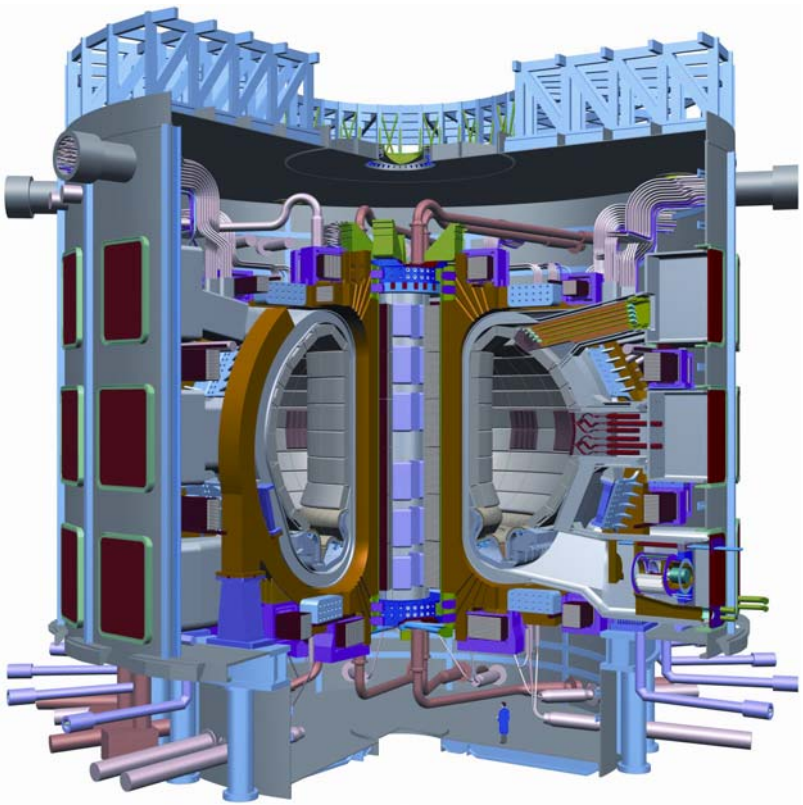
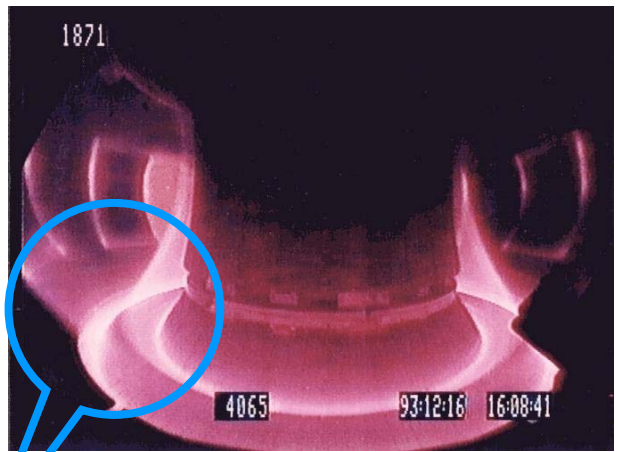
ITER: burning D/T plasma magnetically confined



ASDEX Upgrade



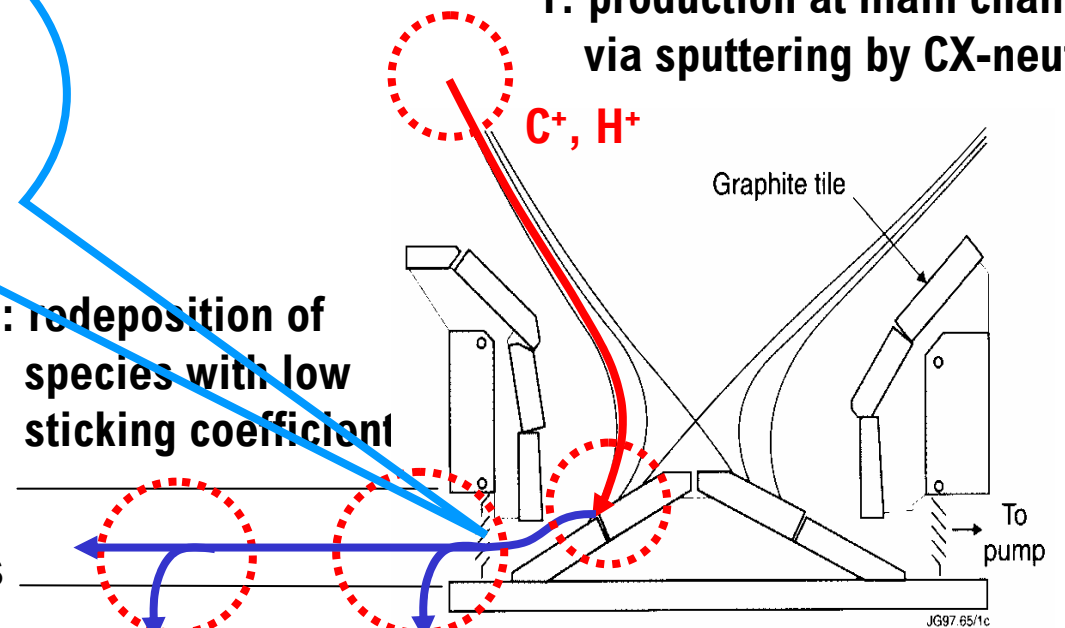
strong plasma wall interaction
between
hot hydrogen plasma and wall
(wanted for various reasons)

carbonaceous walls: challenge of tritium redeposition

N_2 injection may inhibit carbon redeposition

1: production at main chamber walls via sputtering by CX-neutrals

C^+, H^+



4: redeposition of species with low sticking coefficient

5: pumping of stable species

CH_4, H_2

CH_3

C_2H, C_2H_3

3: redeposition of species with high sticking coefficients

2: transformation

$\underbrace{CH_4, CH_3}_{\text{high}}, \underbrace{C_2H, C_2H_3, C_3H_7}_{\text{low}}$

ion energy

A. von Keudell et al. Nucl. Fusion 39, 10 (1999)

Stickstoffbeimischung in Kohlenwasserstoffplasmen - eine Lösung für die Redepositionsproblematik in Fusionsexperimenten?

NITROGEN PUFFING INTO HYDROCARBON PLASMAS – A SOLUTION FOR REDEPOSITION IN FUSION EXPERIMENTS?

