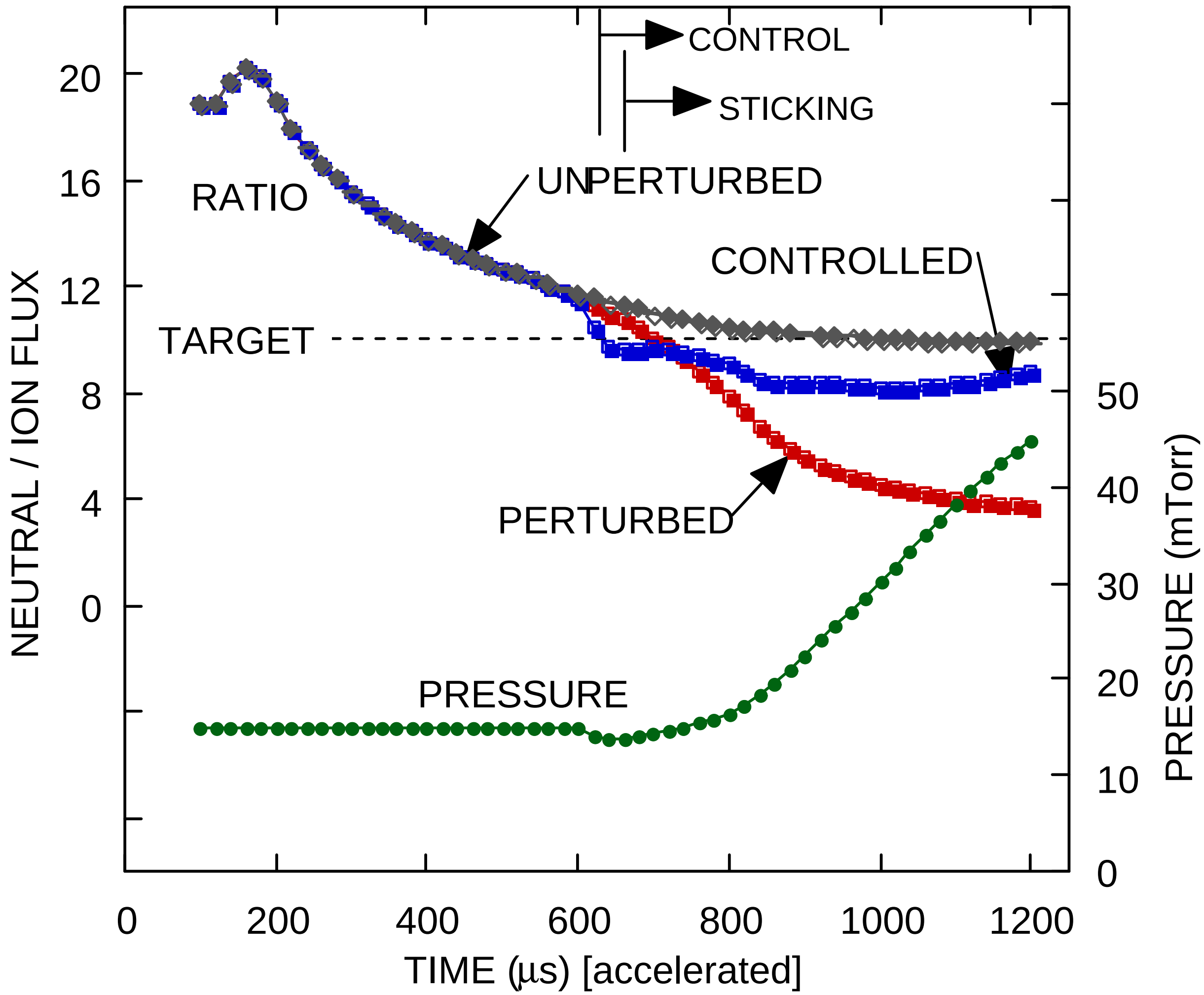
Ar/C_2F_6 NEUTRAL/ION RATIO CONTROLLED

- **Using power and pressure as actuators, the on wafer flux sensors direct increases in both values to maintain flux ratios and power constant.**



- **With on wafer sensors, profile CD control is directly correlated to measurements.**
- **Ar/C_2F_6= 60/40, 200 sccm**

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CONFLUENCE OF MICROELECTRONICS-AND-MEMS: SYSTEMS ON-A-CHIP

- **The plasma processing community has been slow to recognize and potential of combining microelectronics with MEMS to create systems-on-a-chip.**

- **The ITRS lists examples of future SOCs, and cites cost as the present limiting factor in developing such systems.**

