Chemische Zerstäubung mit reaktiven Ionen

Wolfgang Jacob, Christian Hopf, Michael Schlüter, T. Schwarz-Selinger
Max-Planck-Institut für Plasmaphysik, 85748 Garching, Germany

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Motivation

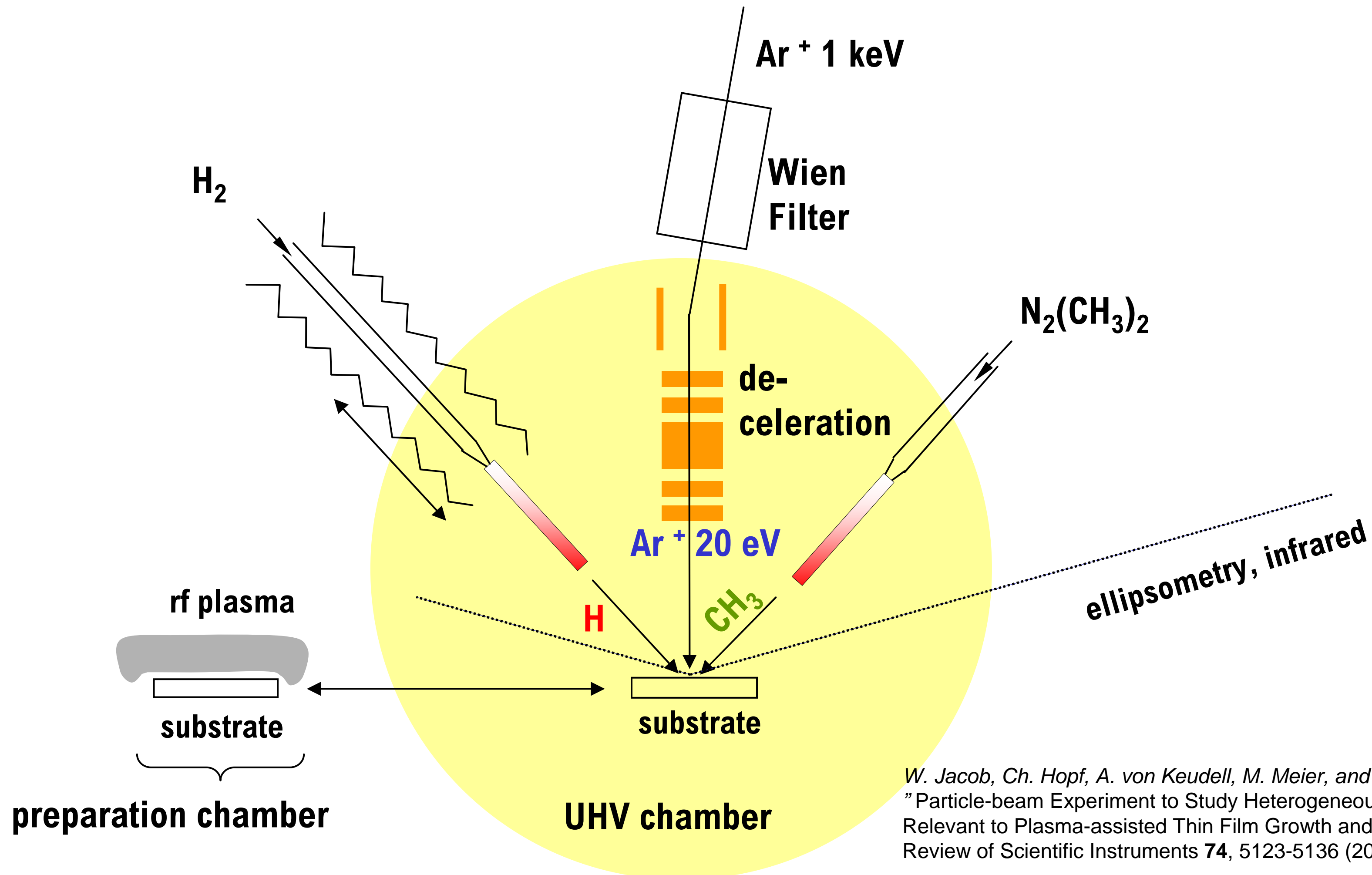
IPP

- ***Chemical Sputtering*** is the dominant erosion mechanism for carbon surfaces in fusion experiments
- safety concerns due to redeposited C:H films
  ➔ erosion of such layers using glow discharges
- removal of C:H layers in technical applications
- other system of huge commercial importance: dry etching of semiconductor devices (e.g. Si + F)