Thomas Schwarz-Selinger,

C. Hopf, M. Schlüter, W. Jacob

XIV. Erfahrungsaustausch
Oberflächentechnologie mit Plasma- und Ionenstrahlprozessen
Mühlleithen 13. März 2007

Outline:

- scavenger effect: the idea behind
- a short reminder on a-C:H film growth
- species in N_2 / CH_4 and N_2 / H_2 plasmas
- film formation and erosion in N_2 / CH_4 and N_2 / H_2 plasmas
- surface loss probabilities in N_2 / CH_4 plasmas
- conclusion

scavenger effect: the idea behind

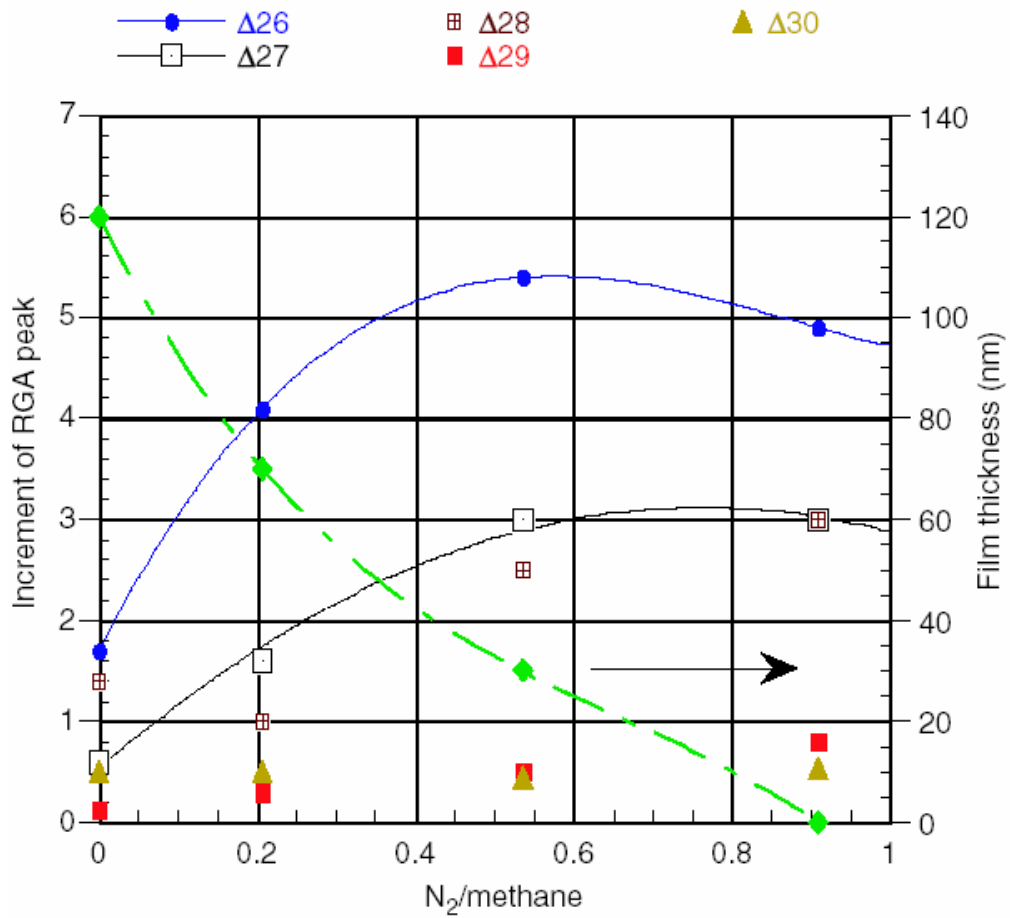
F.L. Tabarés:

use of scavenger techniques for the in-situ, shot-to-shot control of the deposition of T/C layers in fusion devices

(F.L. Tabarés et al., Plasma Phys. Control. Fusion 44, L37-42 (2002))

the scavenger technique proposed by Tabares et al.

"**C_2H_2** and possibly **HCN** are the main stable gaseous compounds in N_2/CH_4 containing H_2 DC plasmas. Their relatively high melting points could allow trapping at liquid N_2 temperatures"



dc discharge in hydrogen

F.L. Tabarés et al., Plasma Phys. Control. Fusion 44, L37-42 (2002)

the scavenger technique proposed by Tabares et al.

the scavanger technique is based on

gas phase reactions of nitrogen (N, N_2; N_x^+) with the growth precursors (CH_3) forming

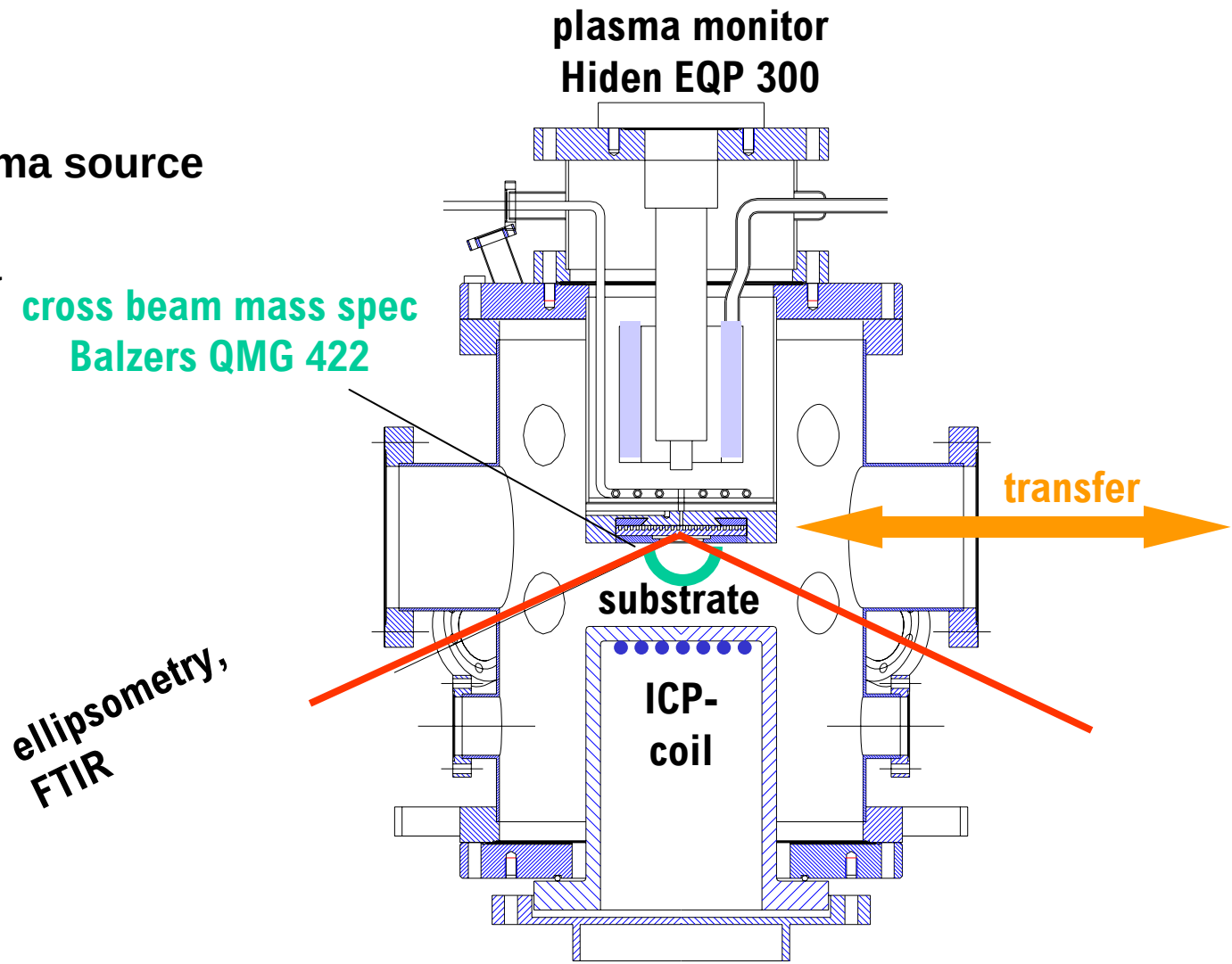
nonreactive species that can be pumped away or condensed on cold surfaces