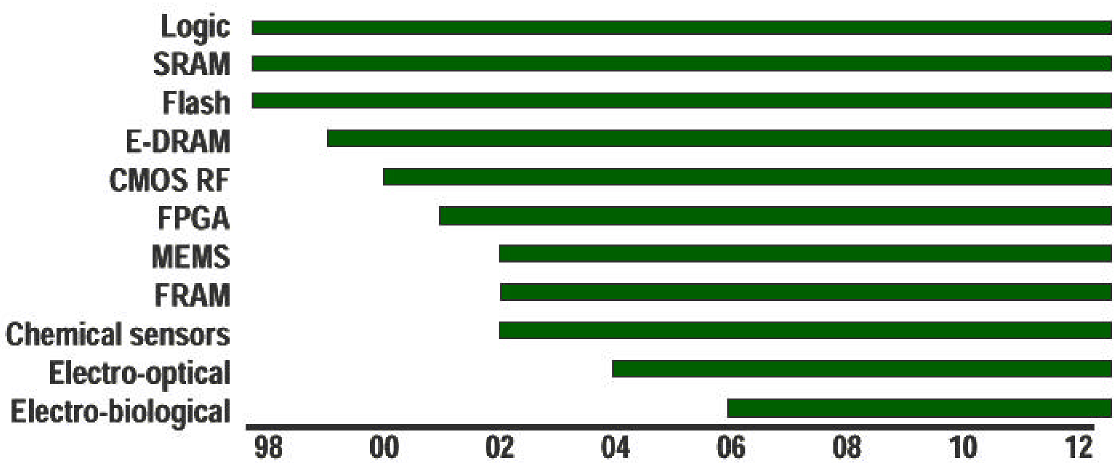
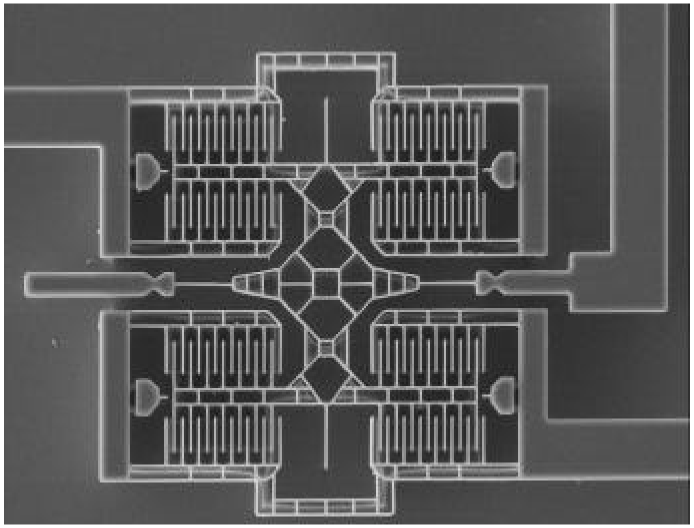


Figure 1 Technologies Integrated on SoC in the Standard CMOS Process

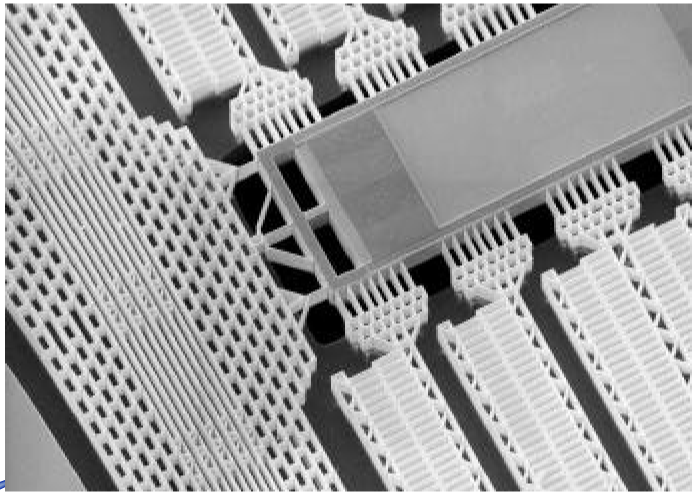
Int. Tech. Roadmap Semi.: System-on-Chip 1999

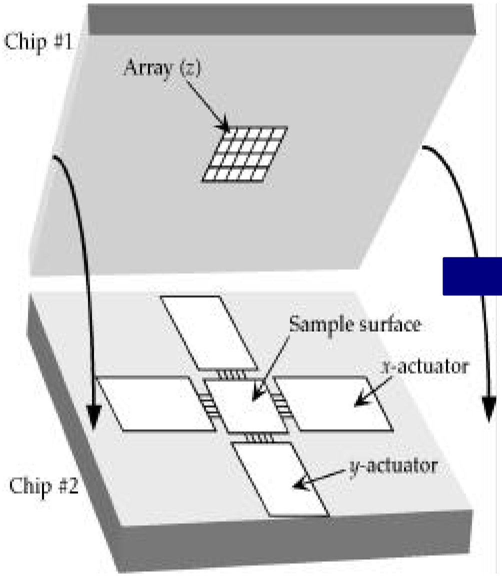
- **Never-the-less, market forces will drive this integration, and so the knowledge base to implement it should be addressed now.**