Chemical sputtering is a rather common phenomenon in reactive plasma processing (Net deposition is in most cases a balance between deposition and erosion)

Experimental set-up: MAJESTIX

UHV experiment with 2 radical beam sources and one ion beam source



W. Jacob, Ch. Hopf, A. von Keudell, M. Meier, and T. Schwarz-Selinger: "Particle-beam Experiment to Study Heterogeneous Surface Reactions Relevant to Plasma-assisted Thin Film Growth and Etching", Review of Scientific Instruments **74**, 5123-5136 (2003).

Chemical sputtering mechanism

H°

ions

volatile species

x

a-C:H film: carbon hydrogen

1. ions break C–C bonds

2. H° passivates broken bonds

Repetition of 1 and 2

3. volatile hydrocarbons

diffusion to the surface

desorption

Energy dependence

$$Y(ions\,|\,H) \propto \int y_{bb}(x) \cdot p_{pass}(x)\,dx$$

bond breaking due to ion impact

passivation by atomic H

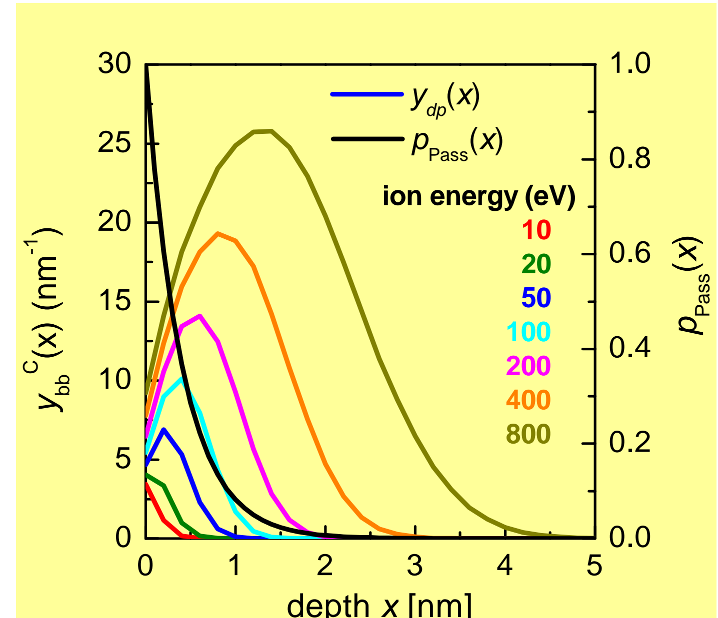
$$Y(ions\,|\,H) = a \cdot \int y_{bb}(x) \cdot e^{(-x/\lambda)}\,dx$$