ICP plasma setup

inductively coupled plasma source

pressure range: 1 - 50 Pa

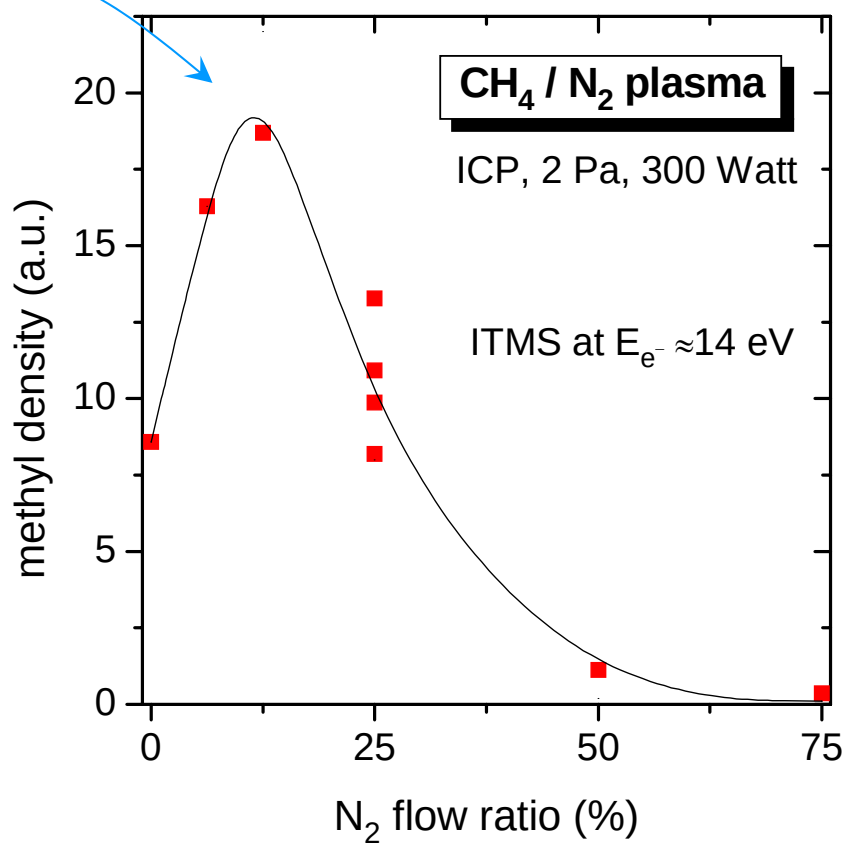
rf power: < 600 Watt



N_2 as methyl scavenger

- Ionization Threshold Mass Spectrometry (ITMS):

N_2 addition increases CH_3 density!!!

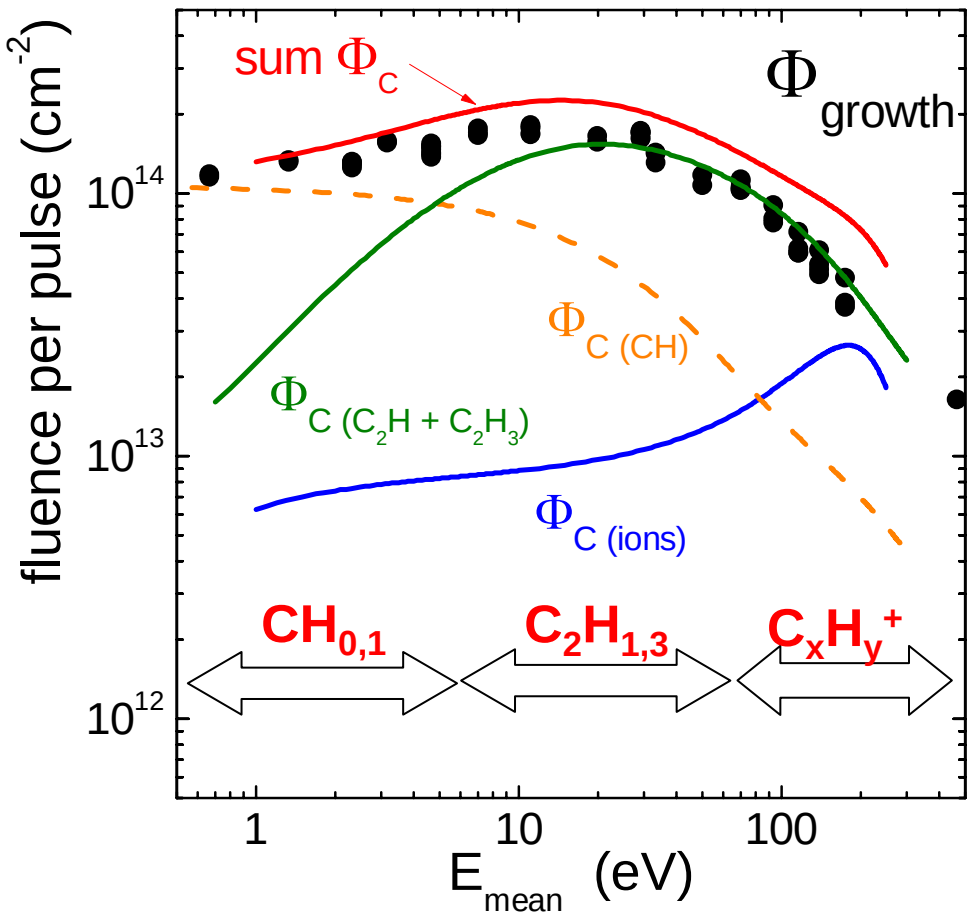


fraction of NH^+ negligible

a short reminder on a-C:H film growth

a-C:H film growth

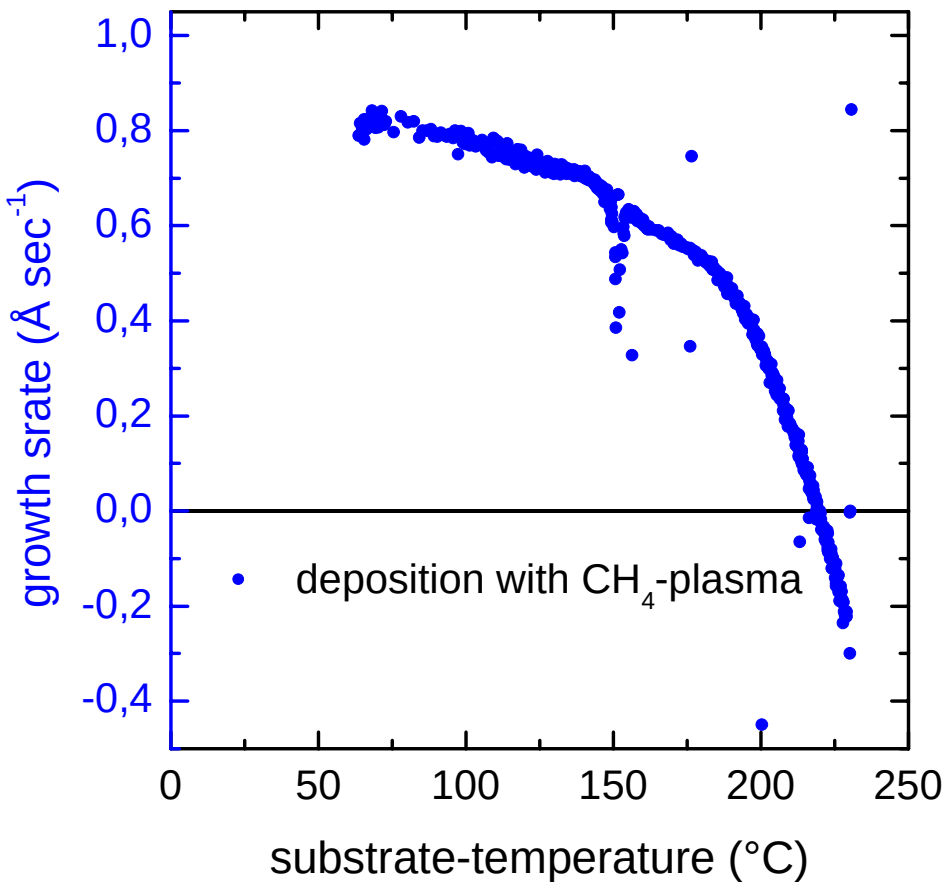
comparsion of reactive flux (flux * sticking) with growth rate:



$$E_{mean} = \frac{P_{mean} \cdot \tau_{residence}}{N}$$

M. Bauer PhD 2004 (IPP report 9/135)
M. Bauer et al. Plasma Sources Sci. Technol. **14** (2005)
M. Bauer et al. J. Appl. Phys. **98**, 2005