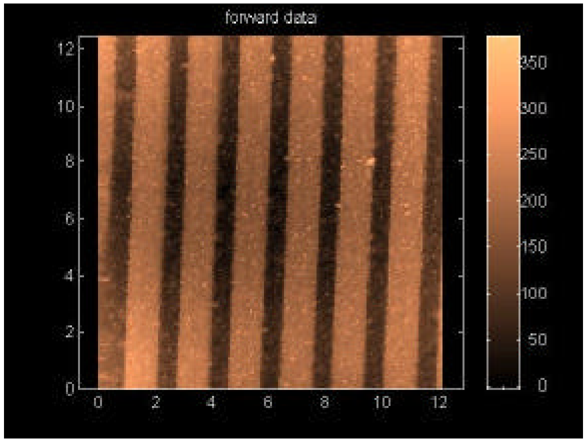
MEMS Actuators for Data Storage



Parallel atomic force imaging with MEMS to exceed densities of conventional magnetic and optical storage



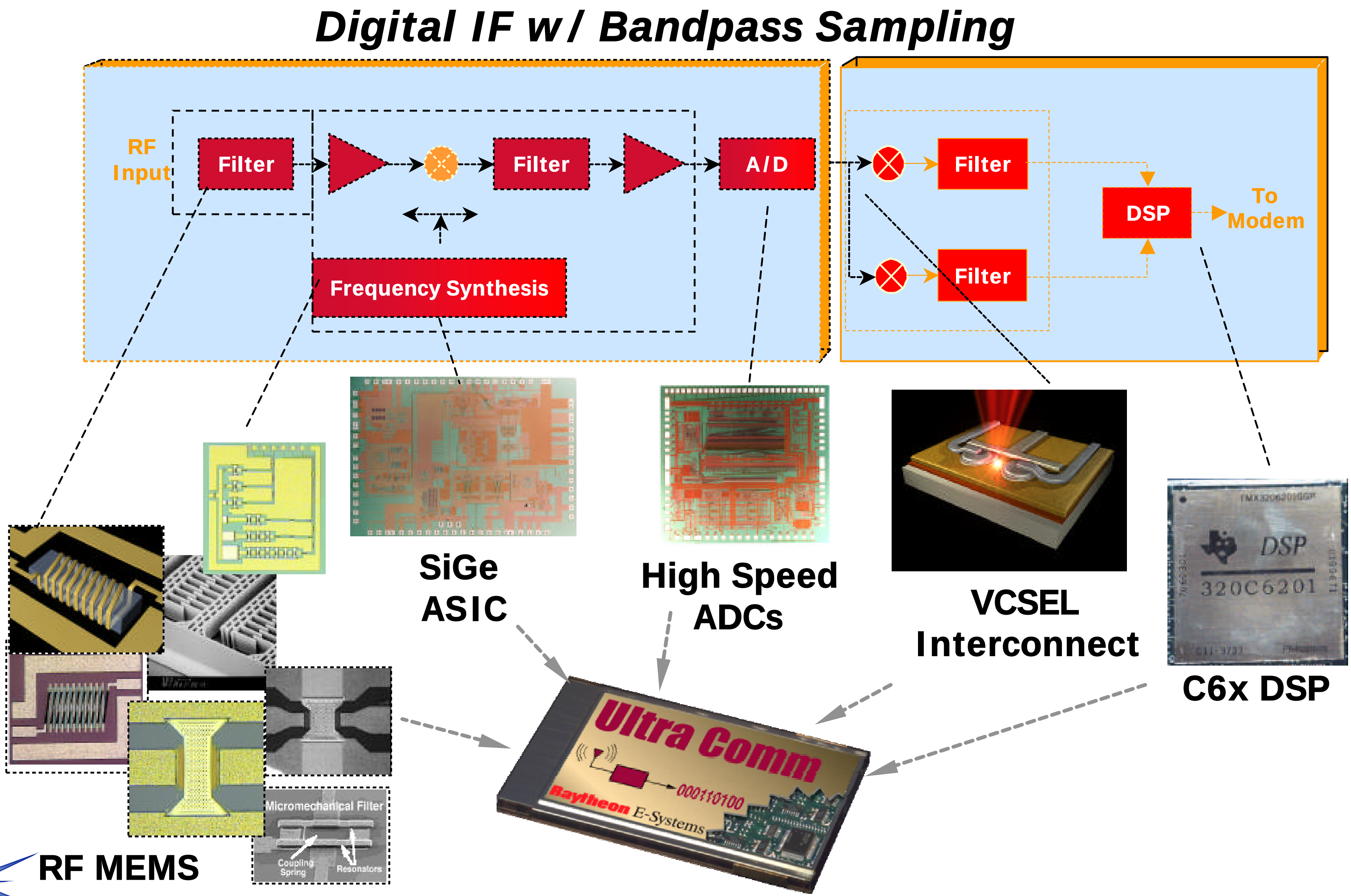




Areal density: 1-100 Gb/cm^2
Transfer Rates: 0.1-10 Mb/s
Size: 0.5 cm^3
Power consumption: <1W