Bond breaking events per depth interval calculated by TRIM.SP

exponential decay, maximum range about 2 nm, known from plasma experiments

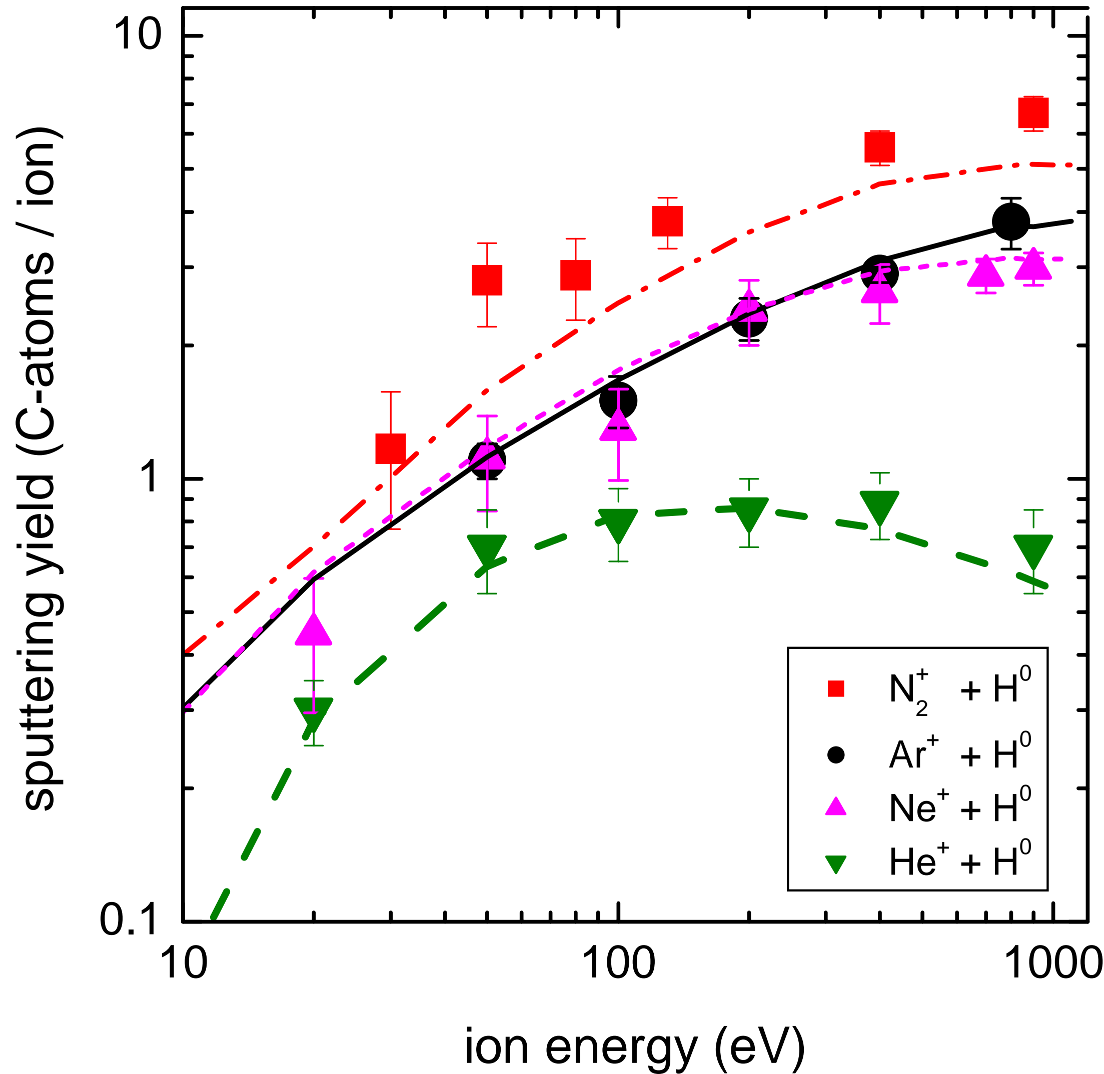
a is a fit parameter

TRIM.SP simulations for Ar ions



$E_{bb}^{C} = 5$ eV, $\lambda = 0.4$ nm

Chemical sputtering: Summary



Strong increase of yield with increasing ion energy

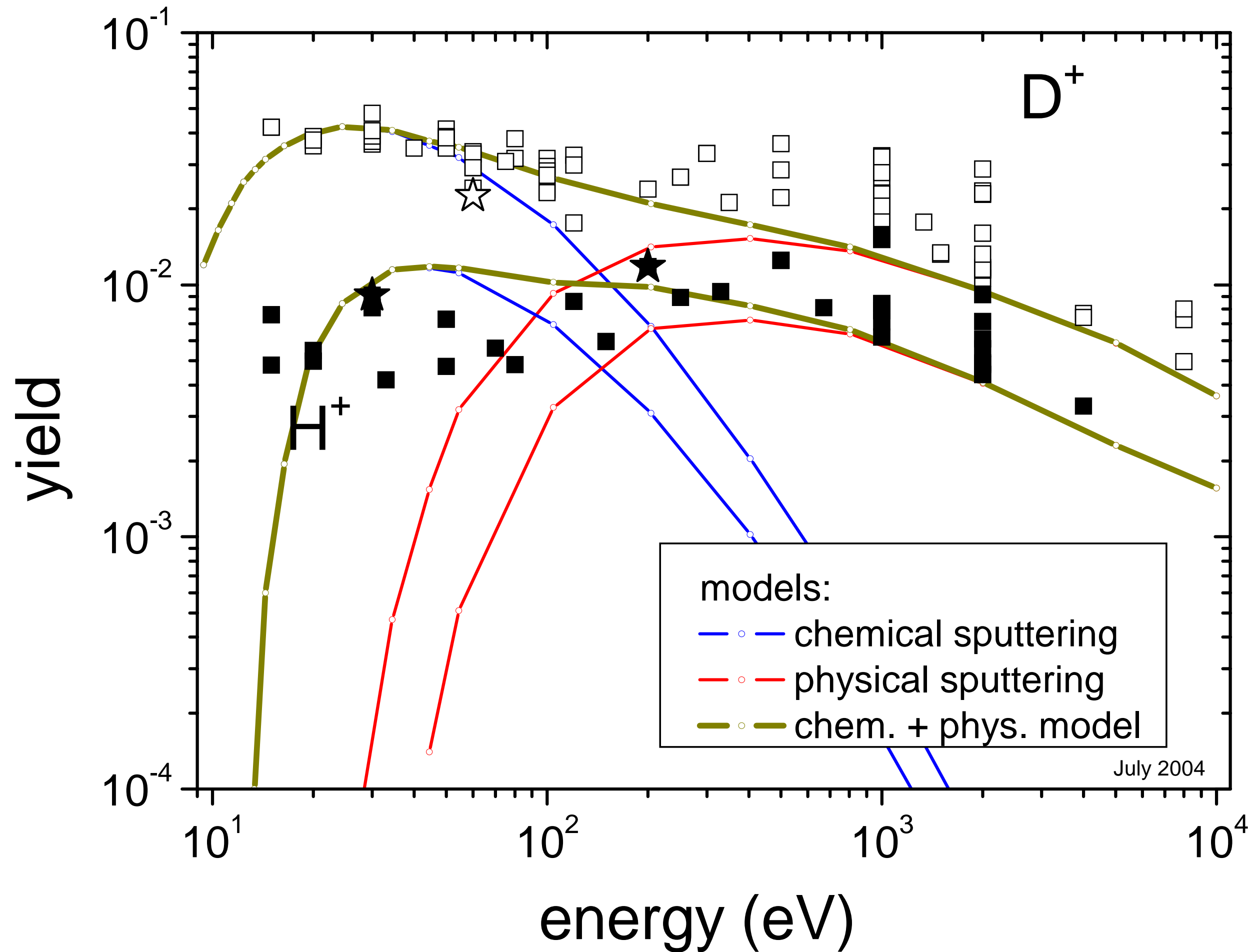
Very good description of the energy dependence for noble gas ions plus atomic H

Deviations for N_2^+ + H

H flux density = 1.4×10^{15} $cm^{-2}s^{-1}$
Ar ion flux density = 3.5×10^{12} $cm^{-2}s^{-1}$

calibration factor a = 0.5

Chemical sputtering with reactive ions: H^+, $D^+ \rightarrow$ graphite



Data: M. Balden, J. Roth, J. Nucl. Mater. ***280****, 39-44 (2000)*
"New weight-loss measurements of the chemical erosion yields of carbon materials under hydrogen ion bombardment"
Model:C. Hopf and W. Jacob, J. Nucl. Mater. , ***342****, 141–147 (2005).*
"Bombardment of Graphite with Hydrogen Isotopes: A Model for the Energy Dependence of the Chemical Sputtering Yield"