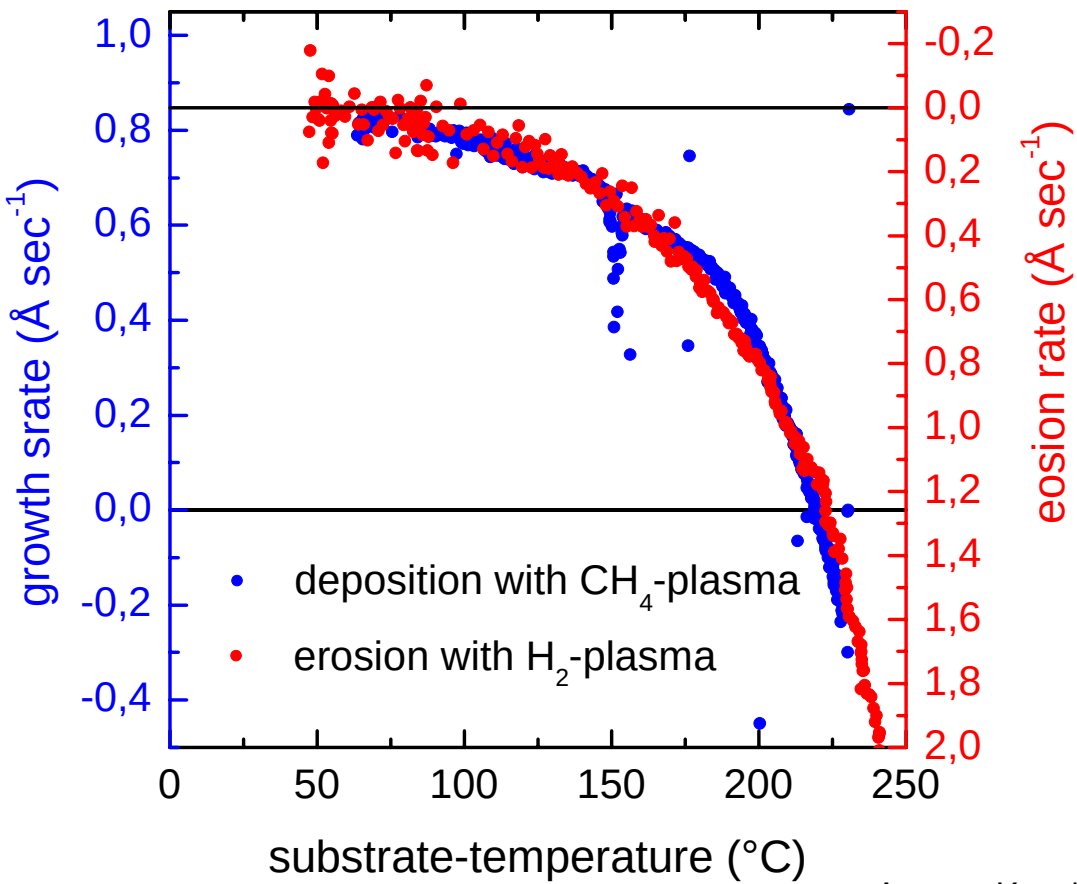
temperature dependent deposition of a-C:H



⇒ A. von Keudell et al. JAP **79** (2)1092 (1997).

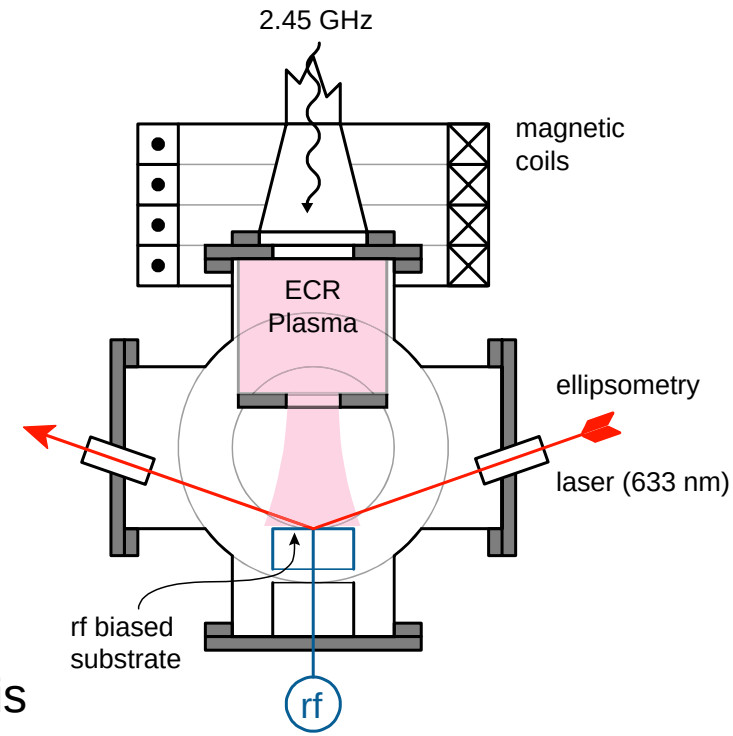
temperature dependent deposition of a-C:H

growth rate = balance between deposition and erosion



⇒ A. von Keudell et al. JAP **79** (2)1092 (1997).

Remote ECR plasma



independent control of
substrate temperature and particle energy

pressure range 10^{-2} - 1 Pa

ECR power: < 300 Watt

ellipsometry to detect erosion and deposition

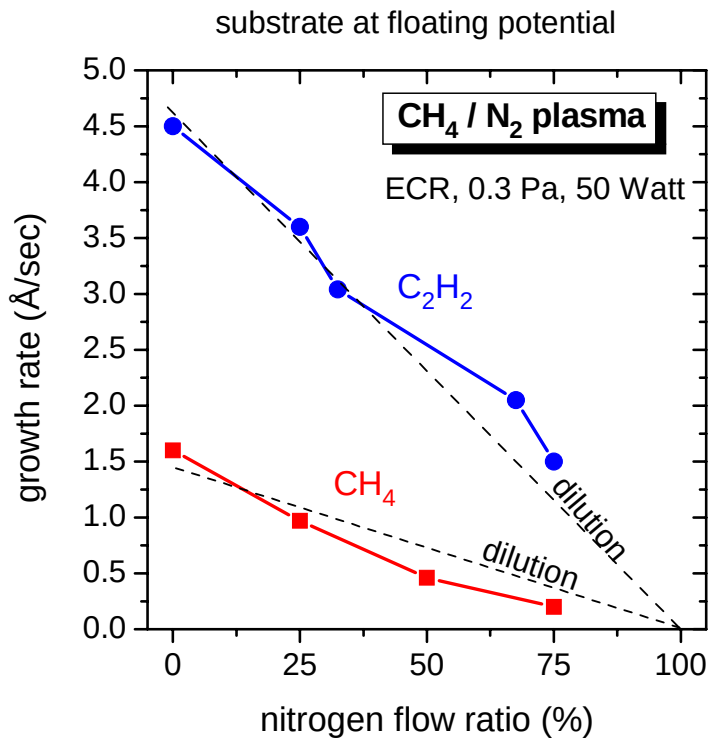
remote mass spectrometer for residual gas analysis

retarding field analyzer (RFA) at substrate position to measure the mass integrated ion flux

growth of nitrogen containing carbon films

A reduction of the deposition rate due to N_2 admixture to hydrocarbon plasmas was confirmed by our experiments but **does not exceed significantly the expected reduction due to dilution**.