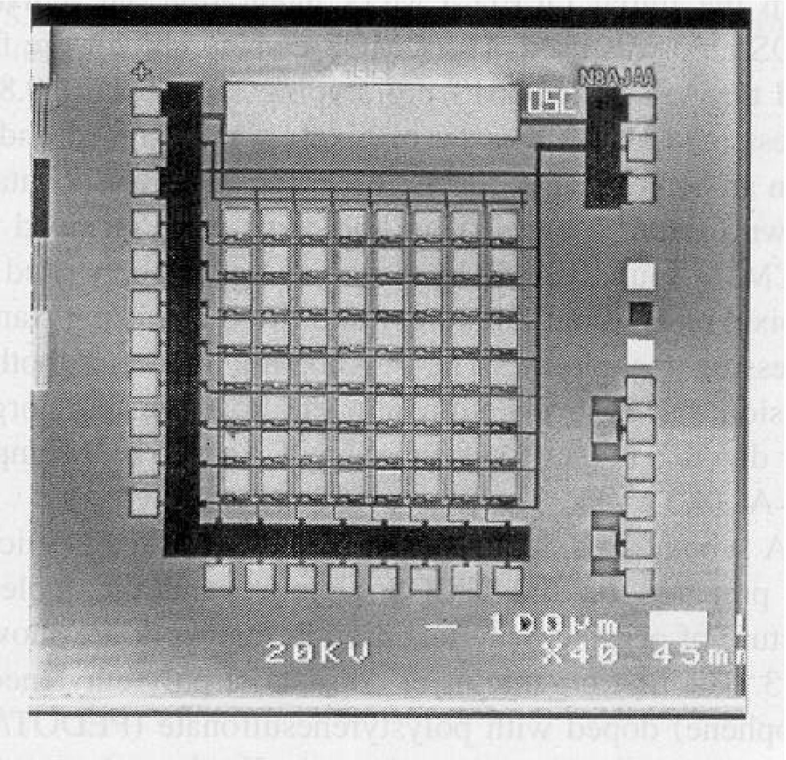
Kionix

Advanced Digital Receiver (ATO)

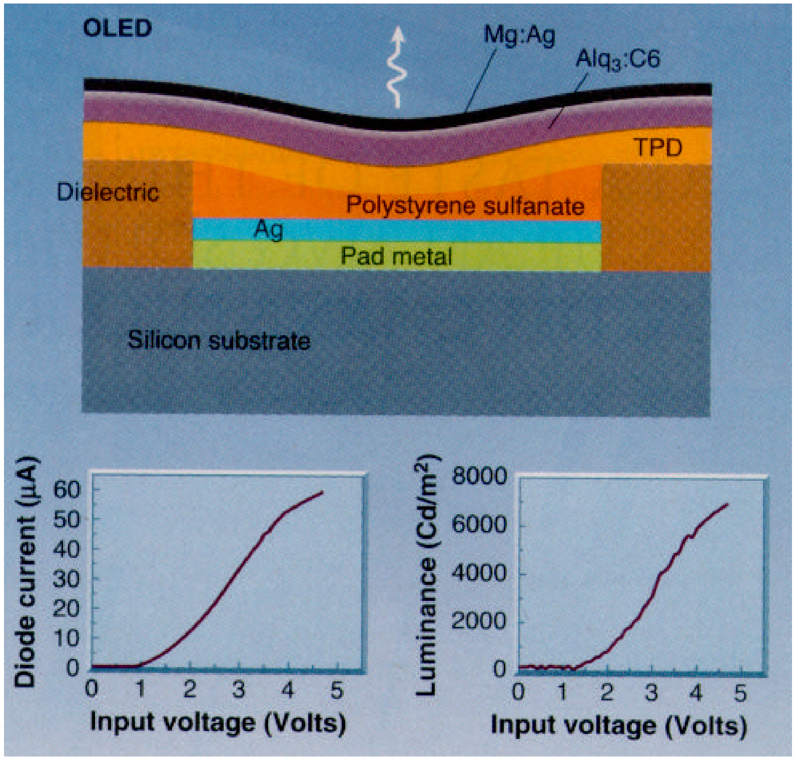


COMBINING ORGANIC LEDs WITH CMOS

- **Combining organic light-emitting-diodes with CMOS provides a means for Si-based optical interconnects for inter/intra-die communication.**



8 x 8 OLED with CMOS Circuitry



Laser Focus, September 2000, p.38

Heterogeneously integrated organic light-emitting diodes with complementary metal–oxide–silicon circuitry

D. L. Mathine,[a)] H. S. Woo, W. He, T. W. Kim,[b)] B. Kippelen, and N. Peyghambarian
Optical Sciences Center, University of Arizona, Tucson, Arizona 85721