Chemical sputtering with reactive ions: model

IPP

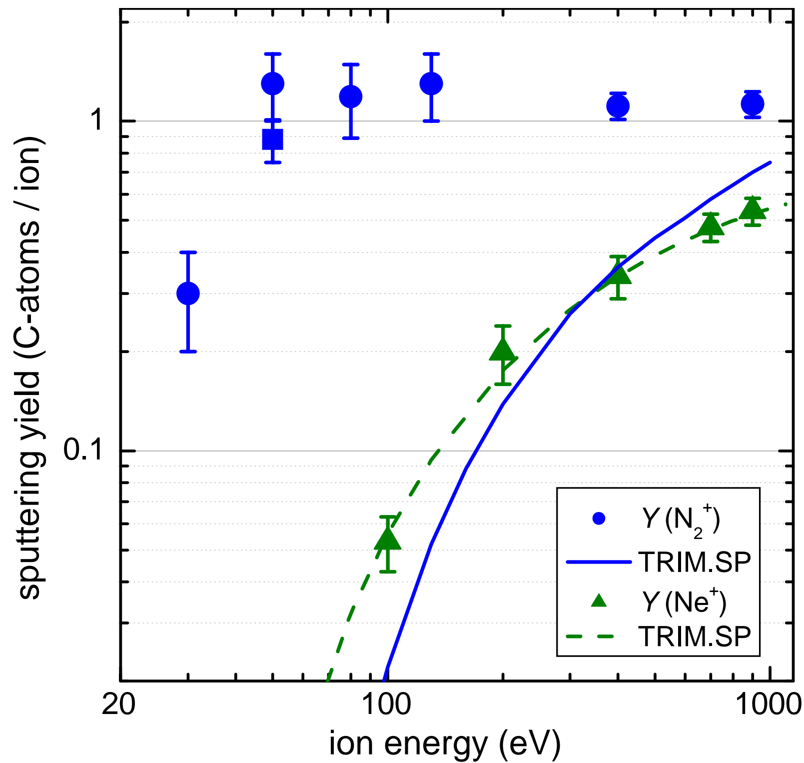
total yield = chemical sputtering + physical sputtering

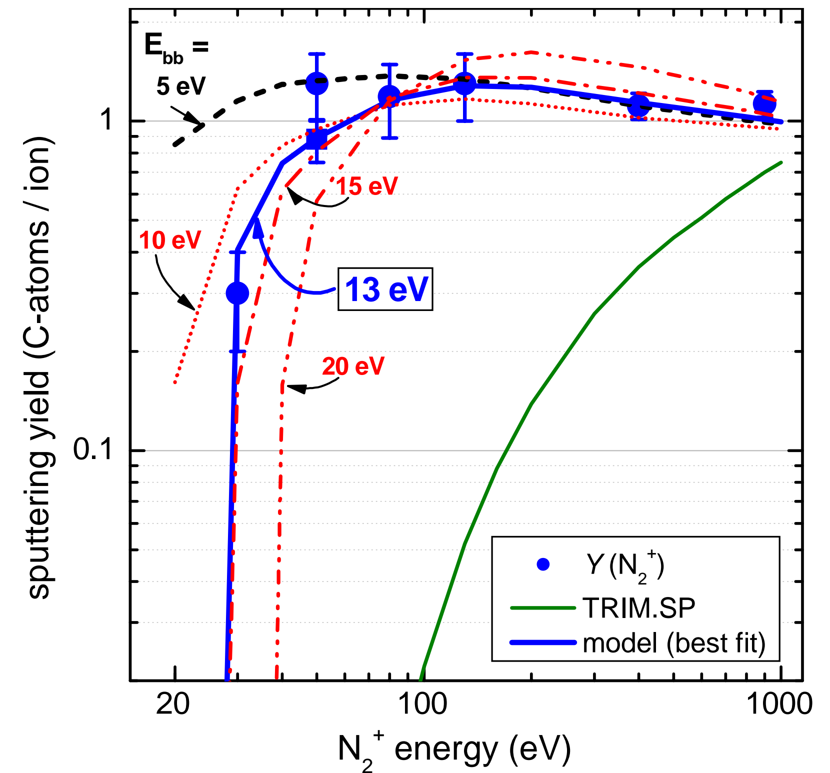
$$Y(E) = \int y_{\mathrm{bb}}^{\mathrm{C}}(x,E)\, n(x,E) \exp(-x/\lambda)\, \mathrm{d}x + Y_{\mathrm{phys}}(E)$$

$Y_{phys}(E)$	phys. sputtering yield	TRIM.SP
$y_{bb}^{C}(x,E)$	ion induced damage	$E_{sb}^{C} = 7.4$ eV $E_{bb}^{C} = 5.0$ eV
$n(x,E)$	implanted hydrogen	

$\exp(-x/\lambda)$	depth dependent probability for outdiffusion of erosion products	$\lambda = 0.4$ nm

Chemical sputtering with reactive ions: N_2^+ on a-C:H





Sputtering with N_2^+ and Ne^+ very different.

