Work on RF plasma reactors at CRPP Lausanne

Alan Howling

Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland

Center for Research in Plasma Physics (CRPP)

start by acknowledging:

Christoph Hollenstein, Laurent Sansonnens

also

Ulrich Kroll, Jacques Schmitt, Benjamin Strahm etc

Note: CRPP is a thermonuclear fusion research institute:

120 people on tokakmak TCV

< 10 people on plasma industrial applications

short CV, then relevant papers in chronological order

- Degree in physics 1979 - 1981
- Masters in Electric Plasmas 1981 - 1982
- PhD "Edge Plasma in TOSCA Tokamak" 1982 - 1985

} Oxford University, England

- Post-doc: RF heating on TCA Tokamak 1986 - 1989
- Start group with Dr. Ch. Hollenstein on

Plasma Industrial Applications 1990 - 2010

} Ecole Polytechnique Federale, Lausanne Switzerland

one specific example: Balzers Displays
Unaxis Displays
Unaxis Solar
OC Oerlikon Solar-Lab
etc

Direct visual observation of powder dynamics in rf plasma-assisted deposition

A. A. Howling, Ch. Hollenstein, and P.-J. Paris

Appl. Phys. Lett. **59** 1409 (1991)

white light illumination of powder in silane plasma

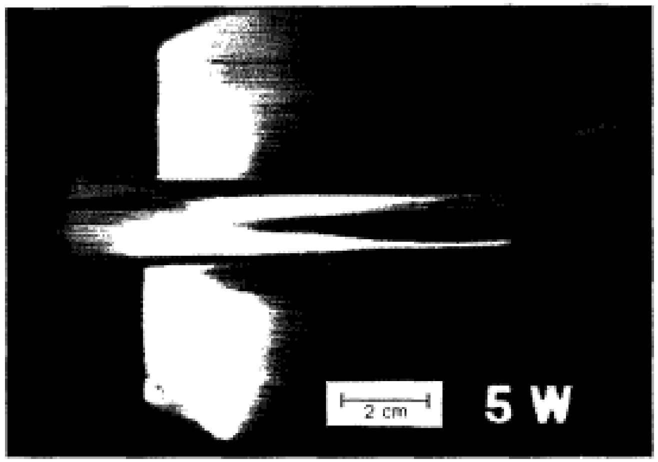
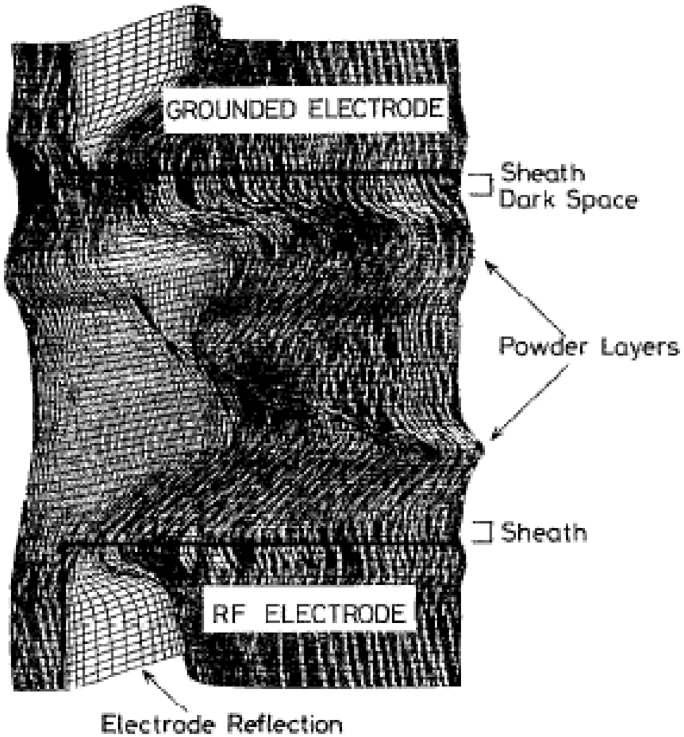
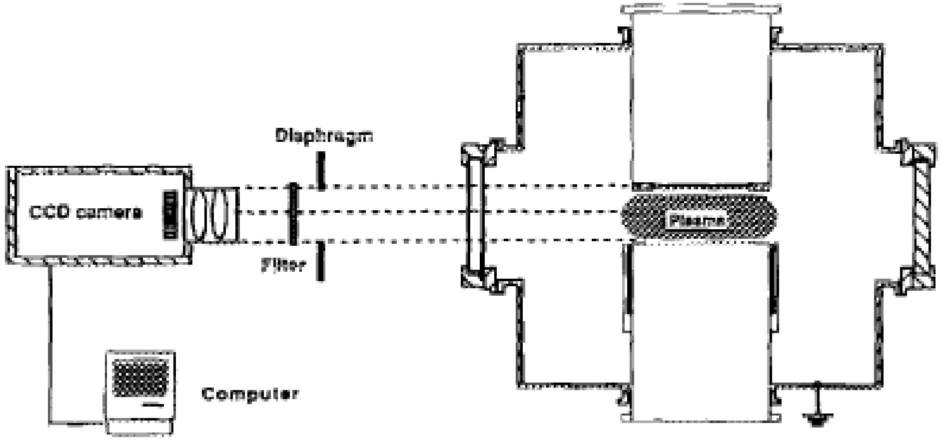


FIG. 1. Video image of an illuminated plasma with a 30 sccm flow of silane at 0.3 mbar, 5 W, 60 MHz, electrode temperature 300 K. The viewing angle obscures the right-hand electrode edge. The stationary powder layers are indistinguishable without illumination.





Frequency effects in silane plasmas for plasma enhanced chemical vapor deposition

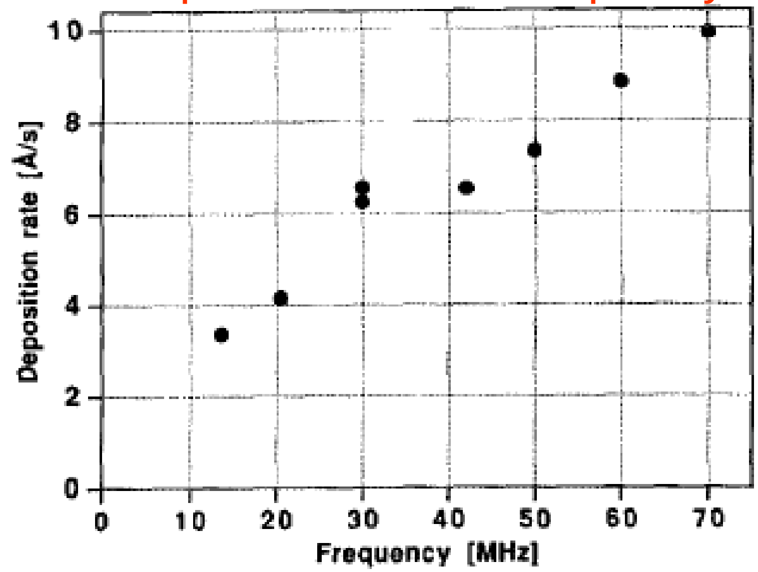
A. A. Howling, J.-L. Dorier, and Ch. Hollenstein
CRPP/EPFL, 21 Av. des Bains CH-1007 Lausanne, Switzerland

U. Kroll
IMT, 2 Rue Breguet, CH-2000 Neuchatel, Switzerland

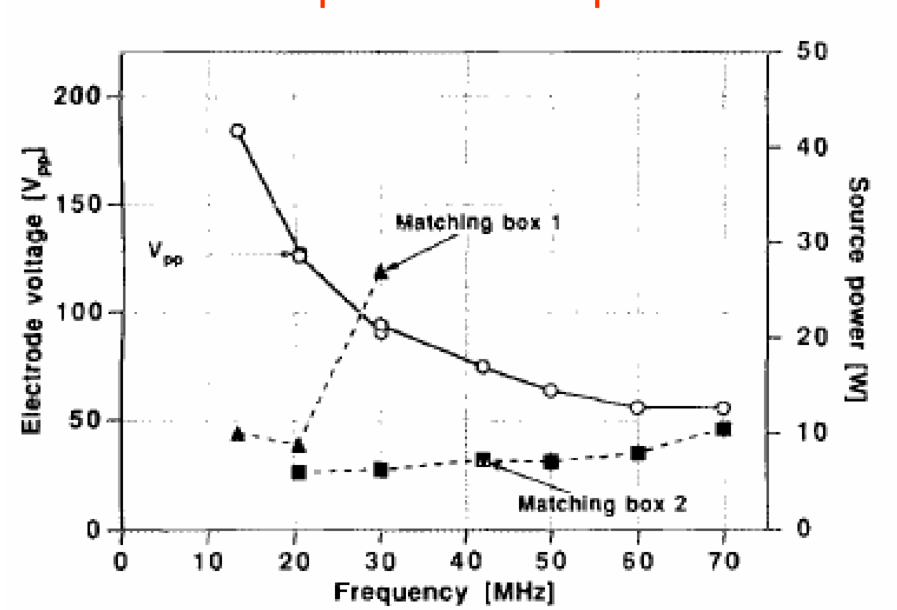
F. Finger
Forschungszentrum Jülich, D-5170 Jülich, Germany

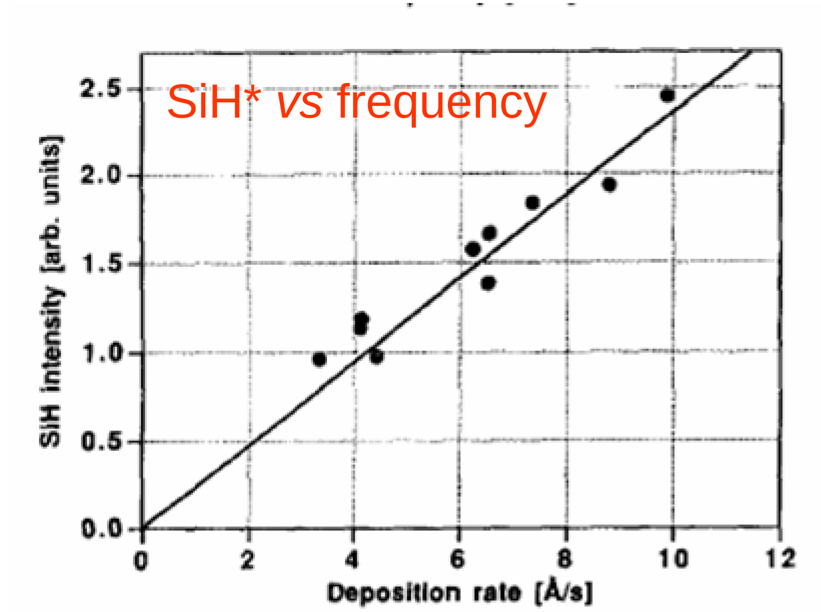
J. Vac. Sci. Technol. **A10** 1080 (1992)