APhL 76, 3849 (2000)

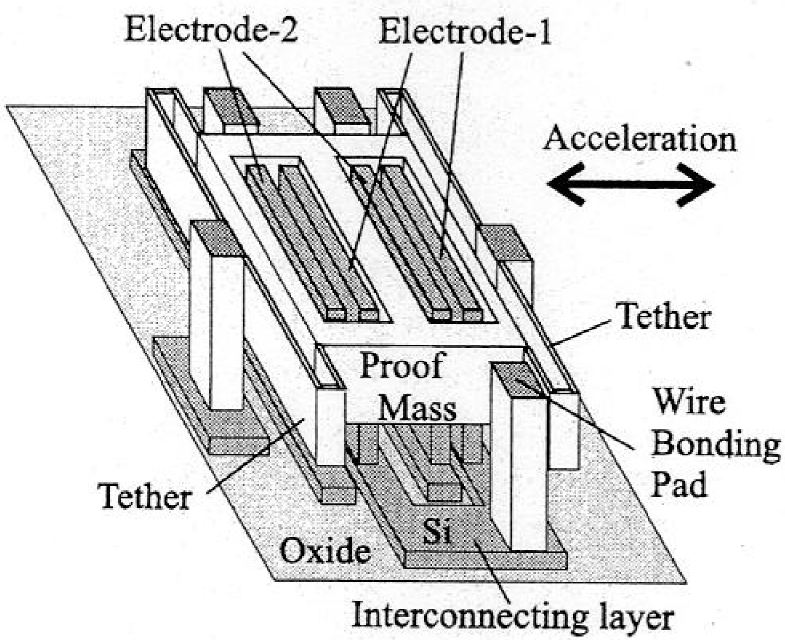
MEMS FABRICATION BRING NEW CHALLENGES

- **Although MEMS dimensions are now large by microelectronics standards, extreme aspect ratios push the state of the art. As MEMS dimensions shrink, these HAR features will rapidly exceed the state-of-the-art.**

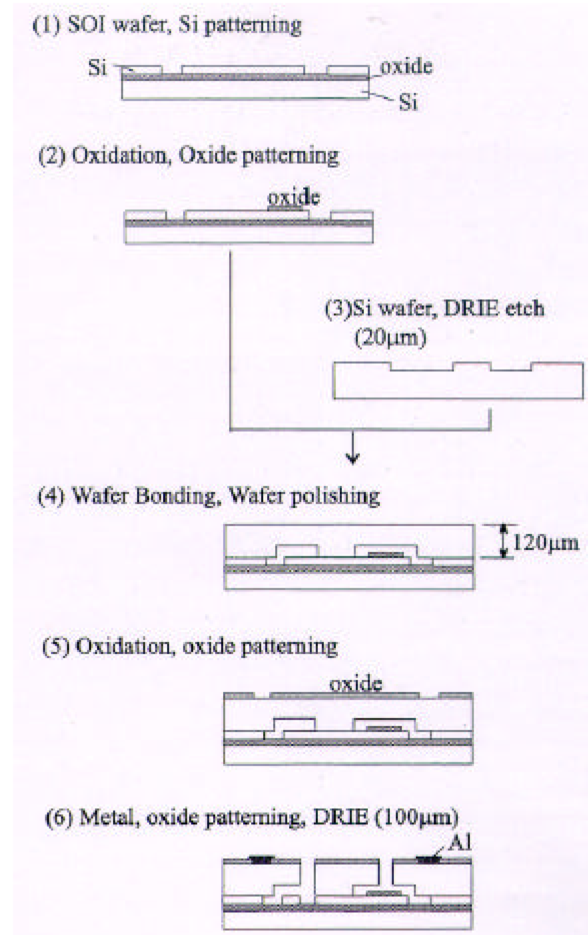
An Inertial Sensor Technology Using DRIE and Wafer Bonding with Interconnecting Capability

Kei Ishihara, Chi-Fan Yung, Arturo A. Ayón, *Member, IEEE,* and Martin A. Schmidt, *Member, IEEE*

