An investigation of target poisoning during reactive magnetron sputtering using ion beam analysis and energy resolved mass spectroscopy

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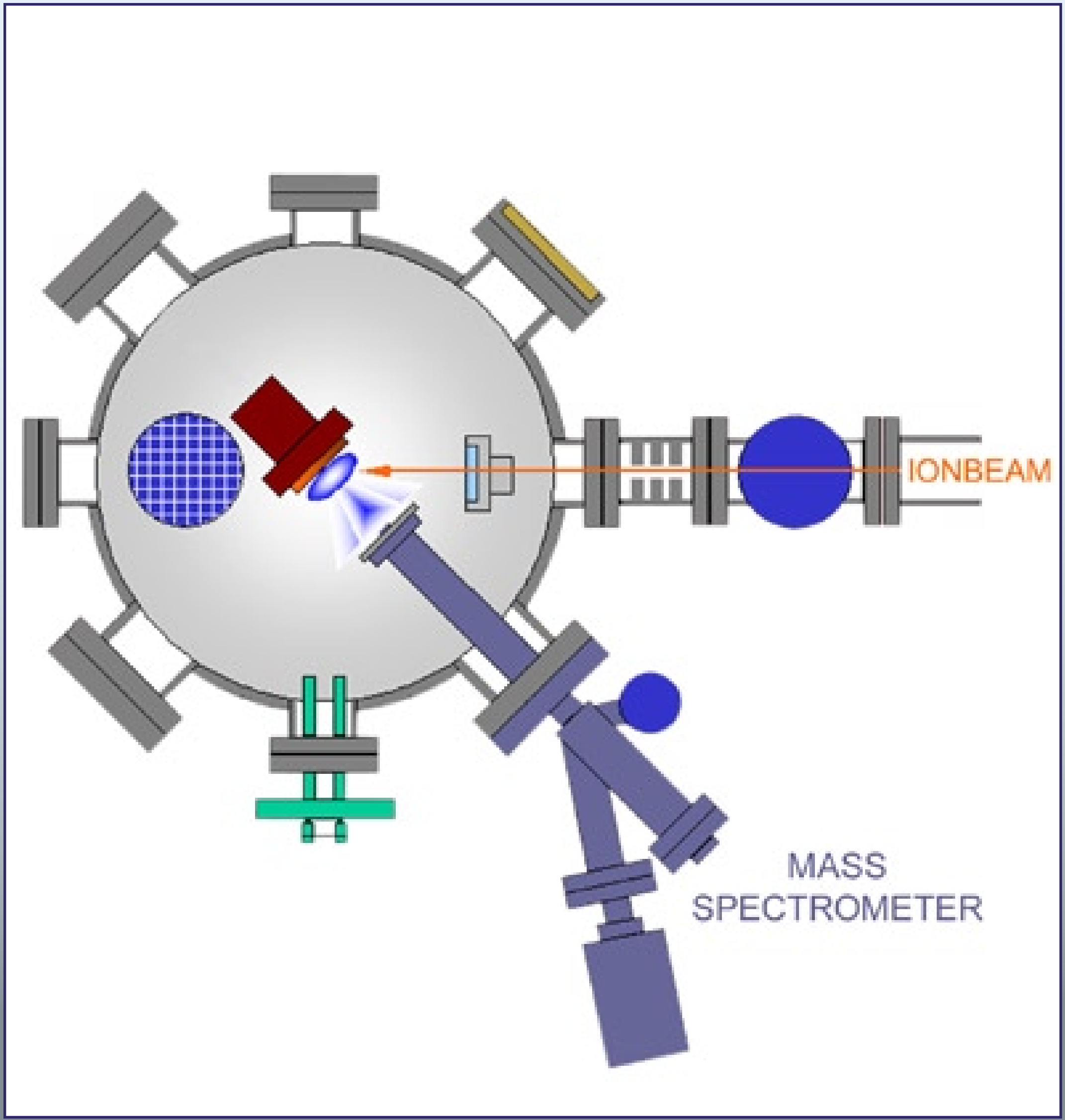
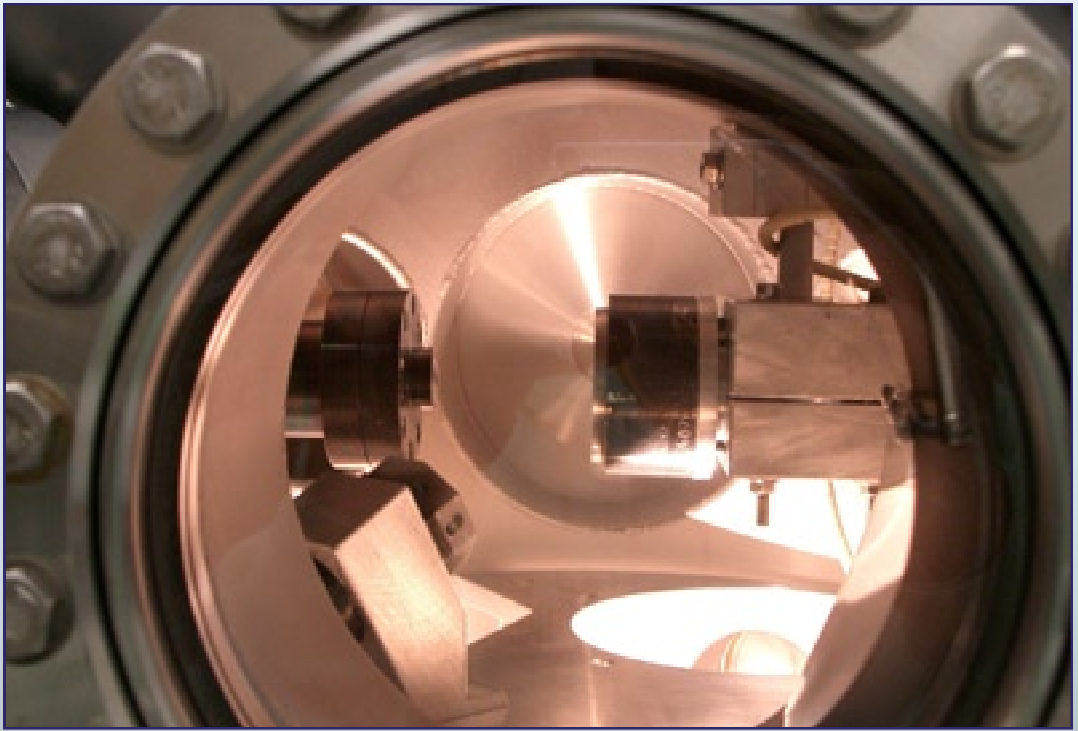
experimental setup