deposition rate *vs* frequency



constant power in the plasma

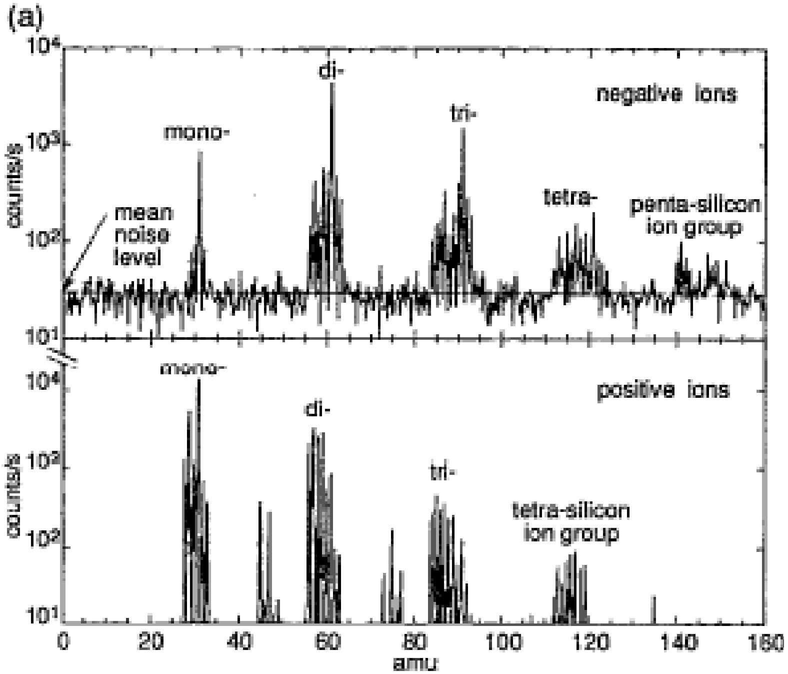


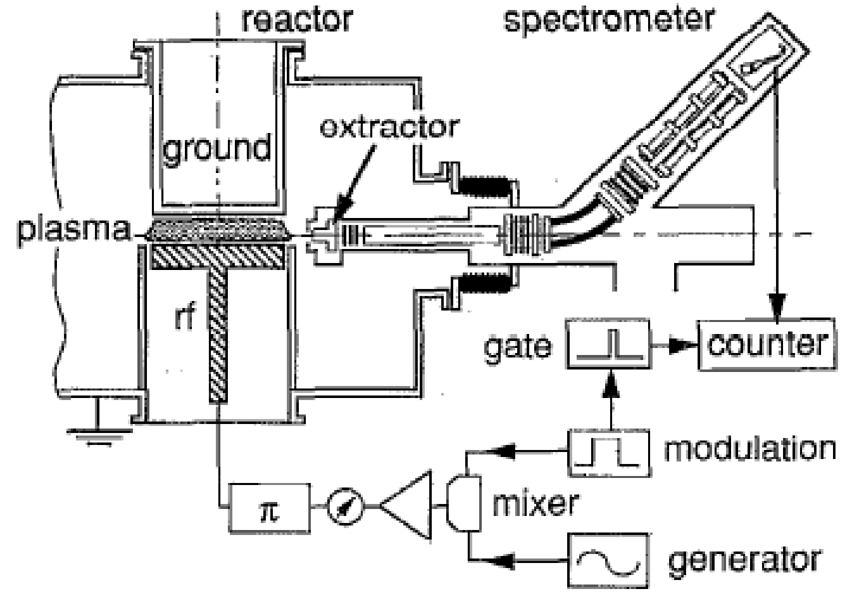


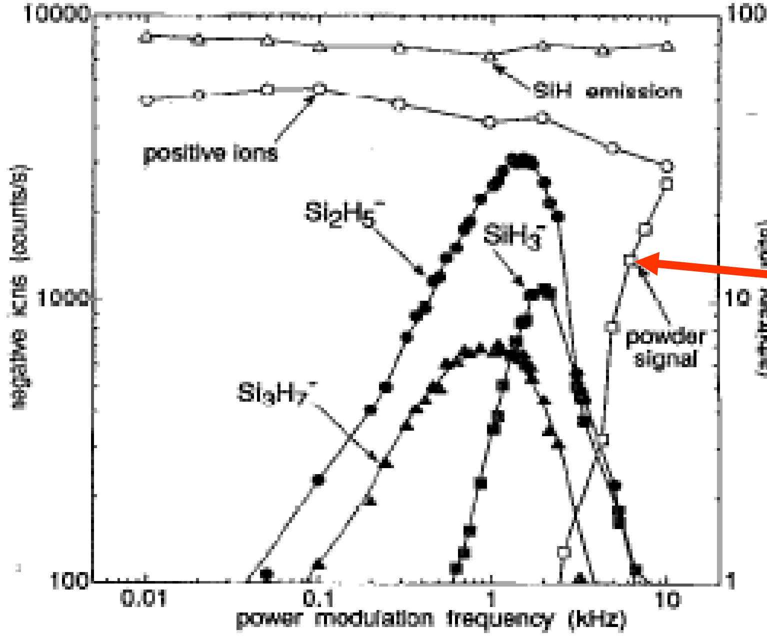
Negative ion mass spectra and particulate formation in radio frequency silane plasma deposition experiments

A. A. Howling, J.-L. Dorier, and Ch. Hollenstein

Appl. Phys. Lett. **62** 1341 (1993)







power modulation effect on powder

negative ion signal
vs
modulation frequency

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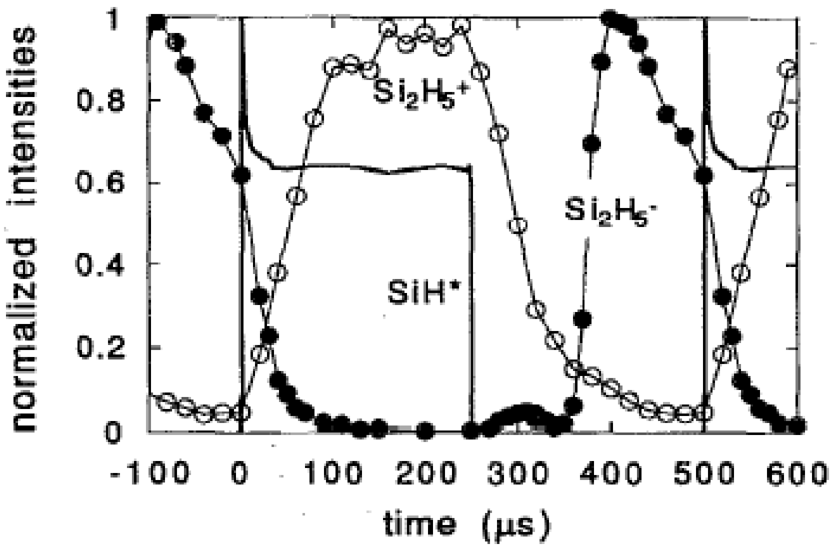
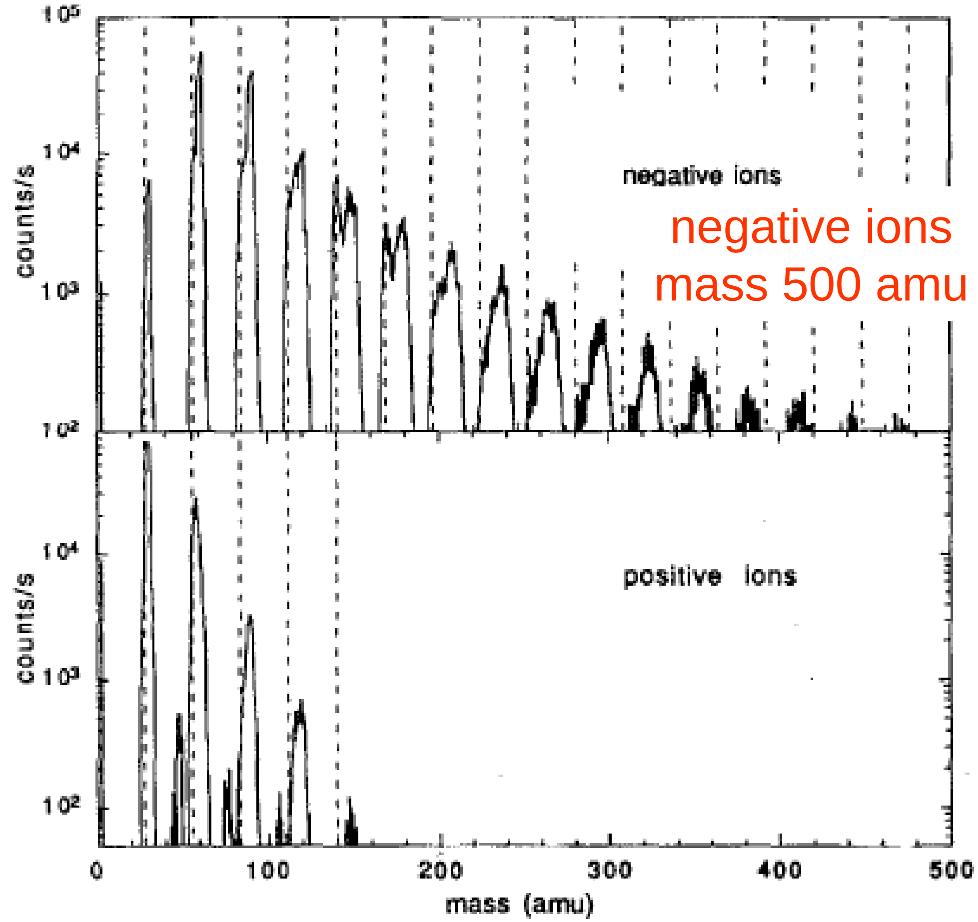
Time-resolved measurements of highly polymerized negative ions in radio frequency silane plasma deposition experiments

A. A. Howling, L. Sansonnens, J.-L. Dorier, and Ch. Hollenstein

J. Appl. Phys. **75** 1340 (1994)

positive and negative ions
vs
time in on-off plasma



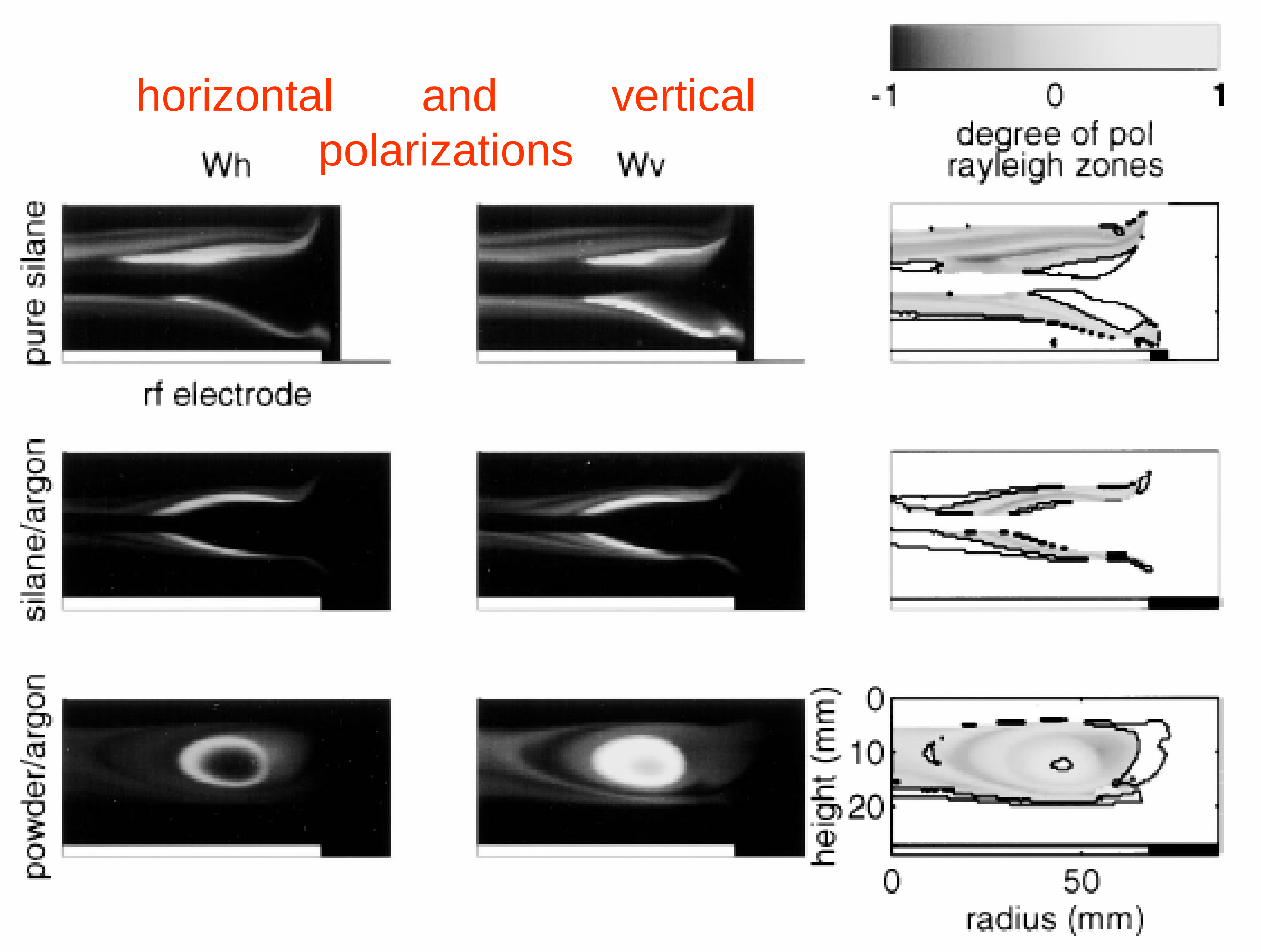


negative ions
mass 500 amu

Spatiotemporal powder formation and trapping in radio frequency silane plasmas using two-dimensional polarization-sensitive laser scattering