Ne^+: data = TRIM.SP

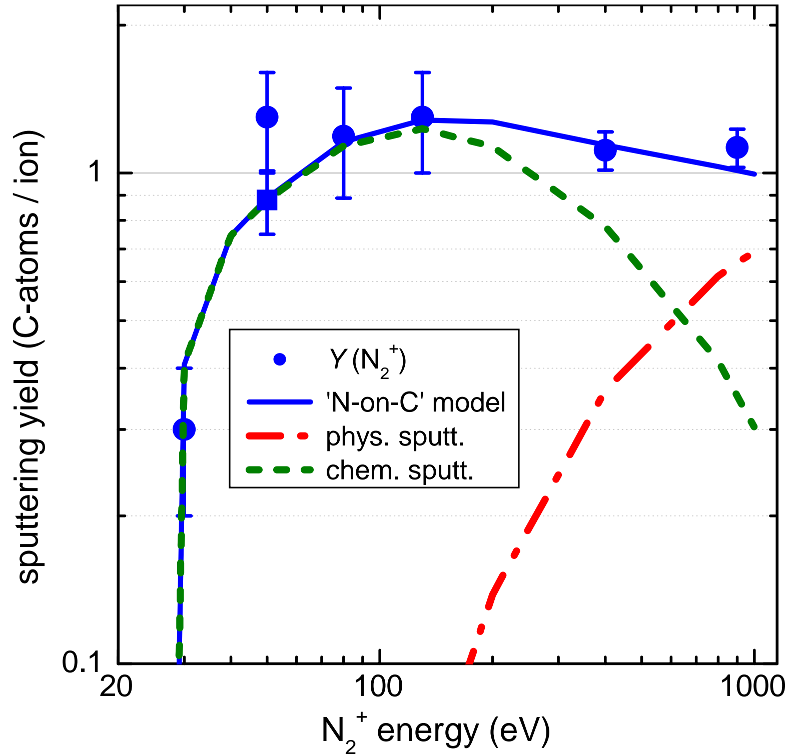
N_2^+ : data ≠ TRIM.SP

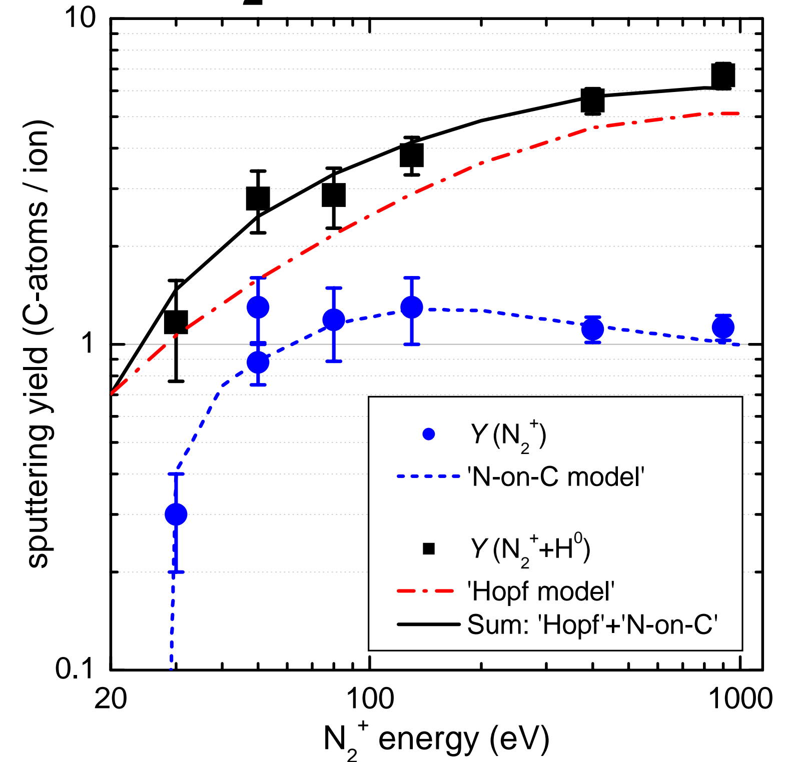
Modeling with standard parameters yields bad agreement