The reduction depends on the hydrocarbon source gas, the mixing ratio, and other plasma parameters such as power, residence time etc.



O. Durand-Drouhin et al. 2000, unpublished

erosion of a-C:H in H_2/N_2 mixtures

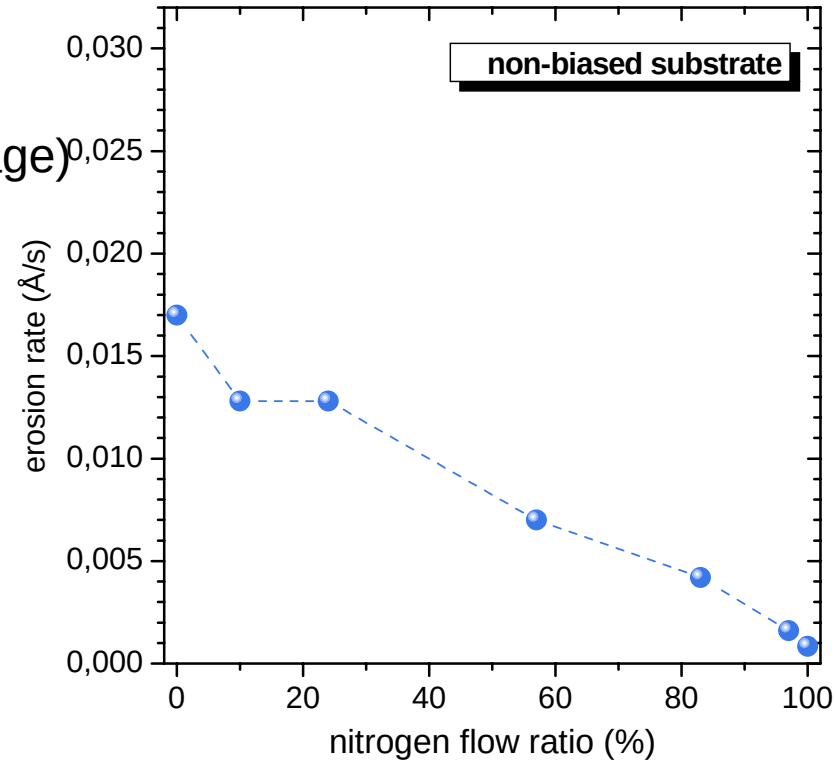
first step: erosion of a-C:H in H_2/N_2 mixtures

Procedure:

- deposition of 100 nm hard a-C:H
- O_2 plasma cleaning of chamber walls (cage)
- erosion in H_2 / N_2 plasma

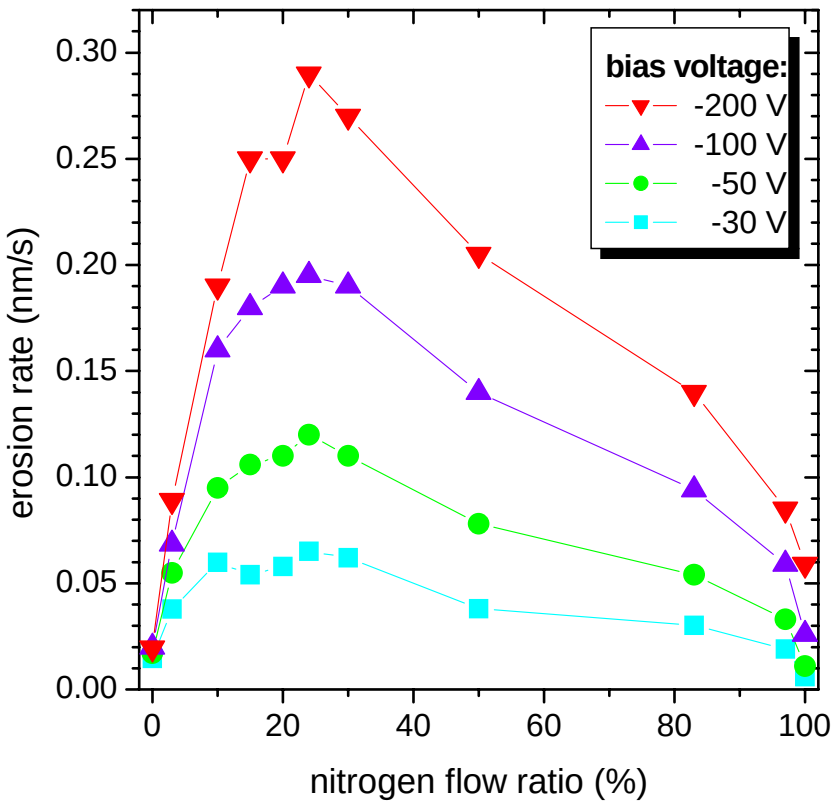
➢ decrease due to dilution ?

➢ nitrogen seems unreactive under these conditions



first step: erosion of a-C:H in H_2/N_2 mixtures

biased substrate:

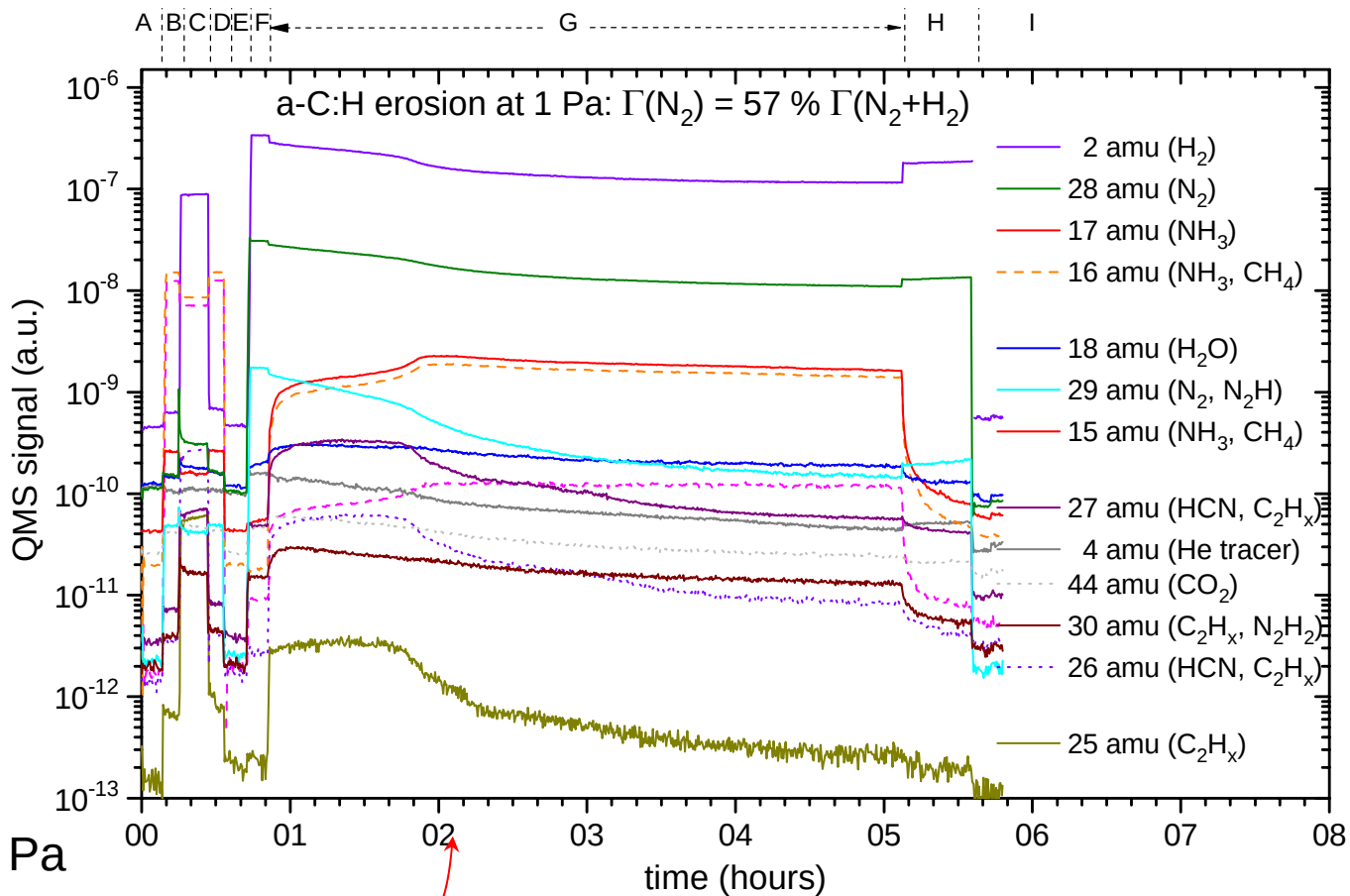


- ➲ erosion rate increases with bias
- ➲ erosion rate for mixtures is higher than in pure H_2 and pure N_2 plasmas
- ➲ erosion rate increases dramatically with N_2 admixture although ion flux decreases
- ➲ clear maximum around 24 % N_2 flow ratio

➲ chemical sputtering

second step: erosion in H_2/N_2 mixtures with coated chamber walls

QMS time trace



Experimental phases:

A, E, I: residual gas

B, D: CH_4 0.2 Pa

C: CH_4 plasma

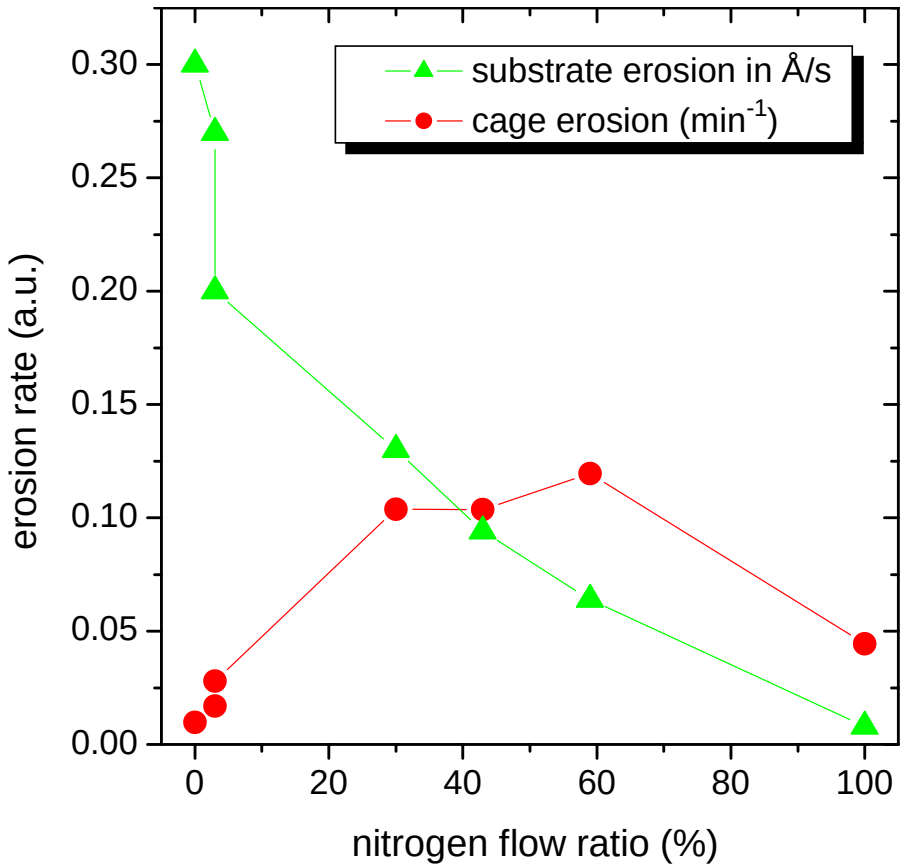
F: H_2 / N_2 mixture 1 Pa

G: H_2 / N_2 plasma

after 2 hours wall coating starts to vanish.
C_xH_y and HCN intensities drop, NH_3 intensity increases.

second step: erosion in H_2/N_2 mixtures with coated chamber walls

- different erosion behavior in the cage and at the substrate
- cage erosion behaves similar to biased substrate erosion (cage erosion measured as the 1/e time of the 25 amu signal)



in the same plasma different behaviour in different areas!

second step: erosion in H_2/N_2 mixtures with coated chamber walls

Procedure:

a-C:H deposition at the chamber wall (cage)