J.-L. Dorier, Ch. Hollenstein, and A. A. Howling

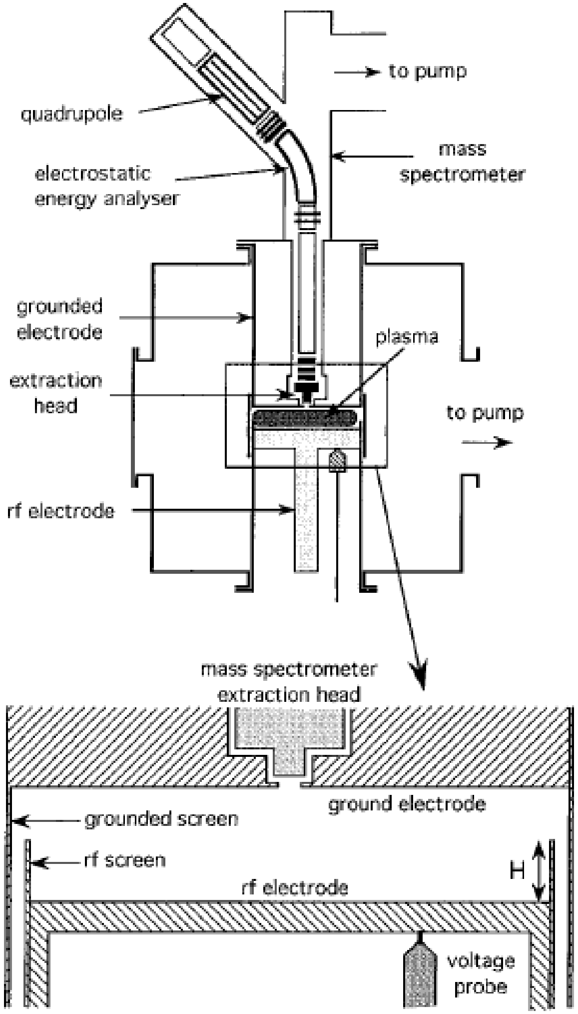
J. Vac. Sci. Technol. **A13** 918 (1995)



Reconstruction of the time-averaged sheath potential profile in an argon radiofrequency plasma using the ion energy distribution

M Fivaz, S Brunner, W Schwarzenbach, A A Howling and Ch Hollenstein

Plasma Sources Sci. Technol. **4** (1995) 373–378.



resonance: charge exchange collisions and RF period

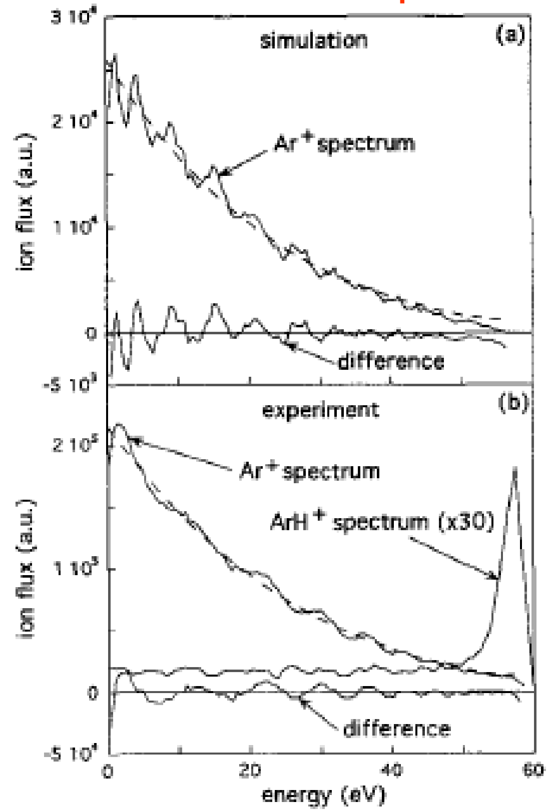


Figure 2. Energy distribution of the argon ion flux at the ground electrode: (*a*) by PIC simulation; and (*b*) as measured experimentally. The broken curves show a nonlinear least-squares fit using equation (1) to each energy distribution, for which $x_s/\lambda = 5.8$ and 5.5 for (*a*) and (*b*) respectively. The peaks are clearly shown by the difference of the energy distribution and the corresponding fitted curve in (*a*) and (*b*). The measured ArH$^+$ energy spectrum (multiplied by a factor 30) is also shown in (*b*). Excitation frequency 25 MHz, for 3 W power in the plasma.

measure parabolic sheath potential

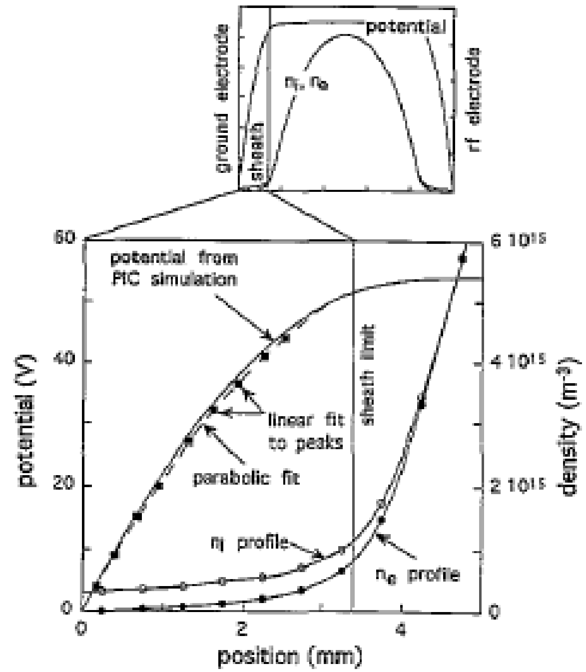
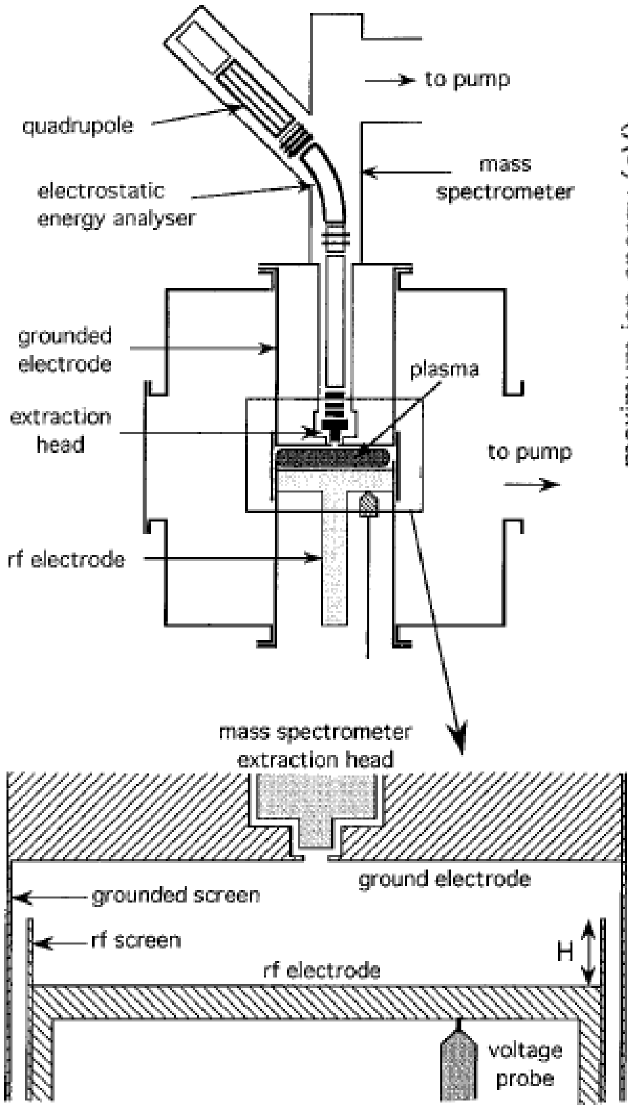


Figure 4. Time-averaged profiles from PIC simulation. The potential profile given by the simulation is shown by the full curve. The linear piecewise reconstruction from the peaks in the simulation ion energy spectrum is represented by the square dots. The parabolic reconstruction is shown by the broken curve. The ion and electron density profiles n_i and n_e are commented upon in section 3.4. Excitation frequency 25 MHz, for 3 W power in the plasma.