Fit with E_{bb} = 13 eV: very good agreement

➔ good description of H and N ions

Chemical sputtering with reactive ions: N_2^+ on a-C:H





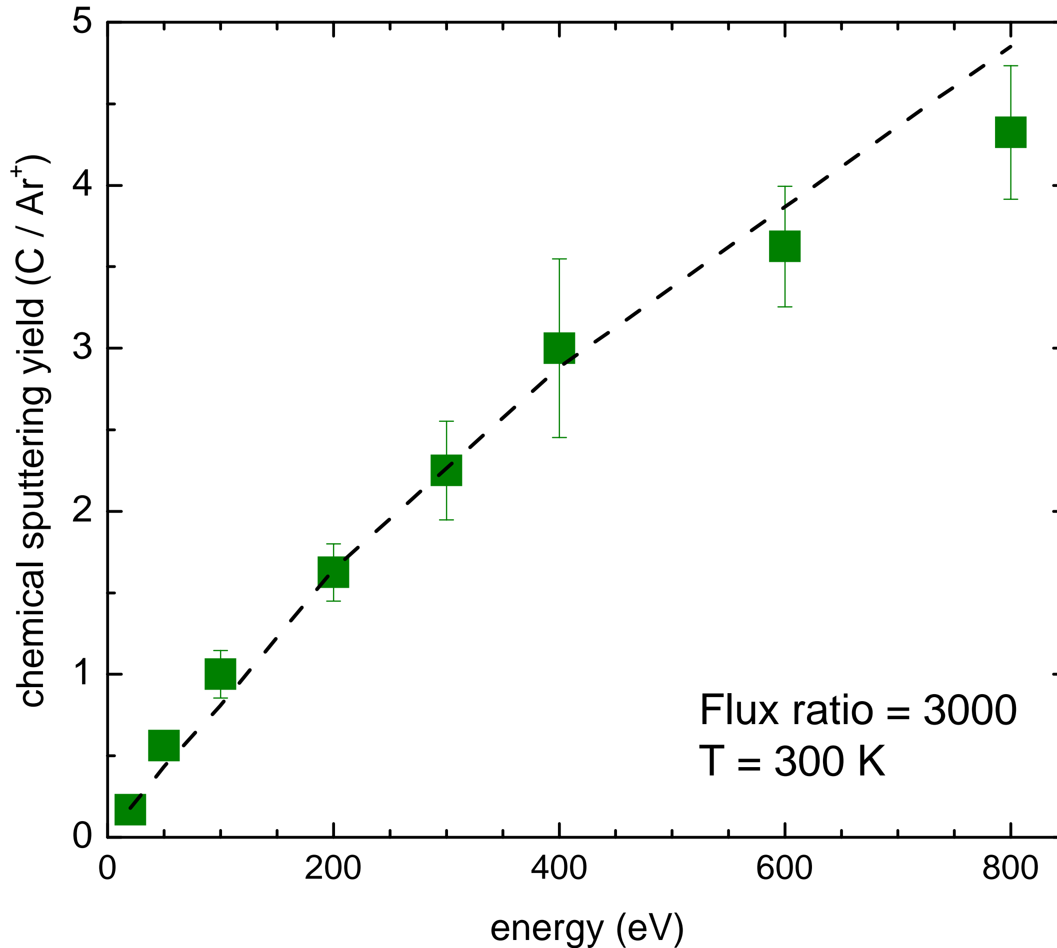
Fit with E_{bb} = 13 eV:
very good agreement

Separate plot of **chemical sputtering** and **physical sputtering** contribution