[2 inch magnetron, Ti target

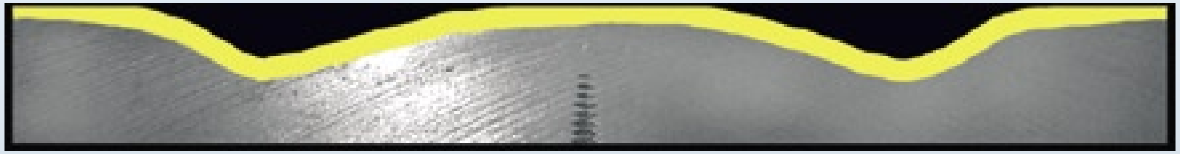
[reactive sputtering in Ar / N_2

[P ~ 120 W (U_T = 370 V, I_T=300 mA)

[IBA - concentration of Nitrogen in the target
MS - plasma species and sputtered particles
...both in situ, during sputtering

motivation

- reactive sputtering: sputtering of elemental targets in the presence of reactive gases (O_2, N_2)
- target poisoning: gas reacts with ejected target material and target surface



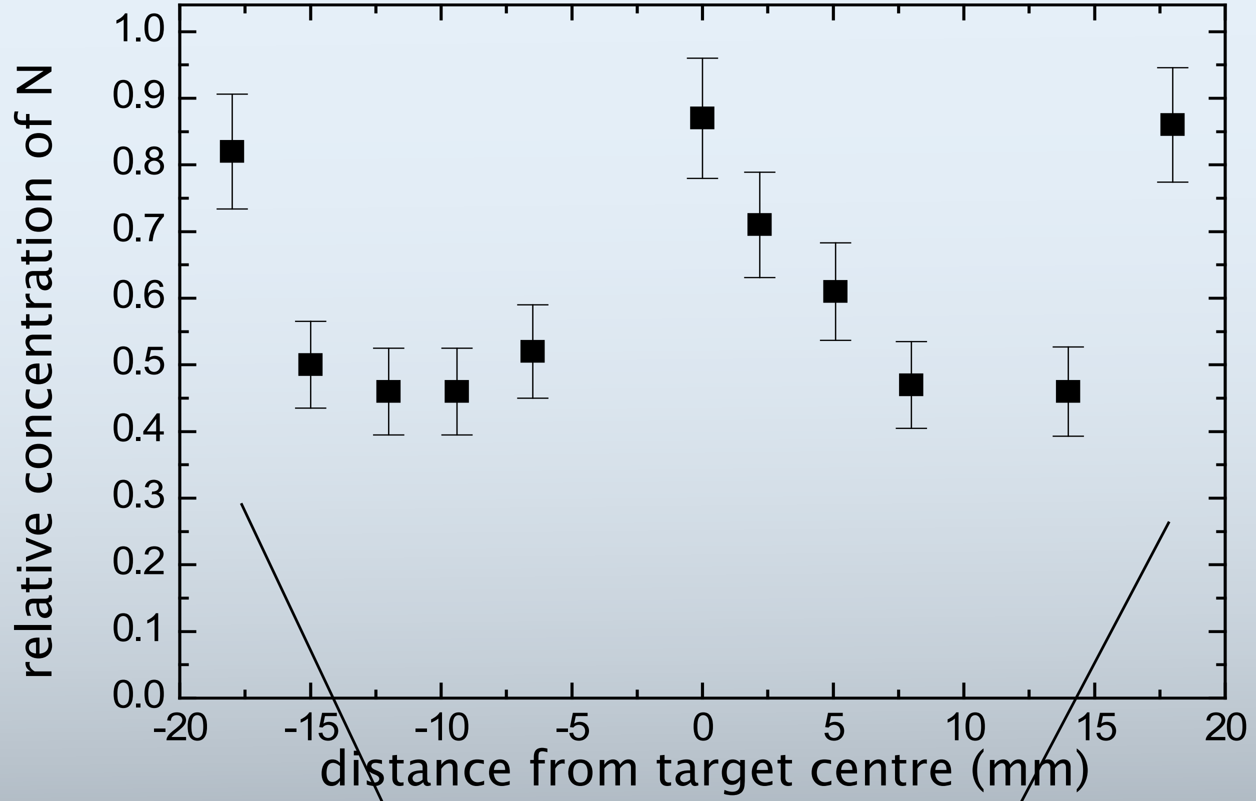
- compound layer formation on the target surface
  - ➽ strong reduction of sputter rate
  - ➽ unstable process parameters

- model of poisoning:
  - consider a homogeneous layer formation on the target due to homogeneous particle fluxes to the target
  - taking into account: $p_{\text{react. gas}}$, pumping speed, sputter yield
  - allows only a simplified understanding

(What happens on the target?)