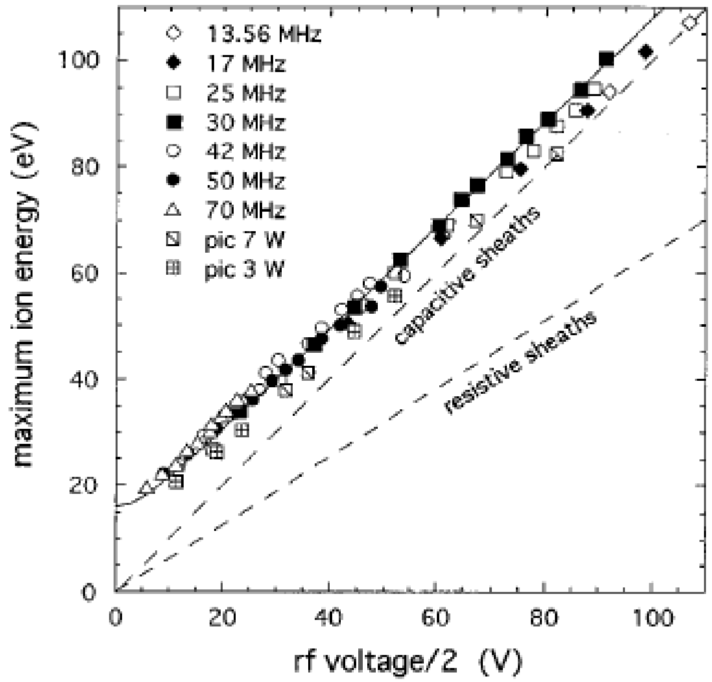
Sheath impedance effects in very high frequency plasma experiments

W. Schwarzenbach, A. A. Howling,[a)] M. Fivaz, S. Brunner, and Ch. Hollenstein

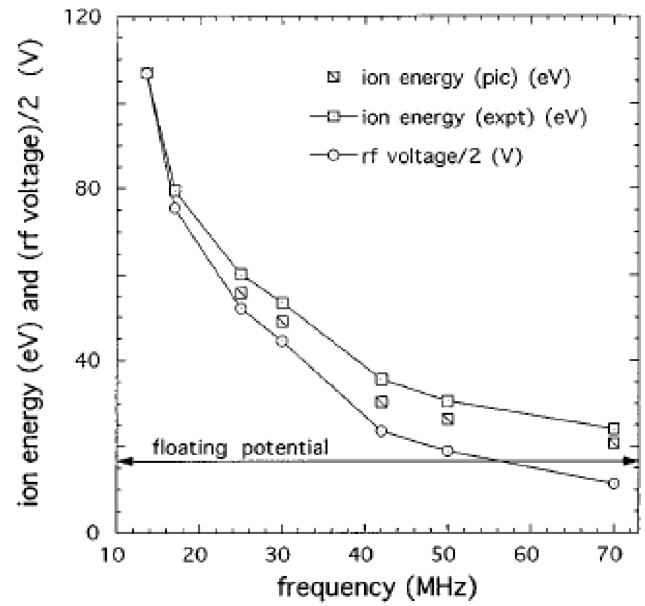
J. Vac. Sci. Technol. **A14** 132 (1996)



adjust for zero
self-bias



ion energy decrease
with frequency in a
symmetric reactor

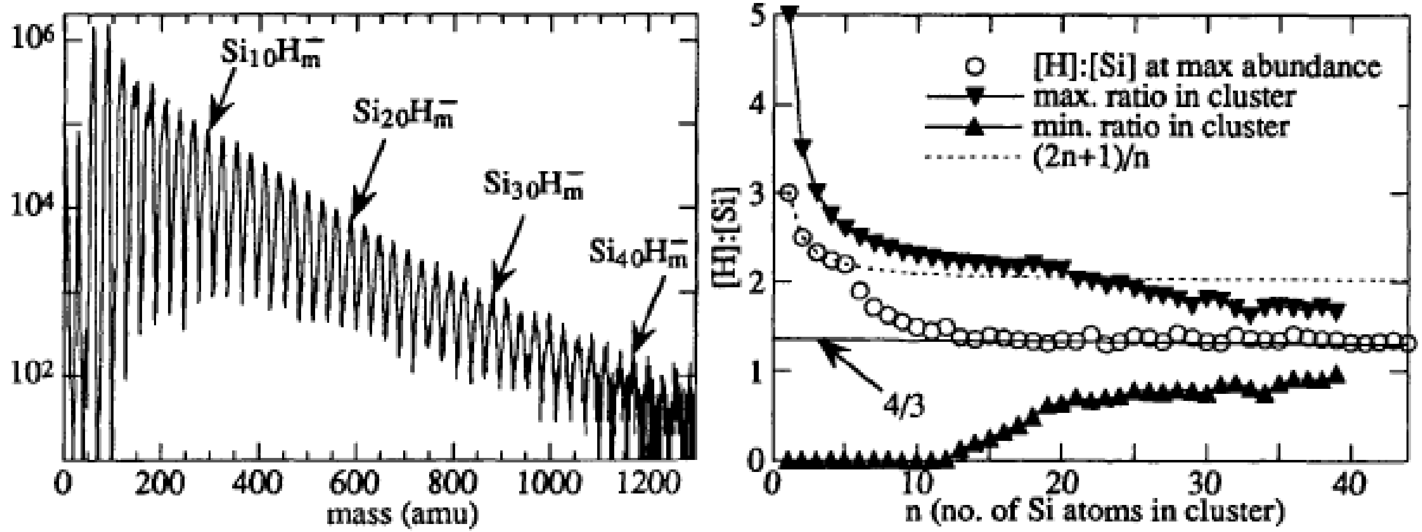


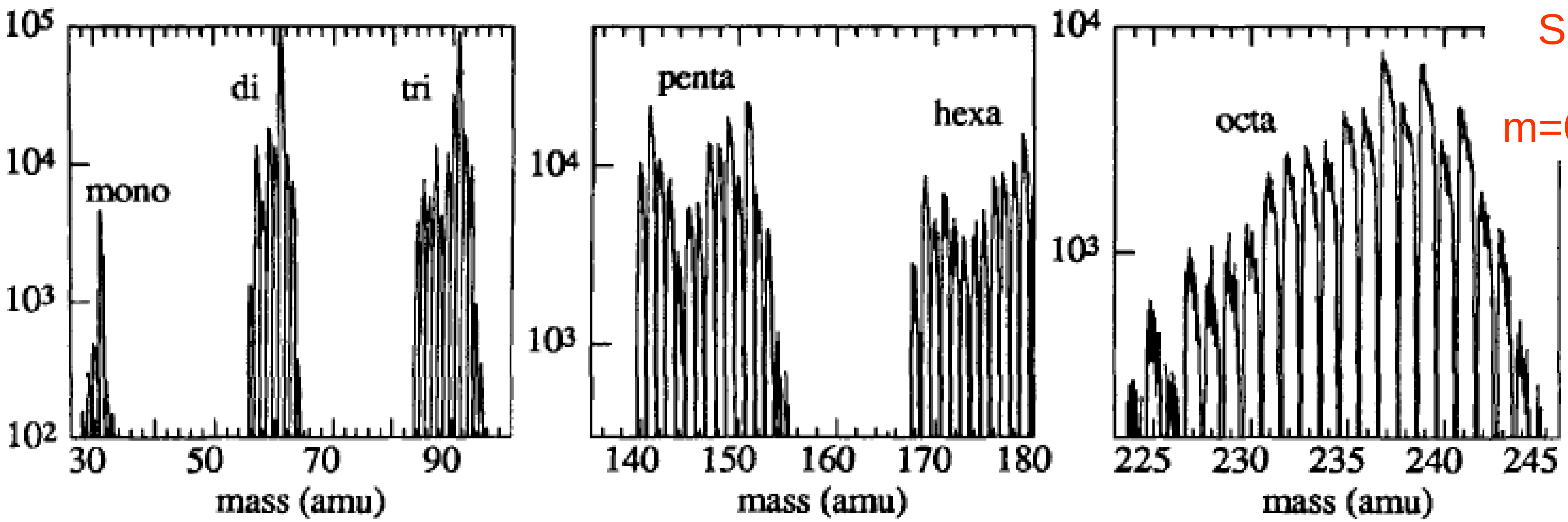
From molecules to particles in silane plasmas

Pure & Appl. Chem., Vol. 68, No. 5, pp. 1017–1022, 1996.

A. A. Howling, C. Courteille, J.-L. Dorier, L. Sansonnens, and Ch. Hollenstein

negative ions
mass 1200 amu





$Si_8H_m^-$

m=0 to 22

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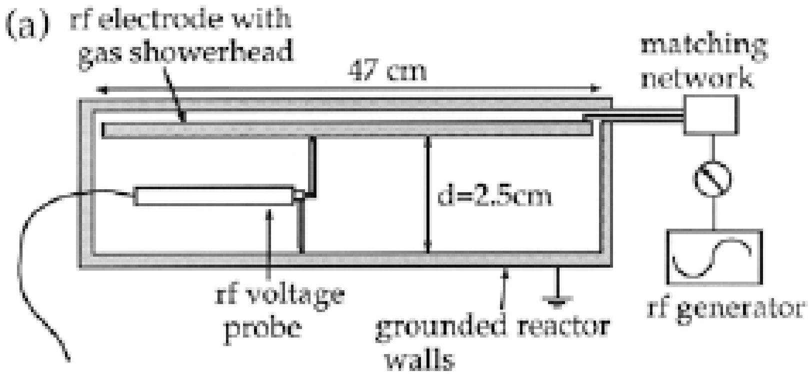
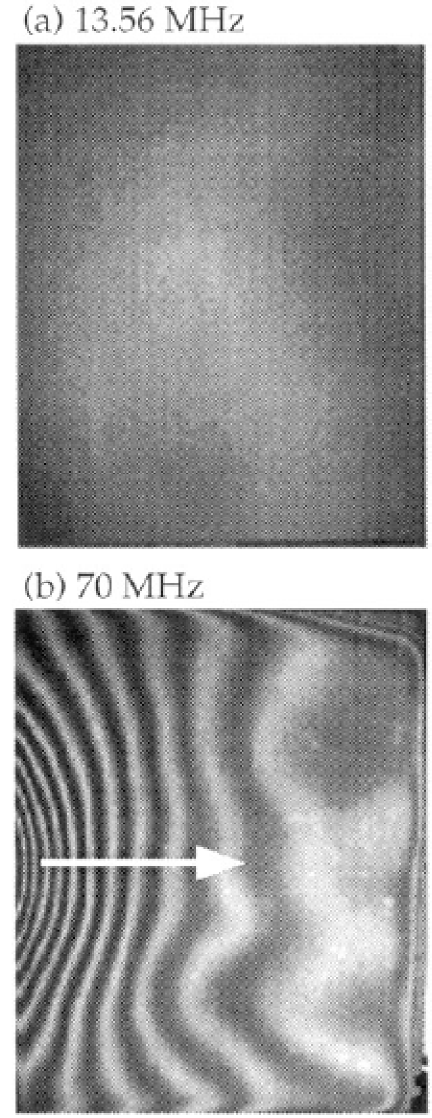
A voltage uniformity study in large-area reactors for RF plasma deposition

L Sansonnens†‖, A Pletzer†‡, D Magni†, A A Howling†, Ch Hollenstein† and J P M Schmitt§

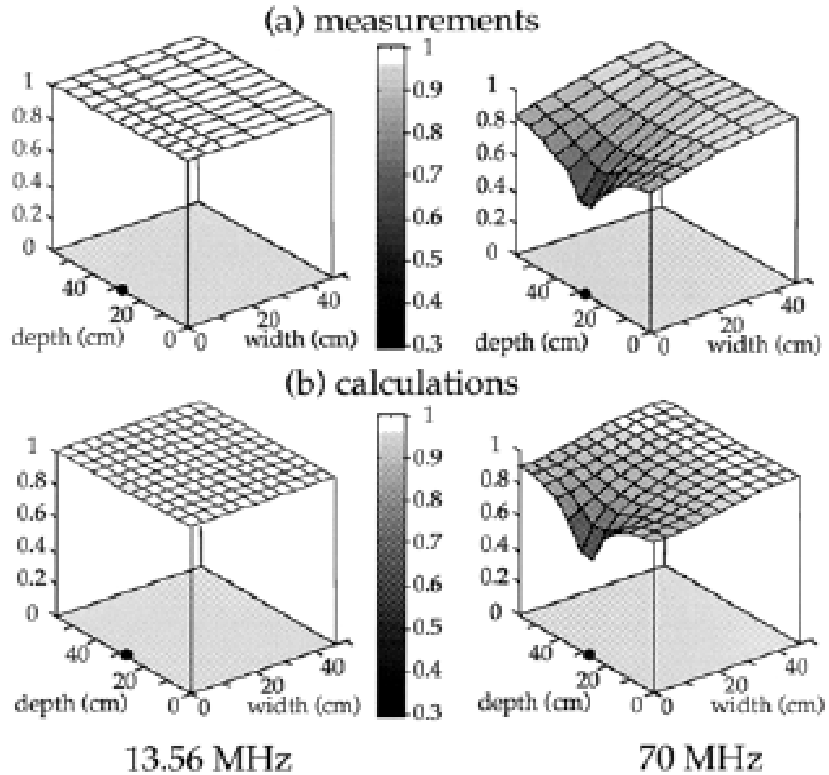
Plasma Sources Sci. Technol. 6 (1997) 170–178.