pure N_2 plasma at 1 Pa

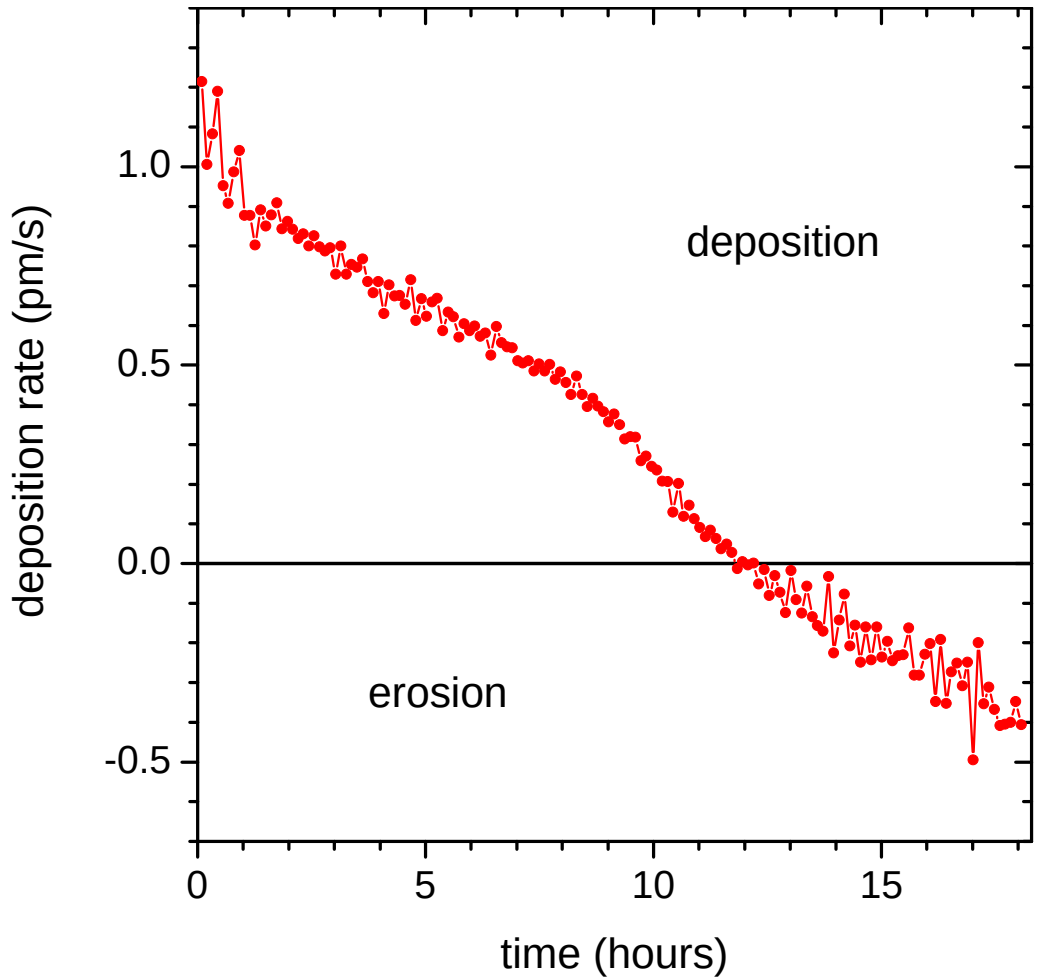
➲ redeposition of a 25 nm thick film

(XPS: $n_N / n_C = 1$; 6 % O_2)

➲ redeposition stops when cage is clean

then:

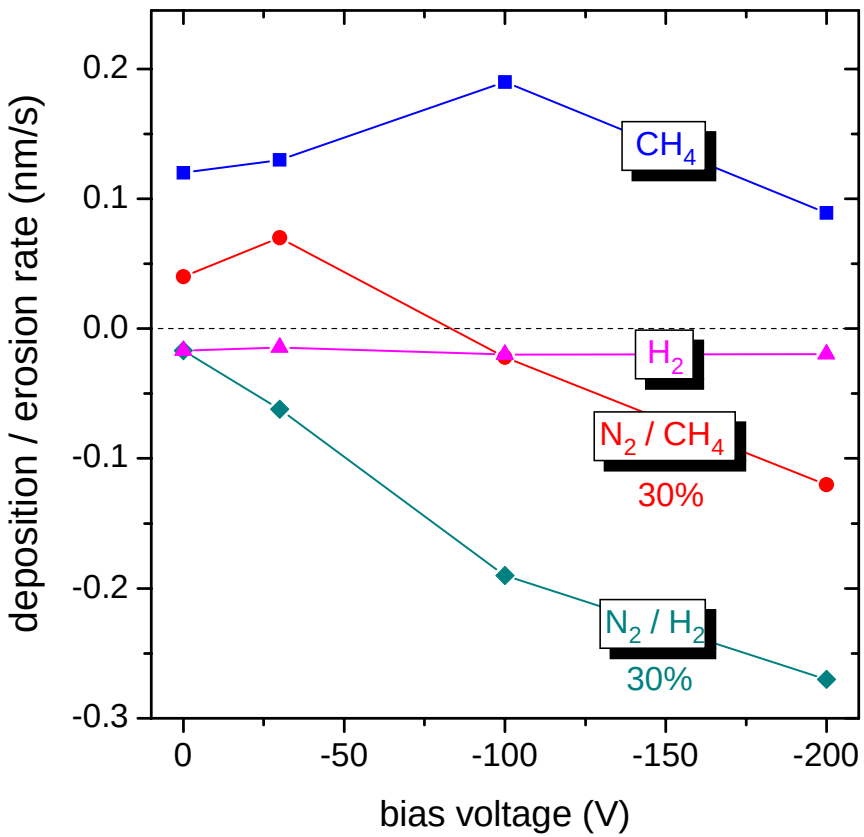
➲ change over to net erosion



summary: experiments with H_2/N_2 and CH_4/N_2 mixtures

erosion and deposition in H_2, CH_4, N_2 mixtures

Erosion and deposition as a function of ion energy



- increase of erosion rate with bias for for N_2 / CH_4 and
- changeover from deposition to erosion for CH_4 / N_2 plasmas at higher ion energies can **only be explained by surface effects** (the gas phase chemistry remains unchanged!)

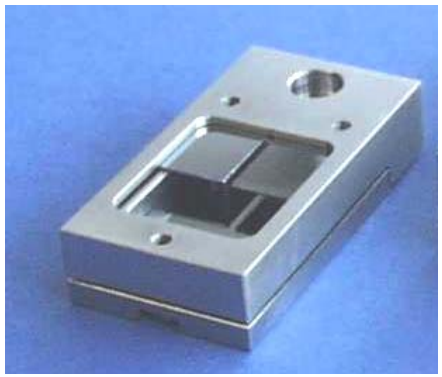
➲ chemical sputtering

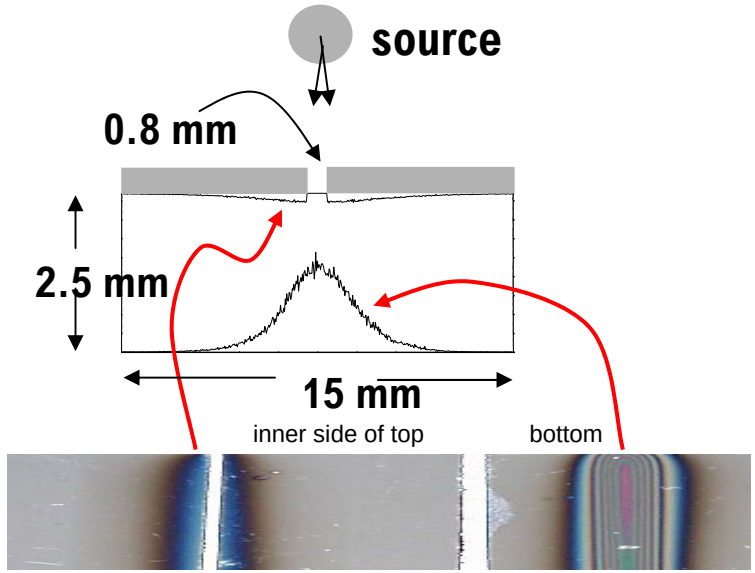
conclusion from laboratory experiments

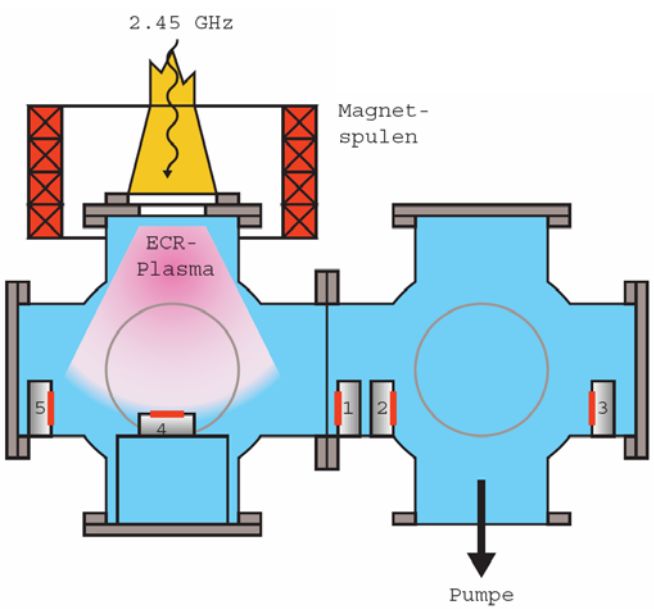
- nitrogen admixture reduces carbon growth rate in low-Temp. hydrocarbon plasmas
- surface: nitrogen/hydrogen shows very pronounced chemical sputtering
- for increased ion energy growth can turn into erosion
- redeposition possible in pure N_2 low-T plasmas
- surface effects (chemical sputtering) are experimentally proven (component lifetime!)
- volume effects: no experimental evidence for scavenger effects