J. MEMS 8, 403 (1999)



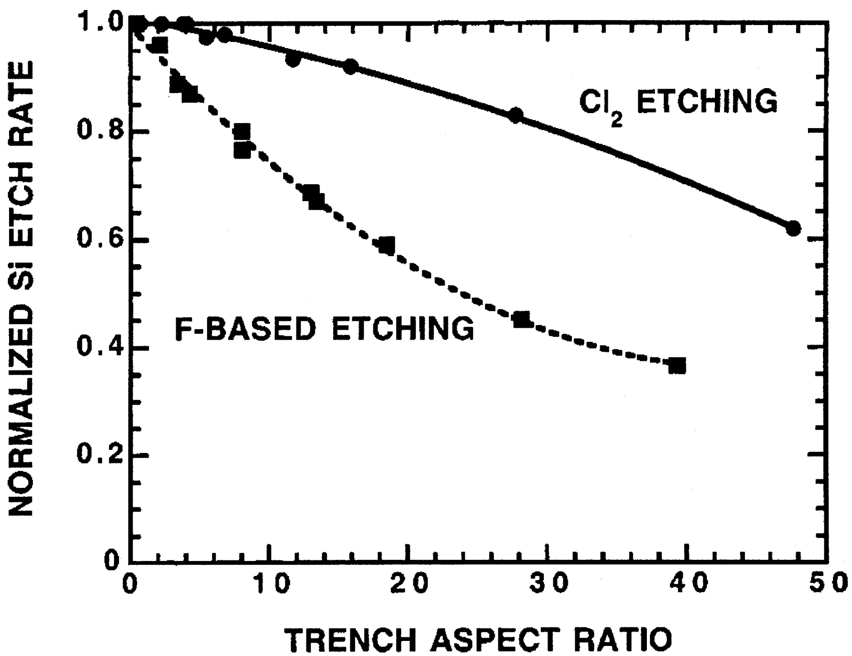
Accelerometer fabricated with Deep RIE

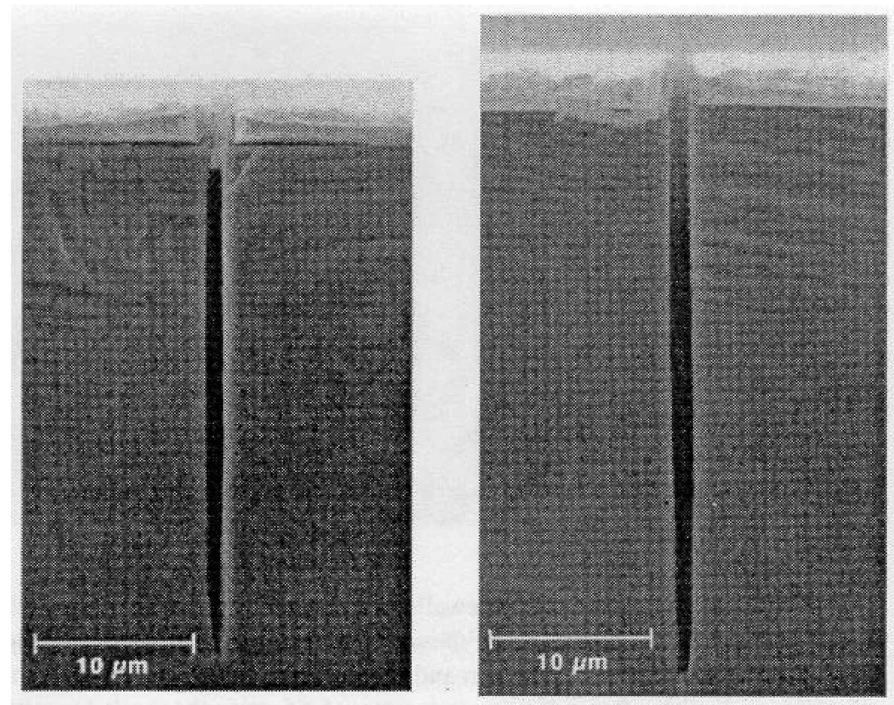


Comparison of Cl_2 and F-based dry etching for high aspect ratio Si microstructures etched with an inductively coupled plasma source

W. -C. Tian,[a] J. W. Weigold,[b] and S. W. Pang[c]
Department of Electrical Engineering and Computer Science, The University of Michigan, Ann Arbor, Michigan 48109-2122

JVST B <u>18</u>, 1890 (2000)





- **Extreme HAR etching using Cl_2 and SF_6/O_2 chemistries**

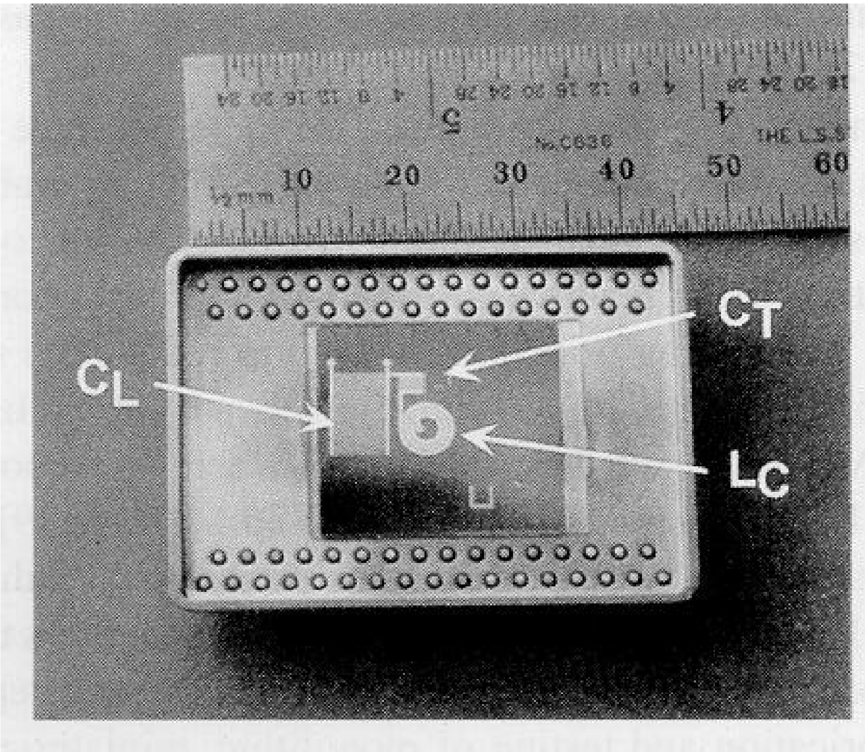
<u>(l) 5 hr Cl_2 ICP etch with (r) 10 min widening process</u>