thin film interferograms (37 cm x 47 cm substrate)



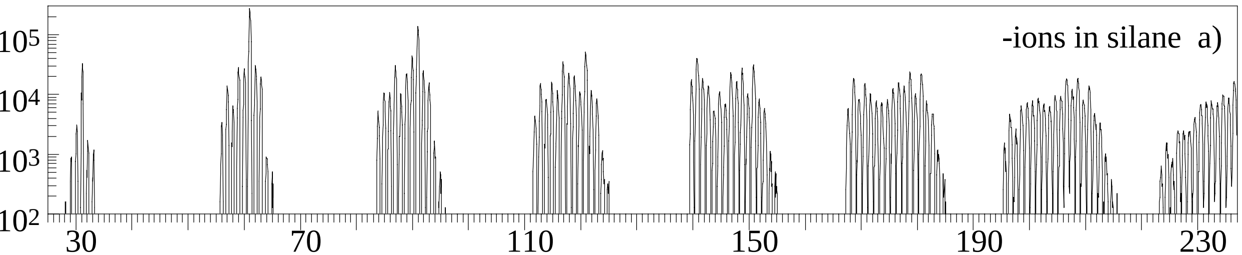
Green's function model with numerical calculation for voltage distribution in vacuum



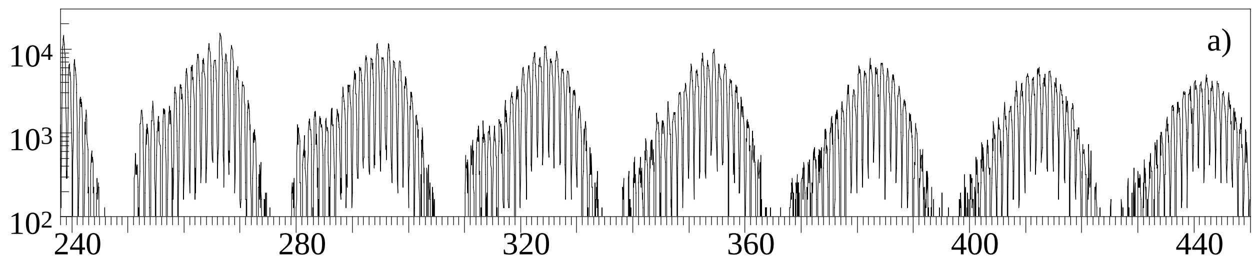
DUST PARTICLE DIAGNOSTICS IN RF PLASMA DEPOSITION OF SILICON AND SILICON OXIDE FILMS

Ch. HOLLENSTEIN, A. A. HOWLING, C. COURTEILLE,
J.-L. DORIER, L. SANSONNENS, D. MAGNI and H. MÜLLER

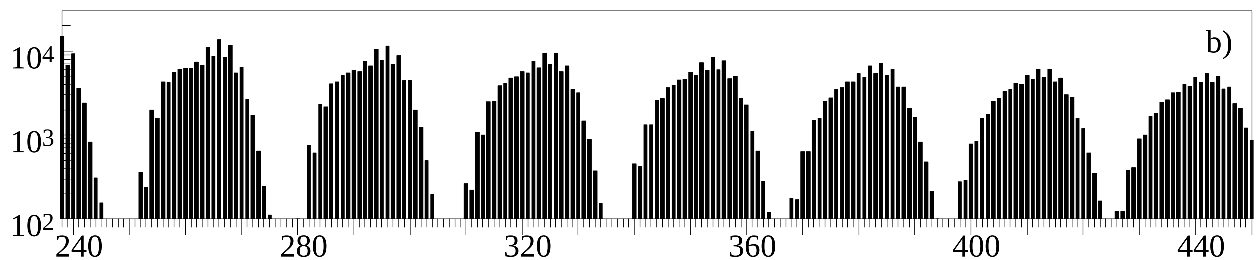
MRS Symp. Proc. Vol. 507 Amorphous and Microcrystalline Silicon Technology, pp547-557 (1998).



negative ion measurement



negative ion model with simple reaction sequence (elimination of H_2 and $2H_2$ in ratio 2:1)



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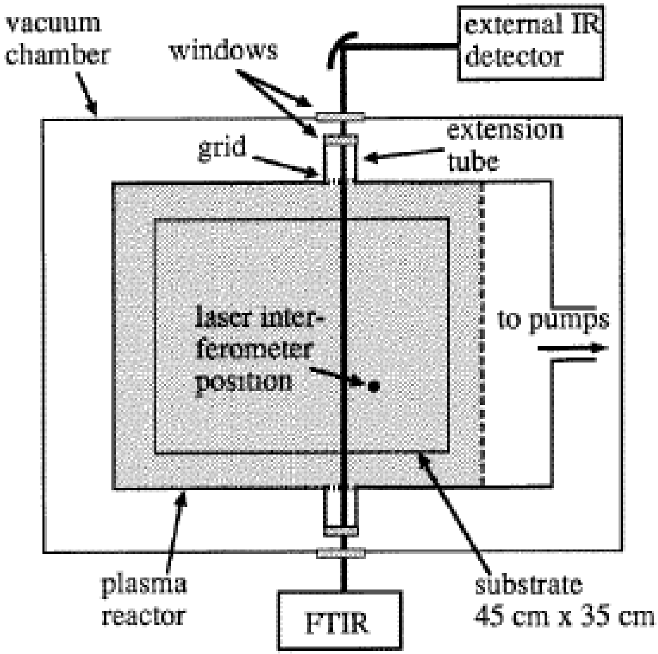
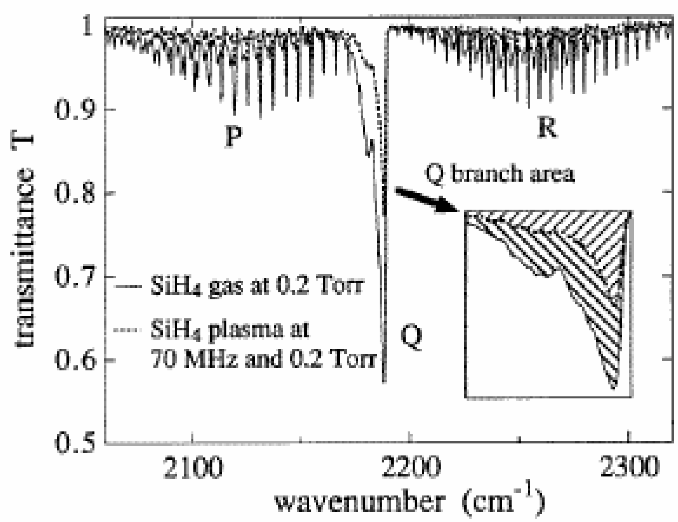
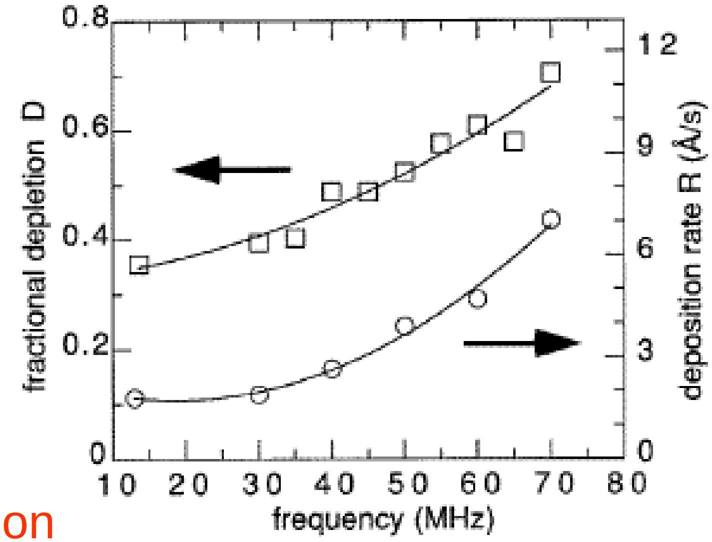
Degree of dissociation measured by FTIR absorption spectroscopy applied to VHF silane plasmas

Plasma Sources Sci. Technol. 7 (1998) 114–118.

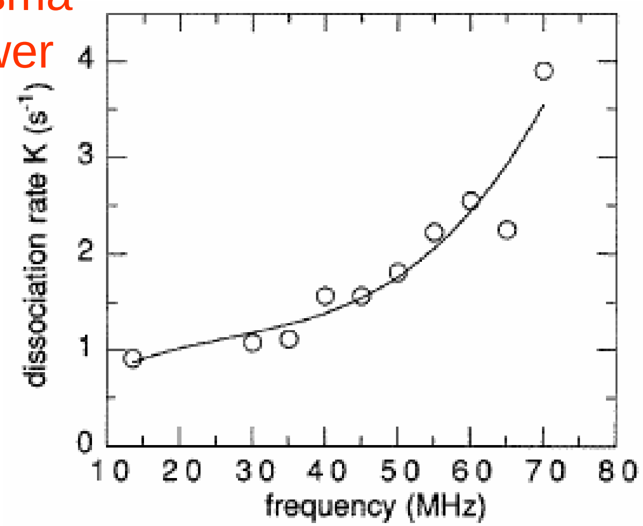
L Sansonnens†, A A Howling and Ch Hollenstein







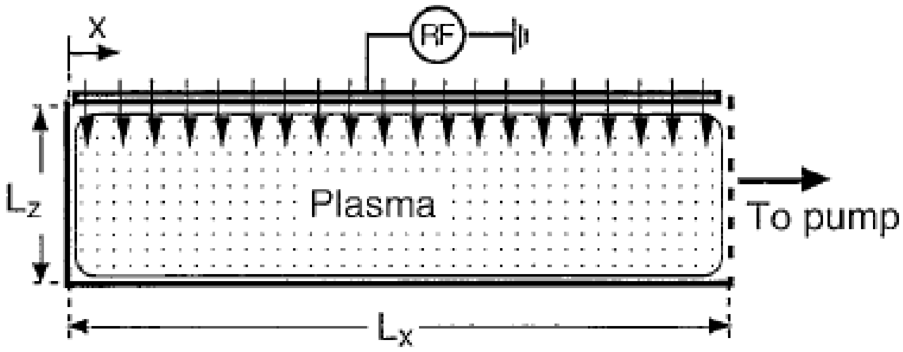
higher dissociation rate for VHF plasma (for constant power in plasma)



A gas flow uniformity study in large-area showerhead reactors for RF plasma deposition

Plasma Sources Sci. Technol. **9** (2000) 205–209.