- experiments: – show a different behaviour

ion beam analysis (across the target)



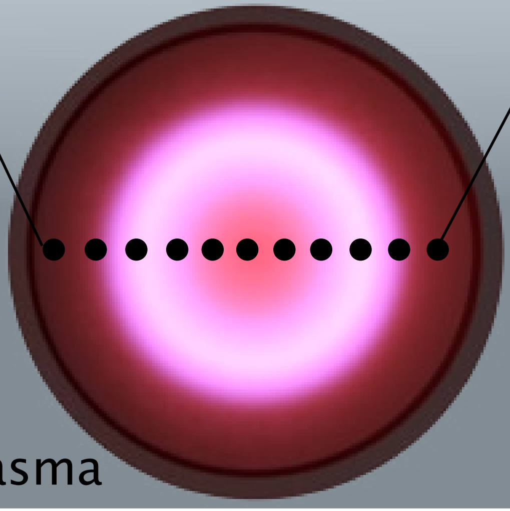


Fig.: view into a
magnetron plasma

[Nitrogen concentration is not homogeneous

[significantly lower in the race track than in the centre & at the edge

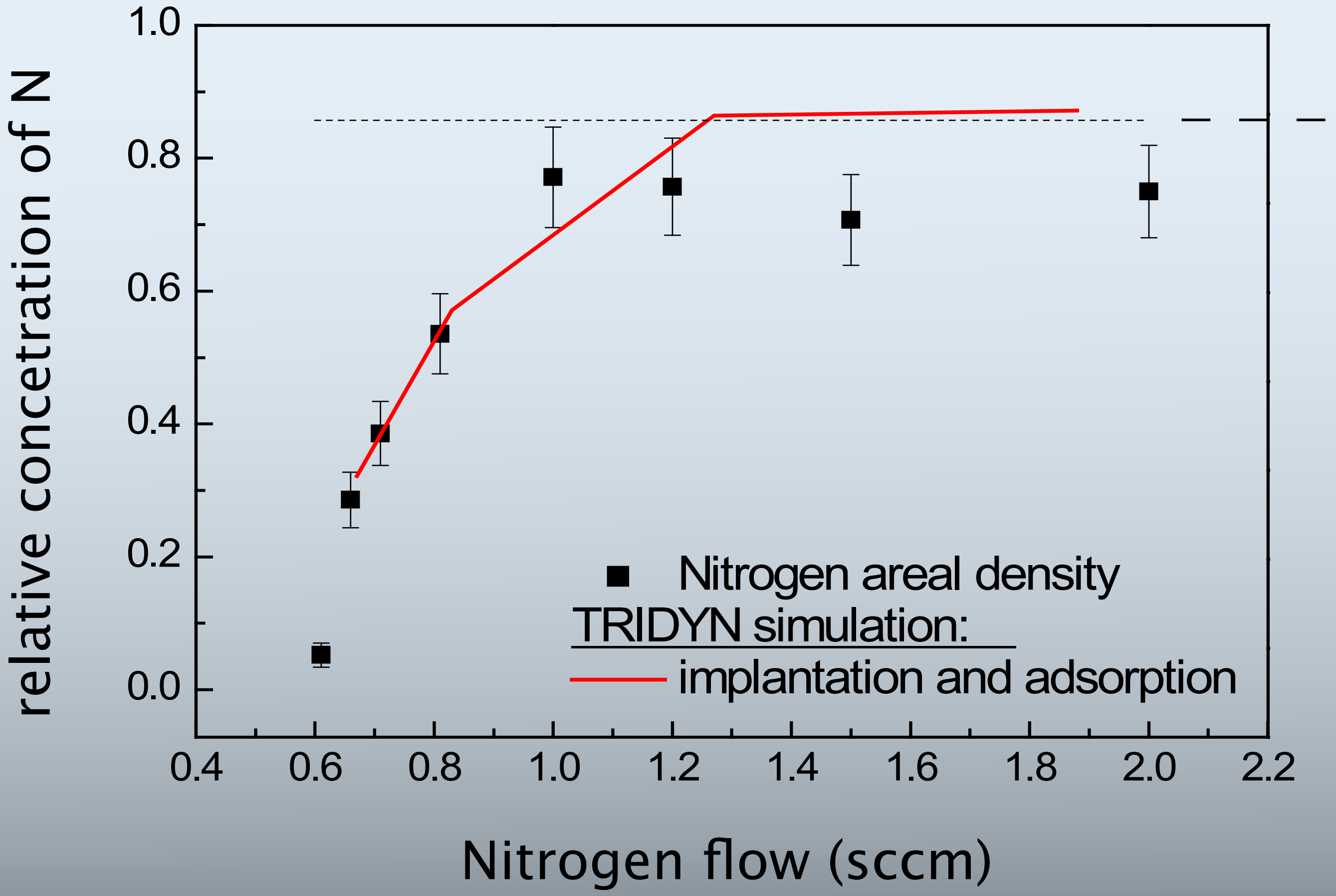
[cannot be explained by existing models

our aim:

[find the mechanism which lowers the target poisoning

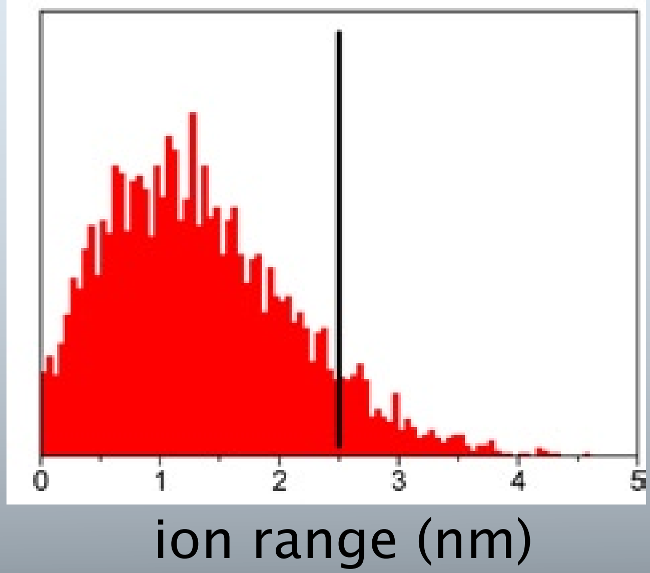
ion beam analysis (race track)

Concentration of Nitrogen in the race track



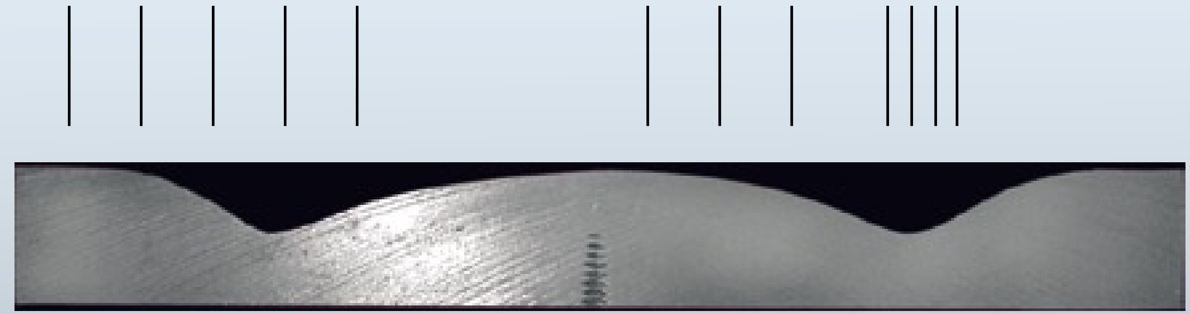
N concentration in stoichiometric TiN for a layer thickness of 2.5 nm

implantation depth profile (N)



[value of concentration exceeds the value of one adsorbed mono layer
[implantation of nitrogen takes place
[N which is not chemicaly bonded in TiN diffuses out