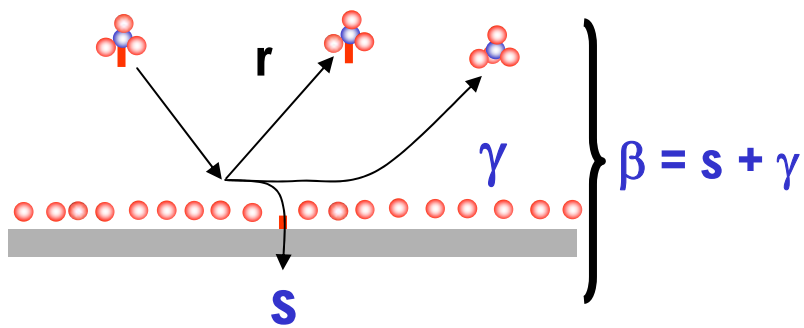
cavity technique: surface loss probabilities of species

Ch. Hopf et al., J. Appl. Phys. 87 (2000)

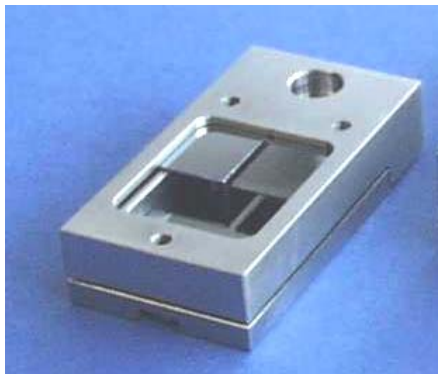




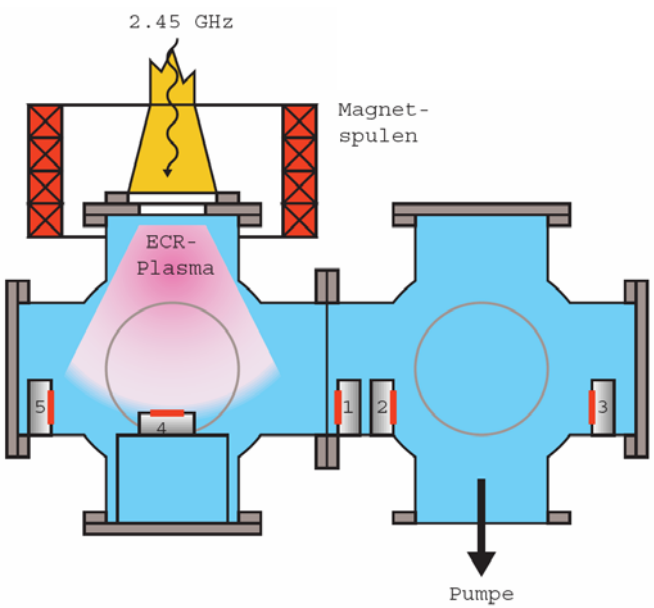


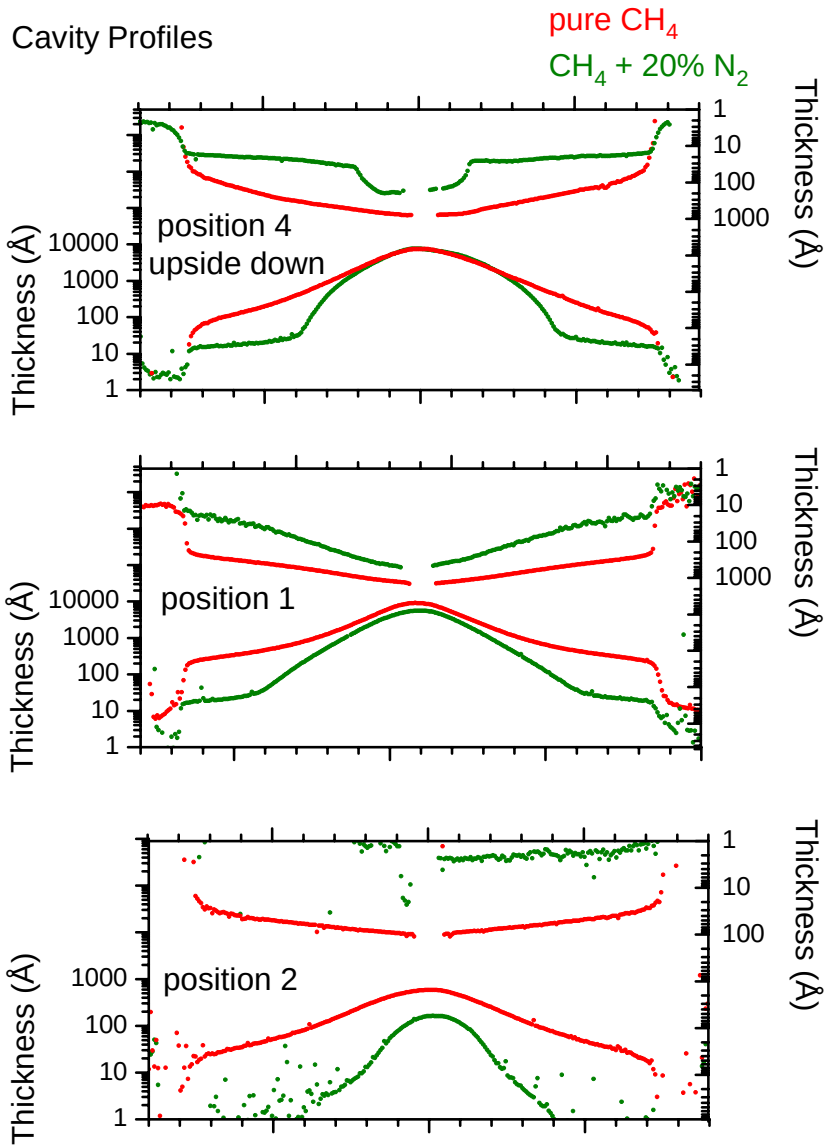


cavity technique: surface loss probabilities of species



reduced deposition in the wings
➲scavanging of low β species!





conclusion

Because of the increased erosion due to chemical sputtering the present data base does not allow to recommend N_2 admixture to divertor plasmas.

even if reduced film growth (e.g. by quartz microbalance) is observed in some areas of the divertor the following aspects have to be checked:

- **total carbon erosion (component lifetime)**
- **reactivity of the eroded species (redeposition)**
- **dust production**