L Sansonnens, A A Howling and Ch Hollenstein



plasma dissociation: $AB_2 + e \xrightarrow{k_d} AB + B + e$ (1)

surface reactions: $AB + \text{surface} \xrightarrow{k_s} A_s + B$ (2)

species continuity equations

$$\frac{d}{dx}(n_{AB_2} v(x)) = D_{AB_2} \frac{d^2 n_{AB_2}}{dx^2} + \phi - k_d n_e n_{AB_2} \quad (5)$$

$$\frac{d}{dx}(n_{AB} v(x)) = D_{AB} \frac{d^2 n_{AB}}{dx^2} + k_d n_e n_{AB_2} - k_s n_{AB} \quad (6)$$

$$\frac{d}{dx}(n_B v(x)) = D_B \frac{d^2 n_B}{dx^2} + k_d n_e n_{AB_2} + k_s n_{AB} \quad (7)$$

$$n_t = n_{AB_2} + n_{AB} + n_B = \text{constant.}$$

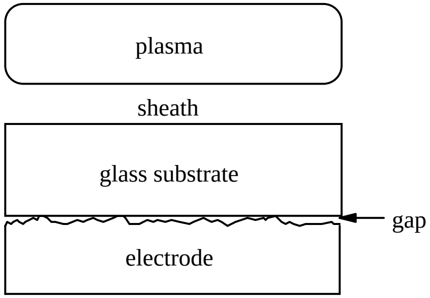
simple model suggests that gas composition is spatially uniform across a showerhead reactor with a uniform plasma

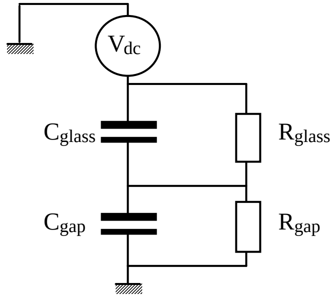
$$v(x) = a\,x \qquad \text{and} \qquad n_i = \text{constant } \forall i$$

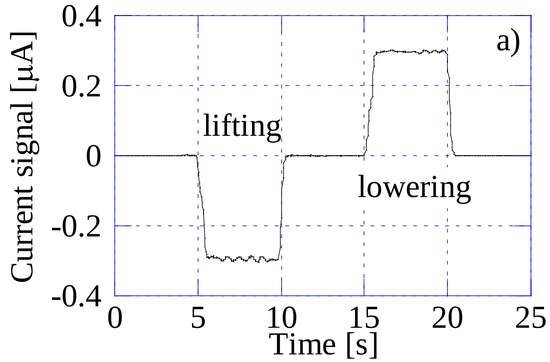
MECHANISM OF SUBSTRATE CHARGING AFTER PLASMA PROCESSING

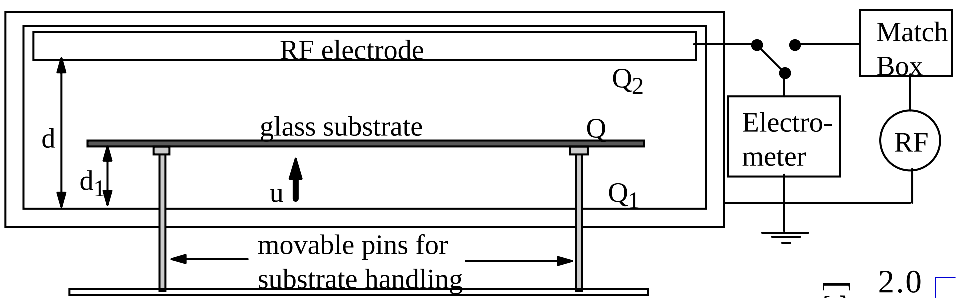
A. Howling[1], A. Belinger[2], P. Bulkin[2], L. Delaunay[2], M. Elyaakoubi[2],
Ch. Hollenstein[1], J. Perrin[2], L. Sansonnens[1], J. Schmitt[2] and E. Turlot[2]

Proceedings of the 15th International Symposium on Plasma Chemistry, Orleans, France, Vol. 1, p33 (2001).

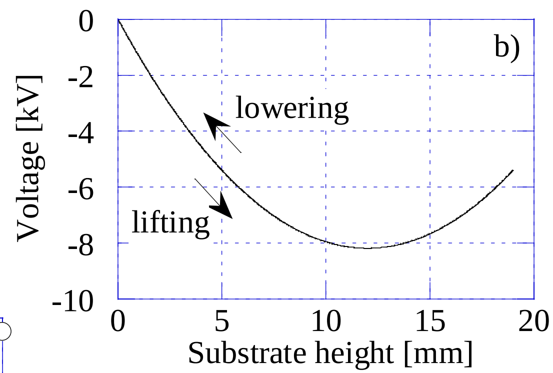


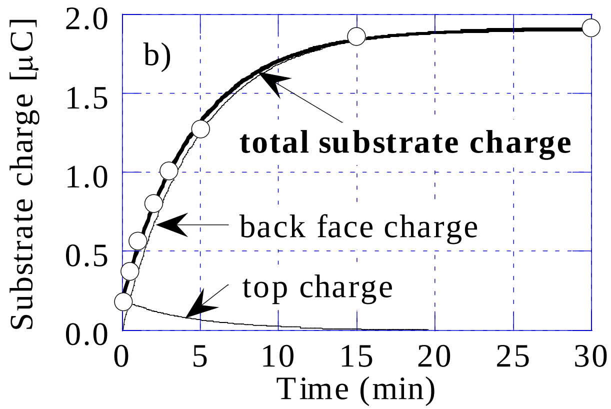






kV potential when substrate lifted after plasma!



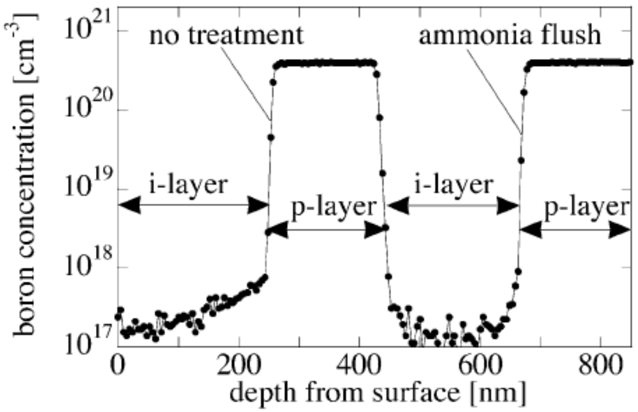


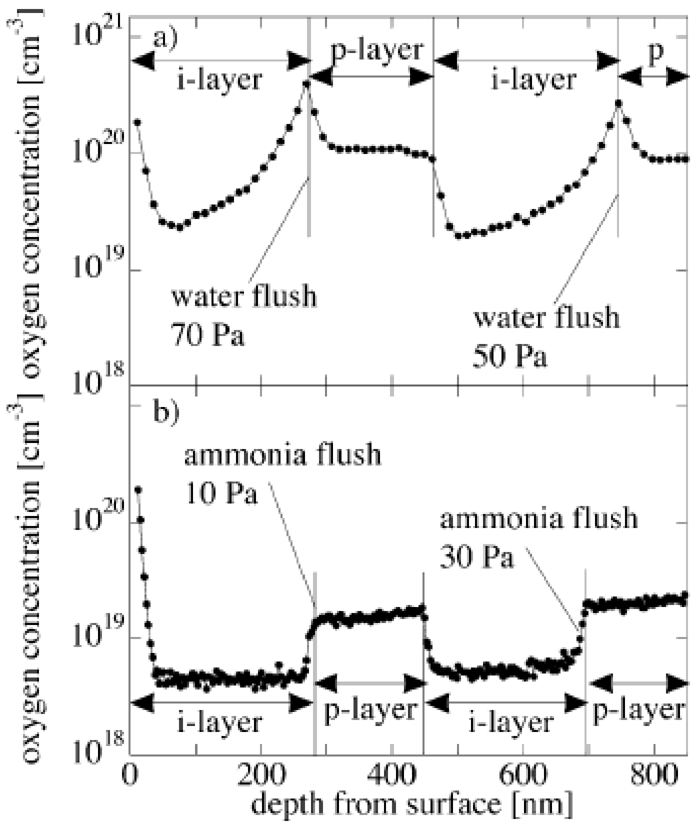
Reduction of the boron cross-contamination for plasma deposition of p–i–n devices in a single-chamber large area radio-frequency reactor

J. Ballutaud[a], C. Bucher[b], Ch. Hollenstein[a], A.A. Howling[a,*], U. Kroll[c], S. Benagli[c], A. Shah[b], A. Buechel[d]