particel fluxes



[neutrals: Ar, N_2, N

constant flux due to the partial pressure

[ions: Ar^+, N_2^+, N^+
[neutrals: N

low flux density

high flux density

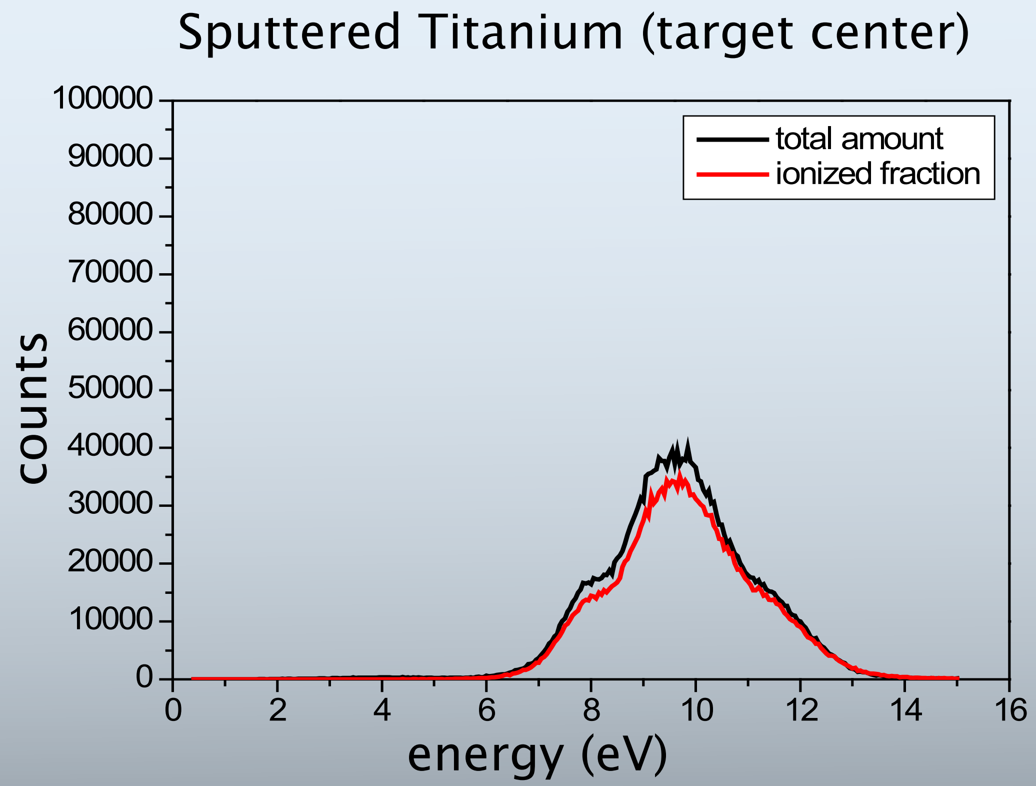
Fig.: cross section magnetron target

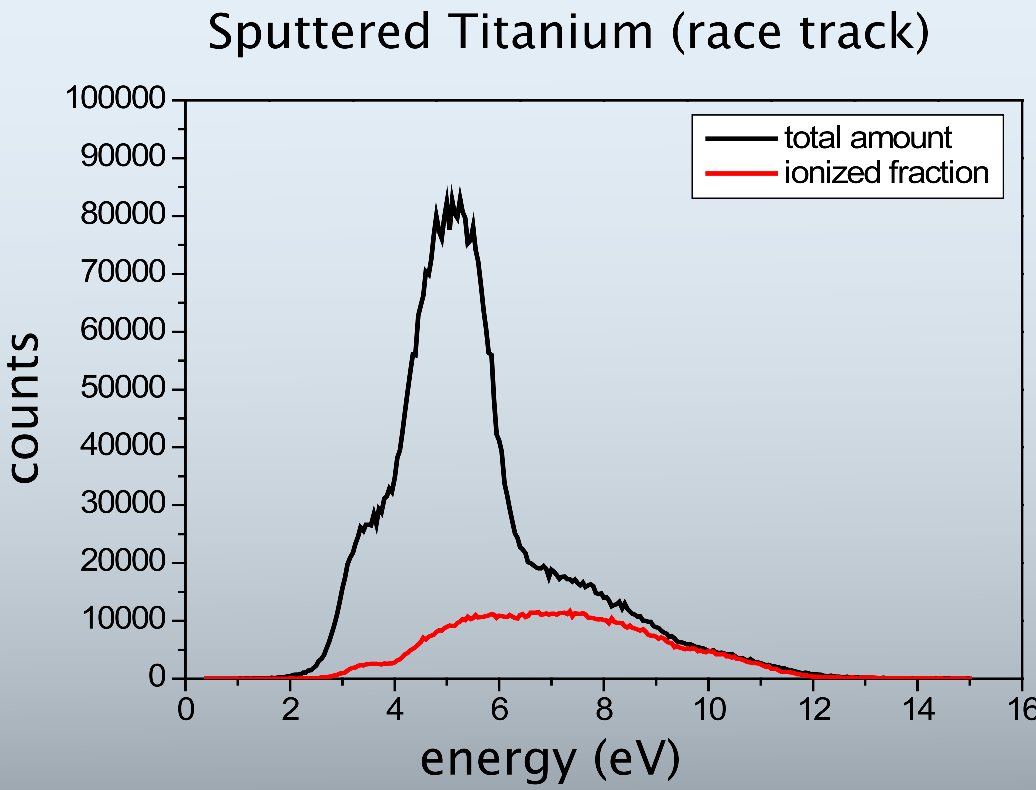
[possibility for a diagnostic with the mass spectrometer ?

[characterization of different fluxes
[change of relation between the certain fluxes across the target
[which mechanism dominates the poisoning (implantation or adsorption and chemisorption)

mass spectroscopy (sputtered Ti)

(sputtering without Nitrogen)


Sputtered Titanium (target center)


Sputtered Titanium (race track)

target centre:

[almost all sputtered particles are ionized
[mean energy around 10 eV

race track:

[increased yield of sputtered Ti
[small ionized fraction
[mean energy around 5-6 eV

mass spectroscopy (sputtered Ti)