$N_2^+ + H^0$: Hopf model yields moderate agreement

Hopf model + 'N-on-C' model:
➔ good description of data

Energy dependence: $Ar^+ + O_2$



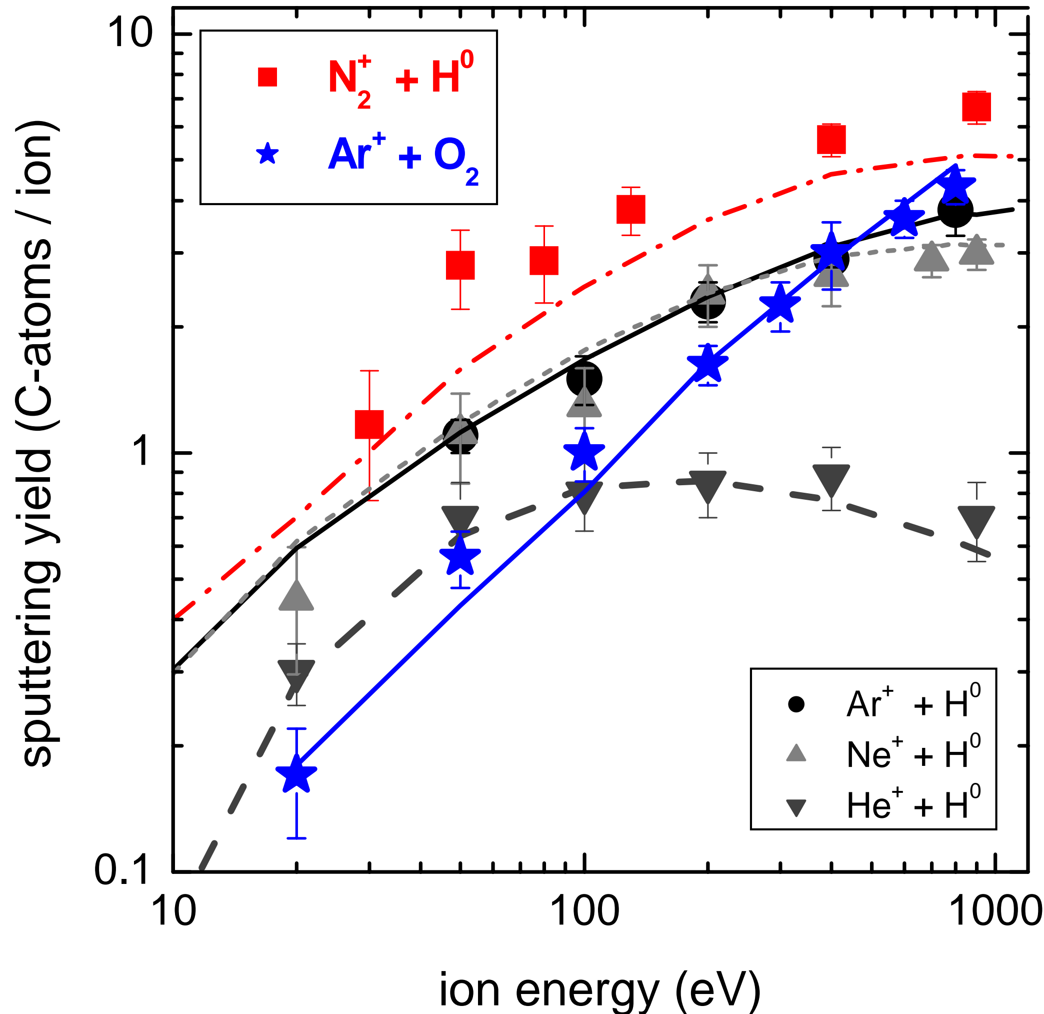
Strong increase of yield with increasing ion energy

Obviously, the ion bombardment plays a decisive role

No saturation up to 800 eV

Increases with flux ratio

Chemical sputtering: Summary



$Ar^+ + O_2$ shows similar behavior as $Ar^+ + H^0$ or $N_2^+ + H^0$

Sputtering yields are of comparable amplitude

No saturation up to 800 eV (except He)

Increases with flux ratio

Zusammenfassung

IPP

Beschuss von a-C:H Filmen mit Ionen führt im Beisein von H^0 oder O_2 zu starker chemischer Zerstäubung

- **Zerstäubungsausbeute steigt mit**
  - zunehmendem Flussverhältnis (reaktive Neutrale/Ionen)
  - zunehmender Ionenenergie
  - mit zunehmender T (therm. aktivierte chemische Prozesse)
- **Ratengleichungsmodell erlaubt konsistente Beschreibung** (Energie-, Temperatur- und Flußverhältnisabhängigkeit
- **Ratenbestimmender Schritt ist in allen Fällen der Energieeintrag durch energetische Teilchen** (ballistische Prozesse)