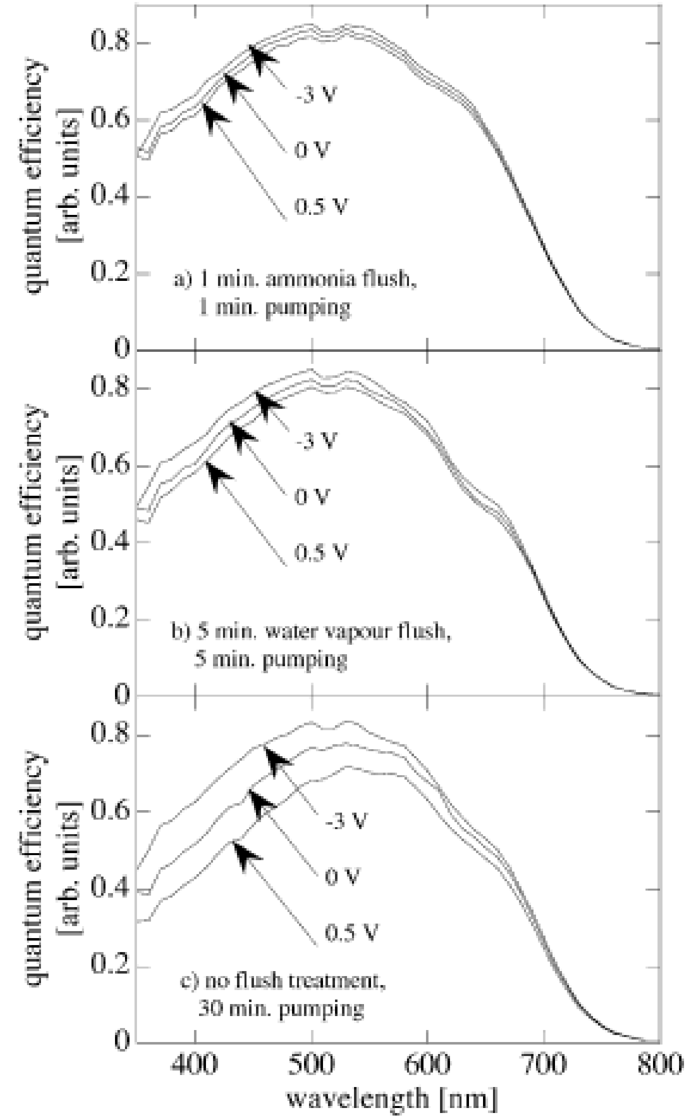
Thin Solid Films 468 (2004) 222–225

ammonia flush





less oxygen than with water flush

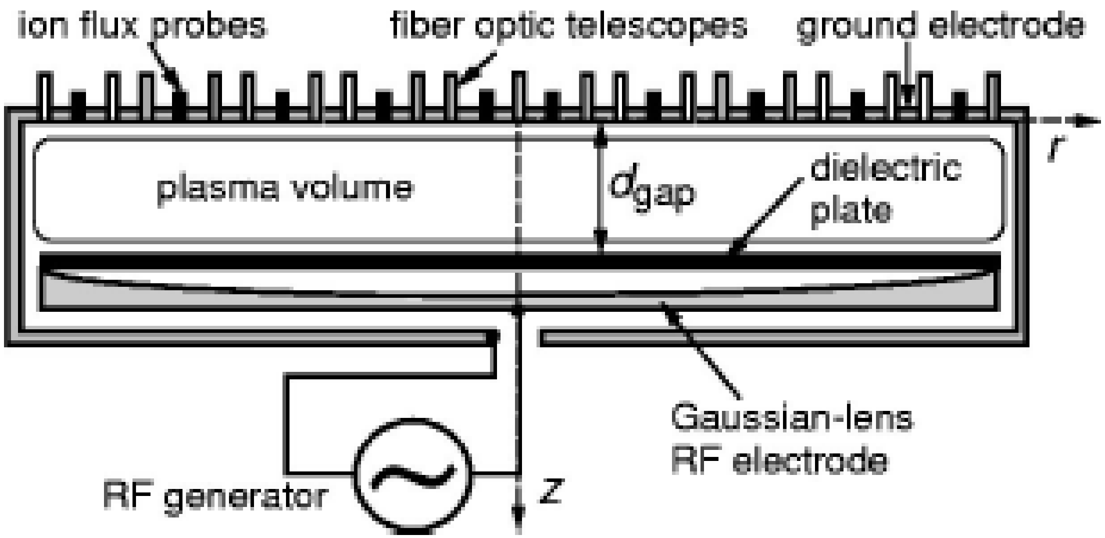


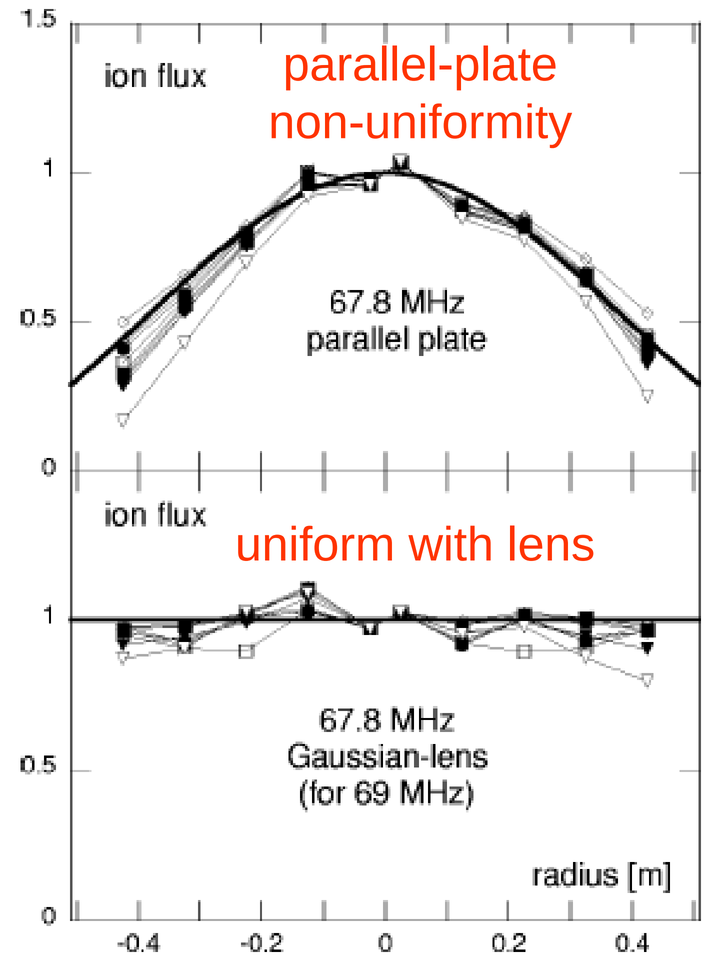
Improving plasma uniformity using lens-shaped electrodes in a large area very high frequency reactor

H. Schmidt, L. Sansonnens, A. A. Howling,[a] and Ch. Hollenstein
Centre de Recherches en Physique des Plasmas, Ecole Polytechnique Fédérale de Lausanne, PPH—Ecublens, CH-1015 Lausanne, Switzerland

M. Elyaakoubi and J. P. M. Schmitt
Unaxis Displays, 5 Rue Léon Blum, F-91120 Palaiseau, France

J. Appl. Phys. **95** 4559 (2004)





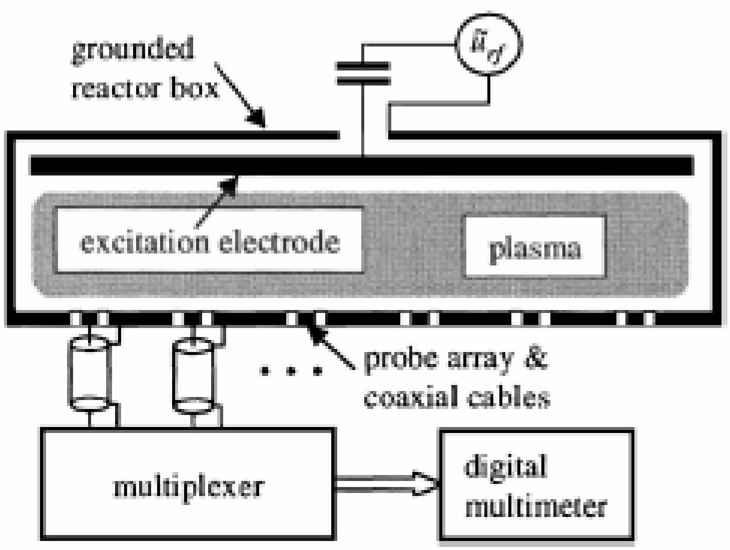
Probe measurements of plasma potential nonuniformity due to edge asymmetry in large-area radio-frequency reactors: The telegraph effect

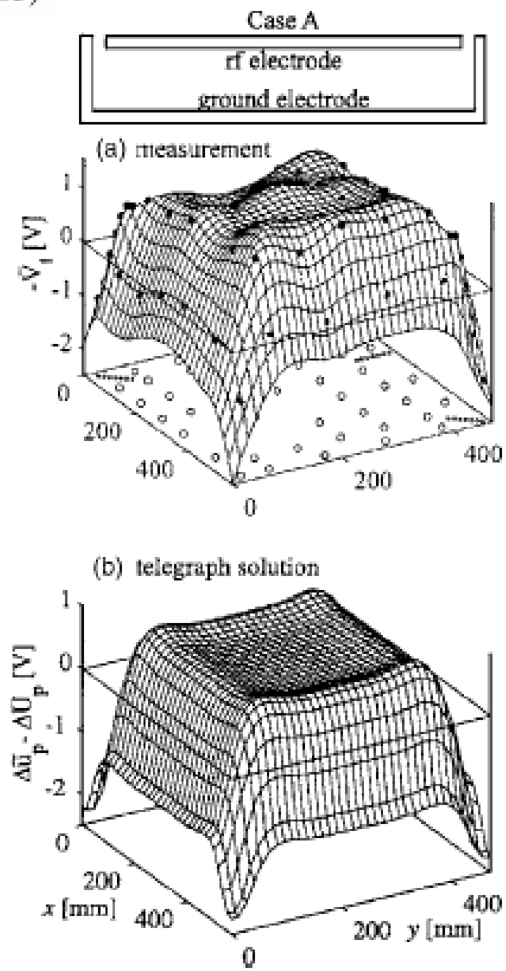
A. A. Howling,[a] L. Derendinger, L. Sansonnens, H. Schmidt, and Ch. Hollenstein
Ecole Polytechnique Fédérale de Lausanne (EPFL), Centre de Recherches en Physique des Plasmas, CH-1015 Lausanne, Switzerland

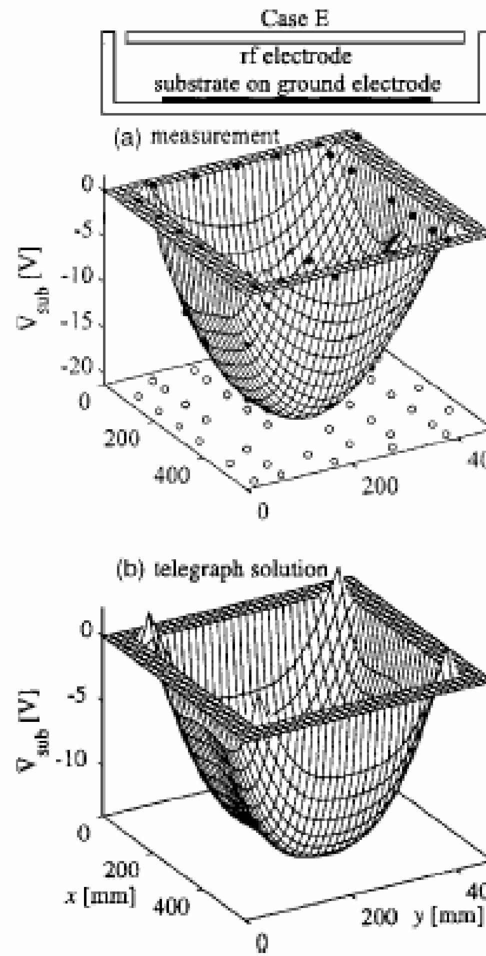
E. Sakanaka and J. P. M. Schmitt
Unaxis Displays, 5 Rue Léon Blum, F-91120 Palaiseau, France

JOURNAL OF APPLIED PHYSICS **97**, 123308 (2005)

negative charge on substrate





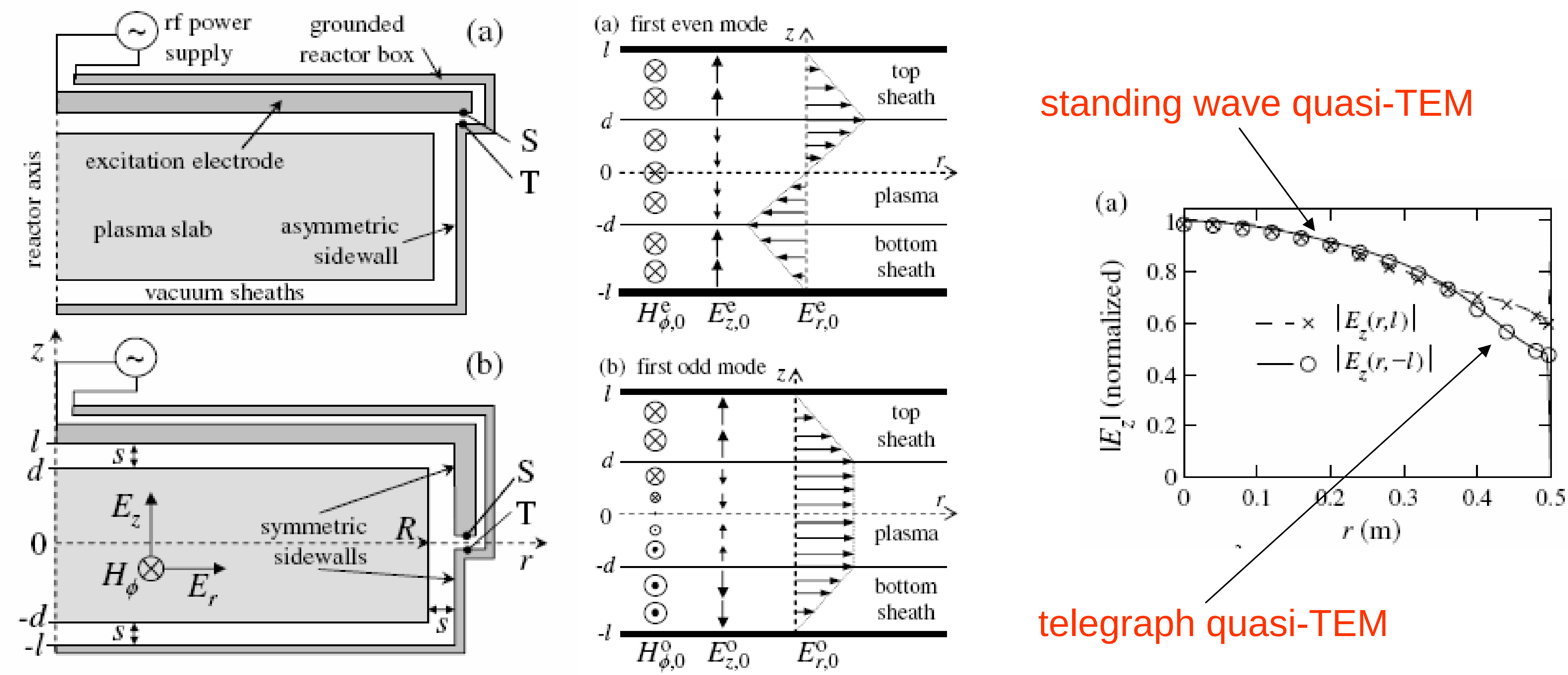


perturbation to plasma RF potential due to sidewall area

Electromagnetic field nonuniformities in large area, high-frequency capacitive plasma reactors, including electrode asymmetry effects