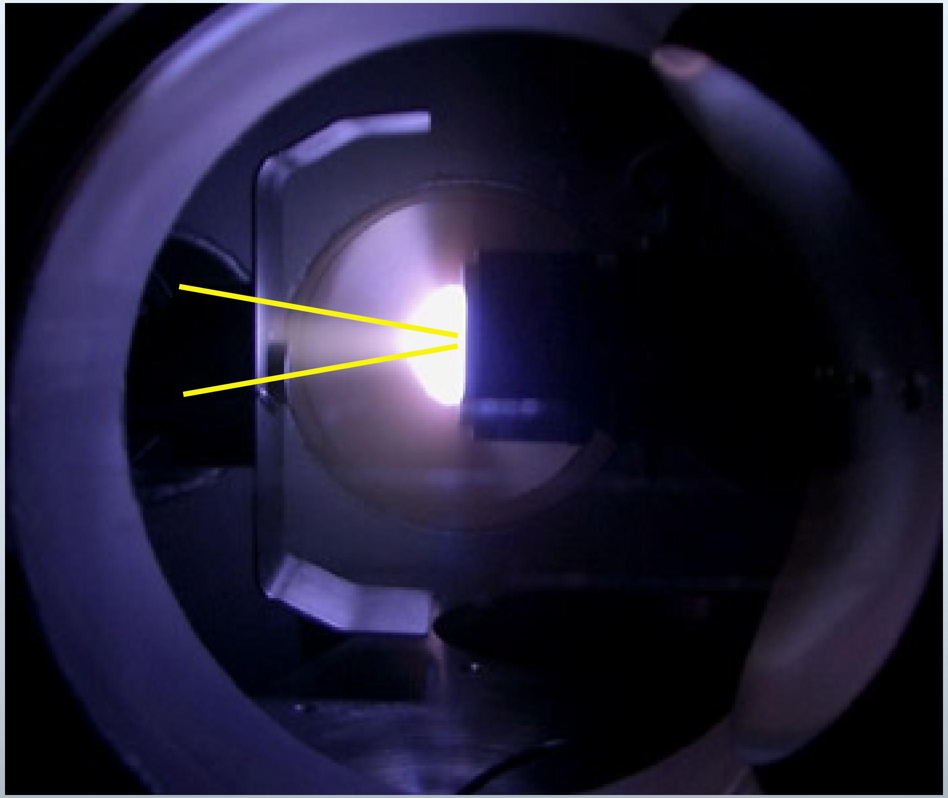
Origin of ionized fraction

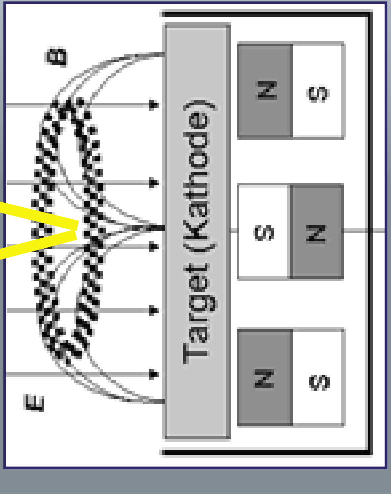
region of plasma after glow:
(centre up to 10 mm outside)

[most of sputtered Ti get ionized
[energy around 10 eV

outside this region:

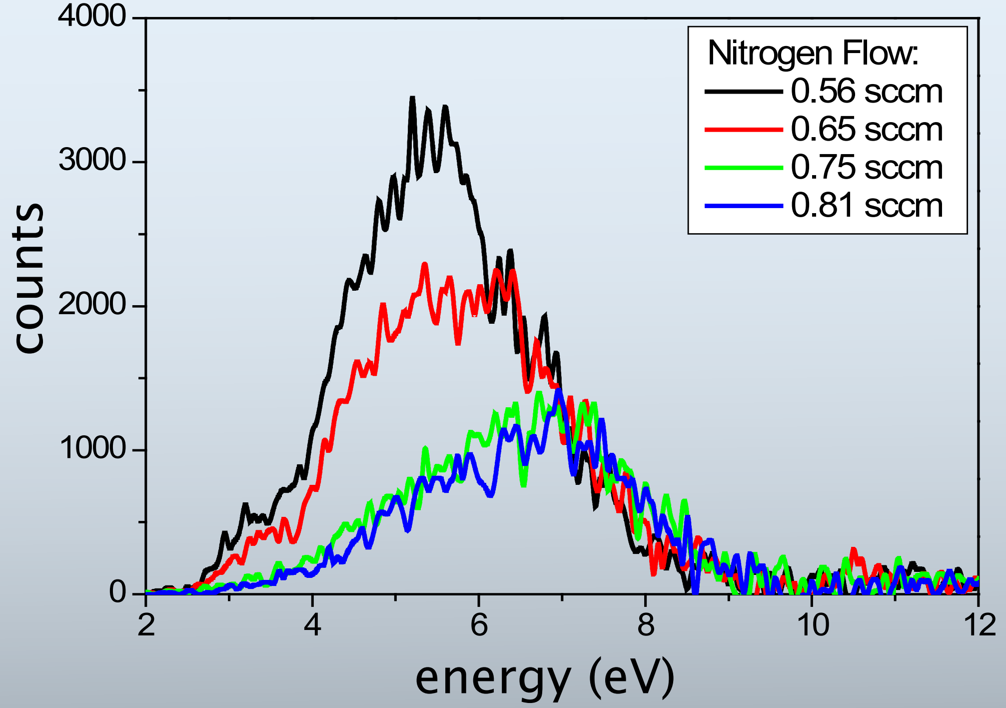
[less ions reach the spectrometer
[lower energy – around 5–6 eV