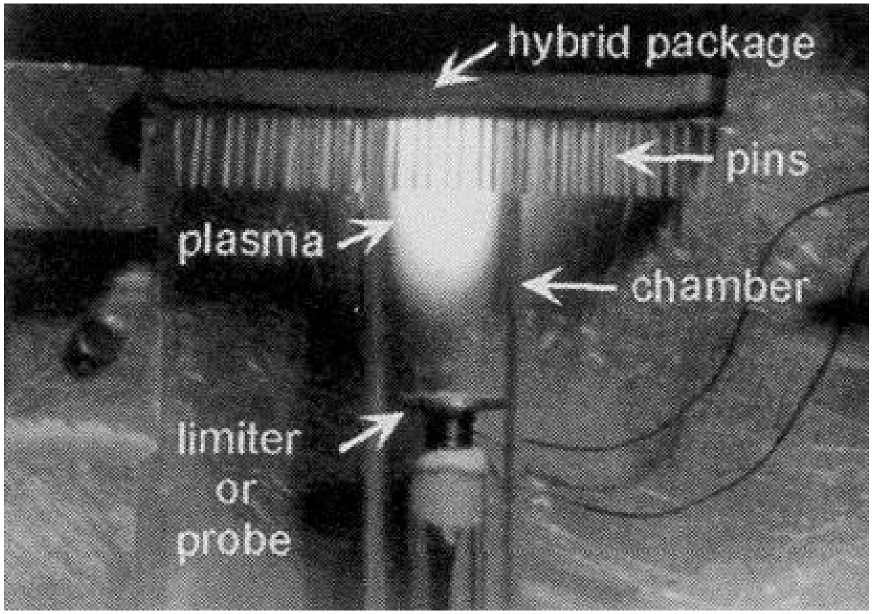
A Microfabricated Inductively Coupled Plasma Generator

J MEMS
9, 309 (2000)

Jeffrey A. Hopwood

- Innovative SAP tools may use real-time-control with sensor equipped smart wafers to guide arrays of plasma sources fabricated using MEMS techniques.





HUMAN RESOURCES: THE SOURCE OF INNOVATION

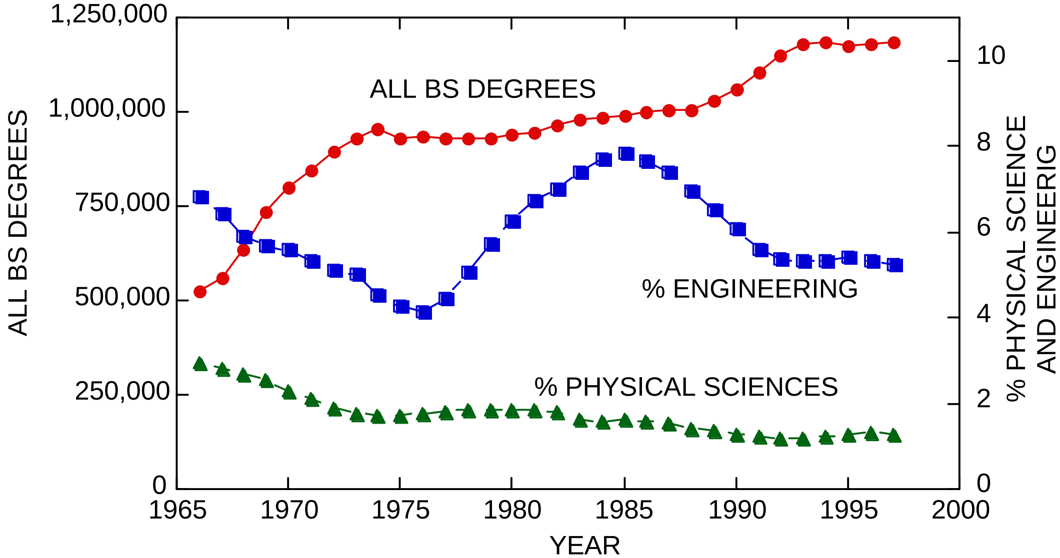
- **Ultimately, our ability to sustain innovation in our field relies on the talent of our human resources.**