Plasma Sources Sci. Technol. 15 (2006) 302–313

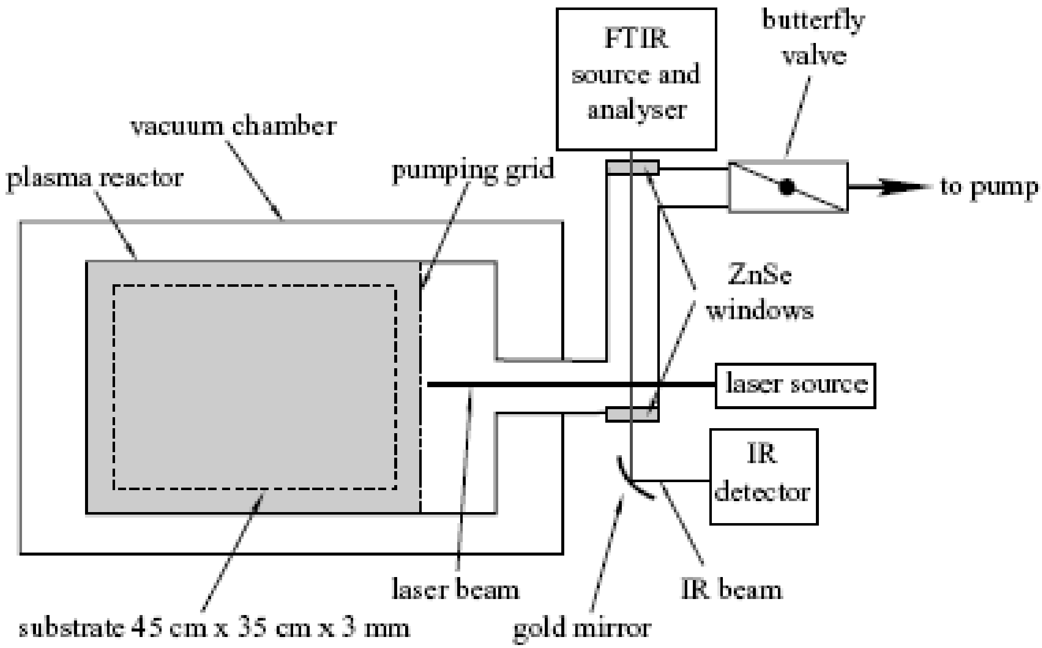
L Sansonnens, A A Howling and Ch Hollenstein

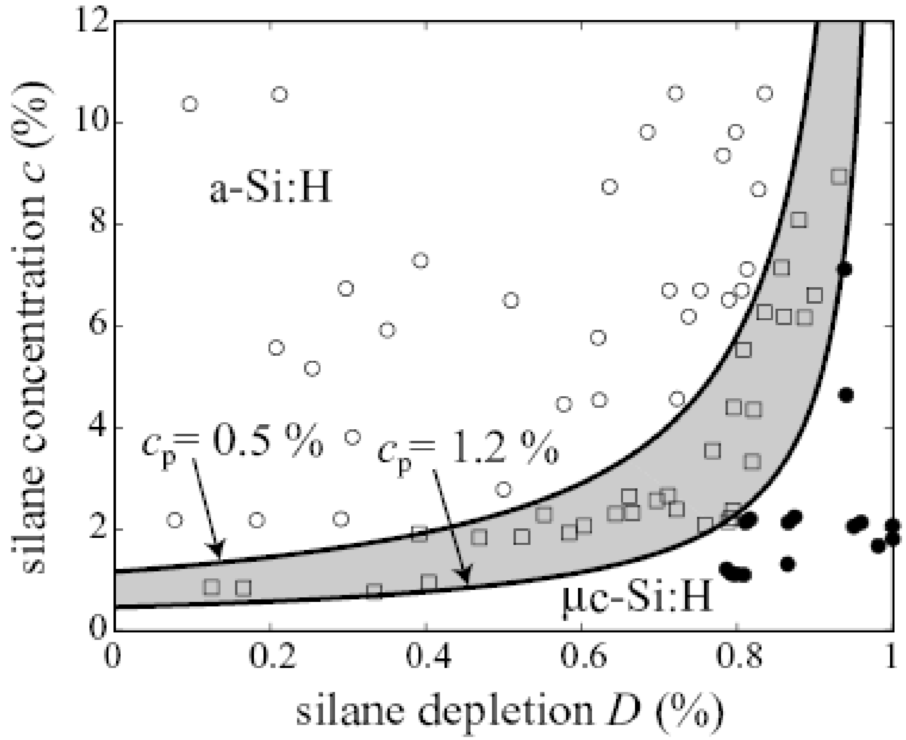


Plasma silane concentration as a determining factor for the transition from amorphous to microcrystalline silicon in SiH_4/H_2 discharges

B Strahm, A A Howling, L Sansonnens and Ch Hollenstein

Plasma Sources Sci. Technol. **16** (2007) 80–89





silane concentration in the plasma determines microcrystallinity

$$c_{\mathrm{p}} = c(1 - D)$$

$$D = \left(1 + \frac{a/kn_{\mathrm{e}}}{(1+c)}\right)^{-1}$$

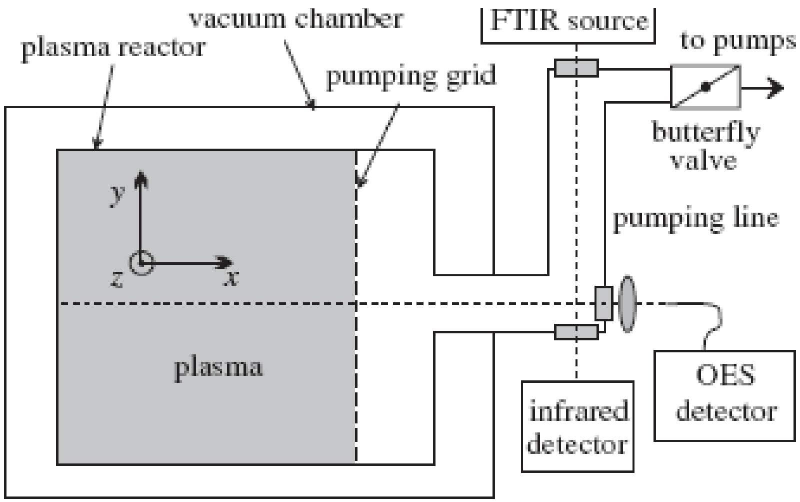
depletion accounts for parameter scaling

$$a_0 = \frac{\Phi_{\mathrm{tot}}}{n_{\mathrm{tot}}} = 6.1 \cdot 10^{-6} T \frac{F_{\mathrm{tot}}}{pV}$$

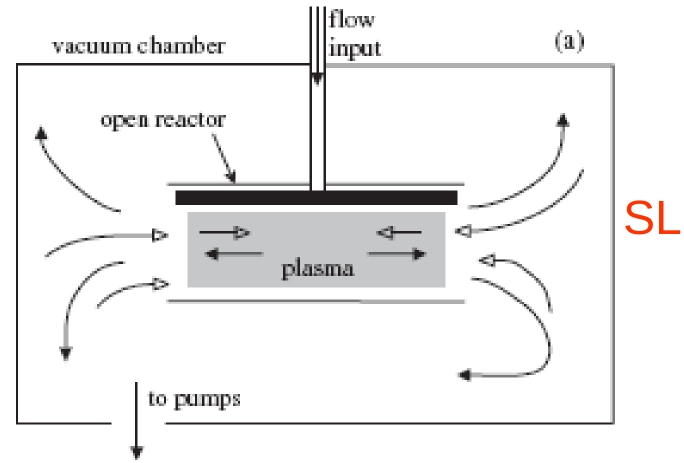
Fast equilibration of silane/hydrogen plasmas in large area RF capacitive reactors monitored by optical emission spectroscopy

Plasma Sources Sci. Technol. **16** (2007) 679–696

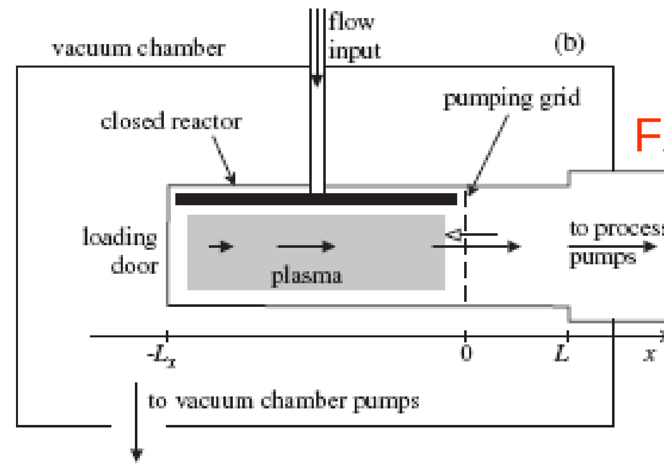
A A Howling, B Strahm, P Colsters[1], L Sansonnens[2] and Ch Hollenstein



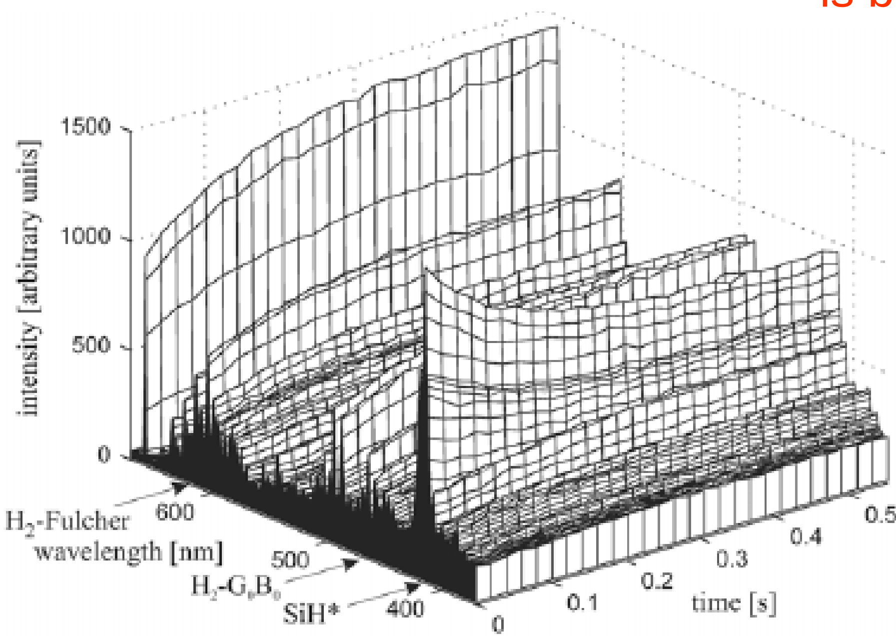
directed flow from a closed reactor is best



SLOW



FAST



Some other industrial topics not mentioned here:

Low pressure plasma torch spray - Sulzer Metco

SiOx deposition for packaging - Tetra Pak

Electrical Discharge Machining - Charmilles

Solar panel drive mechanism for satellites - ESA

RF arc study for reactor design - SwissElectric

Diamond and nitriding by DC arc column - Swiss watch industry

etc