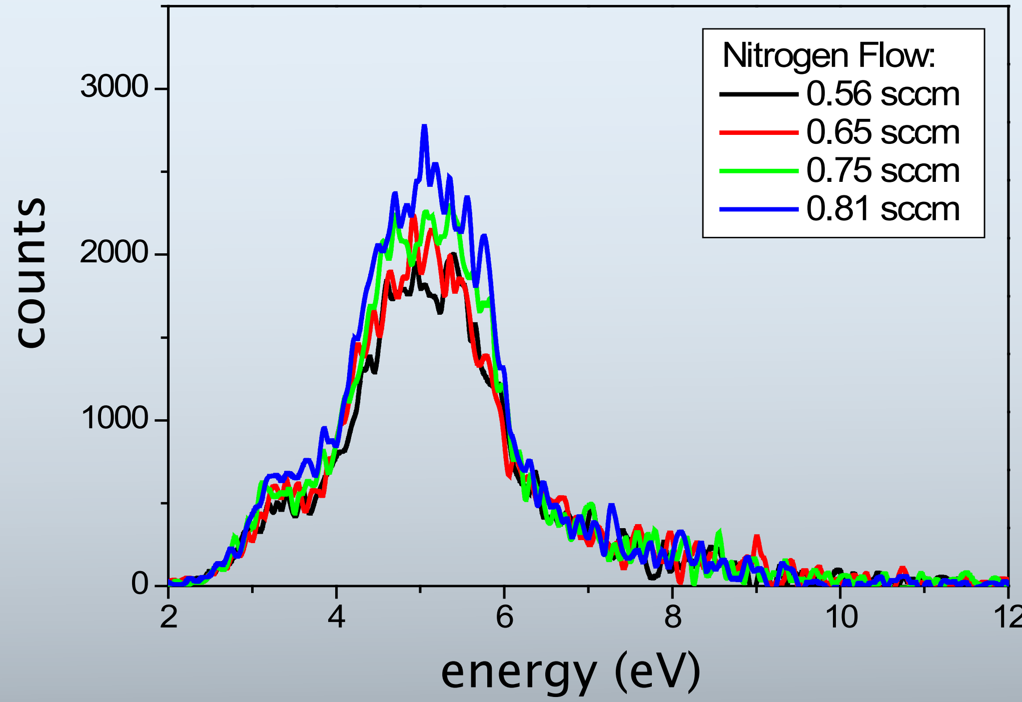


ionization due to
escaping electrons
(unbalanced part)

mass spectroscopy (reactive sputtered Ti)



Energy distribution of Titanium neutrals (target centre)



Energy distribution of Titanium neutrals (race track)

[energy of sputtered particle shift (surface binding energy Ti/TiN ?)

[yield decreases with increasing nitrogen flow and keeps constant

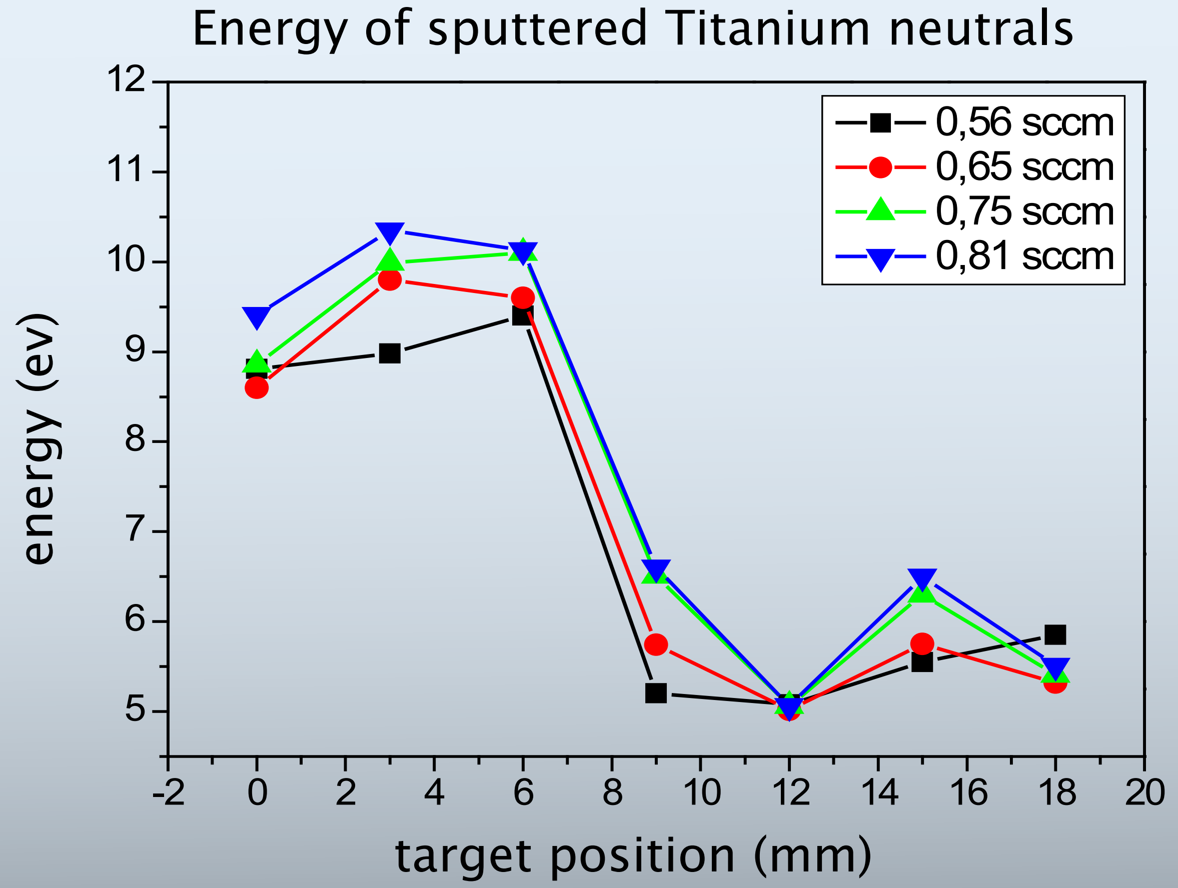
=> indicates that the target is poisoned

[no energy shift in the race track

[slightly increasing sputter yield with higher nitrogen flow

=> indicates that target is still metallic

summary energy shift (sputtered Ti)