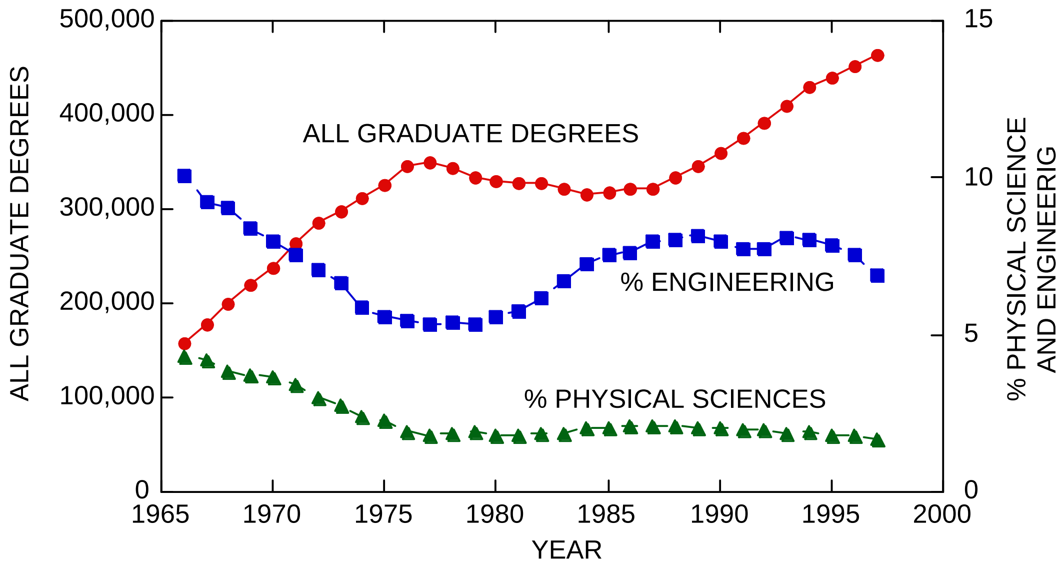
- **Our field is perhaps unique is that innovations are generally produced by broadly educated scientists and engineers, as opposed to narrowly defined specialists.**

- **As a result, the "yield" from science and engineering college graduates is typically not high.**

- **To maintain and increase our progress, we must continue to capture the best and brightest of our college graduates.**

HUMAN RESOURCES: THE SOURCE OF INNOVATION





- **Although the total number of BS and graduate degrees continues to increase, the fractions in Engineering and Physical Sciences are decreasing.**

<u>Ref:</u> NSF00-3100
S&E Degrees 1966-97

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AVS00_07

HUMAN RESOURCES: THE SOURCE OF INNOVATION

- Although a single field in a given industry cannot change reverse these trends, the health of our field requires pro-active measures on our parts.

  - Mentoring programs
  - University collaborations
  - Internships
  - Scholarships and Fellowships
  - Grammar and secondary school outreach.

- Student attitudes towards science and engineering, particularly for under-represented groups, are typically unchangeable after junior high. Outreach programs must also target these younger prospects.

GENERATING THE KNOWLEDGEBASE

- Generating the knowledge base required to fulfill this challenge is as large a challenge as implementing the solutions.
- Collaborations are clearly the most viable option to achieve these goals.
- Looking ahead 10 years, one must also reflect on how well industry wide collaborations have served us during the past 10 years.
- SRC, Sematech, DARPA, NSF Initiatives have all served in this capacity with varying degrees of success.
- The emphasis on pre-competitive, collaborative research (industry-university-national lab) has, however, declined of late. A reassessment of that strategy is necessary.

FOR MORE INFORMATION

- **Copy of today's presentation:**

  http://uigelz.ece.uiuc.edu $\rightarrow$ "Presentations" link at top of page

- **PS-TuM7 [next paper], R.L. Kinder, "Electron Transport and Power Deposition in Magnetically Enhanced Inductively Coupled Plasmas"**

- **PS2-ThA4, D. Zhang, "Reaction Mechanisms and SiO_2 Profile Evolution in Fluorocarbon Plasmas: Bowing and Tapering"**

- **PS1+MS-WeA7, E.A. Edelberg, "Productivity Solutions for Eliminating Within-Wafer and Wafer-to-Wafer Variability in a Silicon Etch Process through Plasma and Surface Diagnostics"**

- **PS2-ThM8, M.J. Sowa, "Electron Temperature and Ion Energy Measurements with A High-resolution, Sub-micron, Retarding Field Analyzer"**

- **PS2-TuA2, H. Singh, "Comprehensive Measurements of Neutral and Ion Number Densities, Neutral Temperature, and EEDF in a CF_4 ICP"**