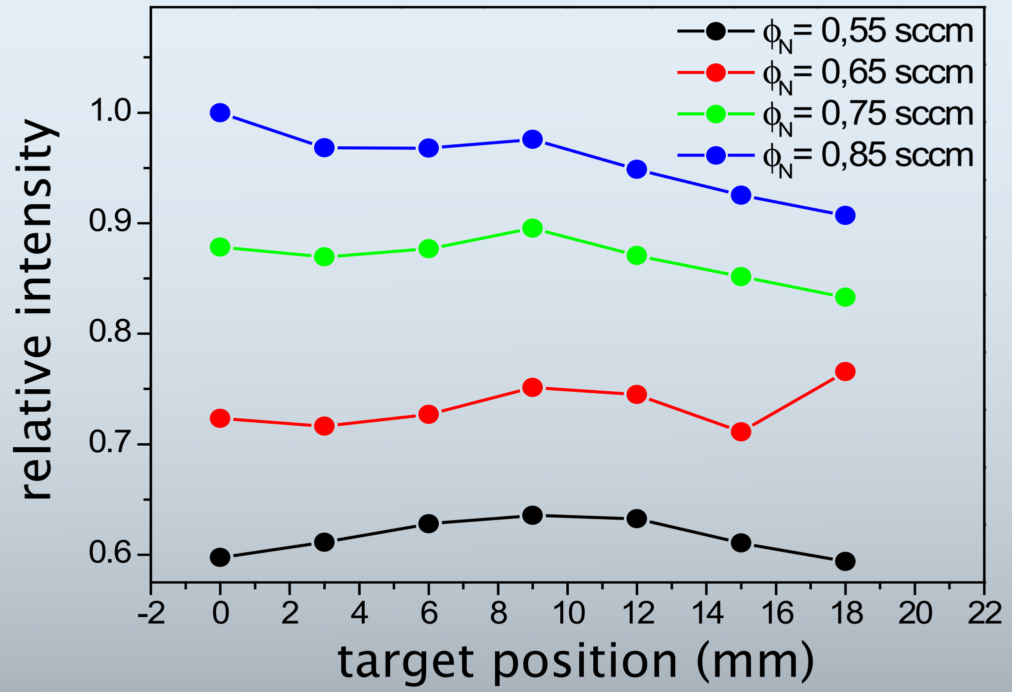
[high energy shift (due to a higher plasma potential in the plasma after glow)

[low energy shift due to the compound layer formation & different surface binding energy of Ti/TiN

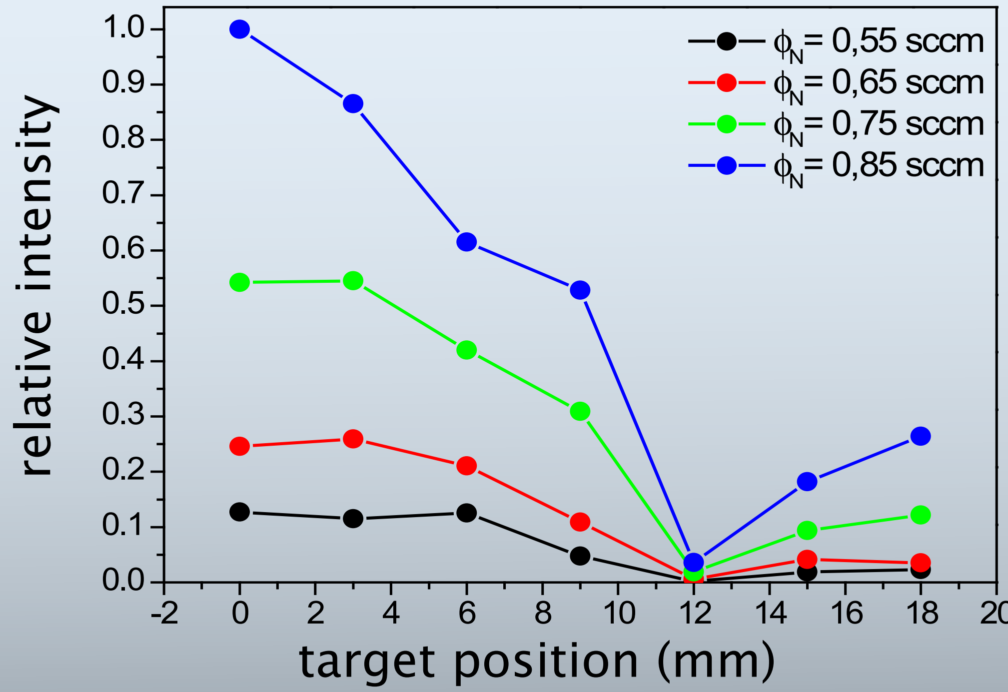
[no shift in the race track (12mm) ➻ target still metallic

N_2 yield measured across the target

Nitrogen neutrals (N_2)



Nitrogen ions (N_2^+)



[constant yield of nitrogen neutrals
=> indication for the origin – gas pressure

[low yield of nitrogen ions in the r. t.
=> possible reasons have to be discussed
[out of the plasma after glow
[influence of the magnetic field
[high dissociation N_2 –> N ?

discussion

[ion beam analysis

- nitrogen areal density $n_N = 4...11 * 10^{15}$ atoms/cm^2
- saturation at a concentration when stoichimetric TiN is formed

=> proved that implantation and adsorption of reactive gas takes place

- found a lower reactive gas concentration in the race track

=>characterization of particel fluxes with energy resolved mass spectrometer

[energy shift in the energy distribution of ions

- big shift ... for the sputtering in Ar & Ar/N_2 => changed plasma potential
- small shift... in connection with the nitrogen flow => indicates target poisoning and the changed surface binding energy Ti<->TiN

[constant yield of nitrogen neutrals across the target => no sputtering of N_2

[small amount of Nitrogen ions N_2^+ in the region of the race track

- but high ionization in this region

=> Do they disappear on their way to the mass spectrometer?

=> Is there a high dissoziation $N_2^+ \rightarrow 2N^x$?