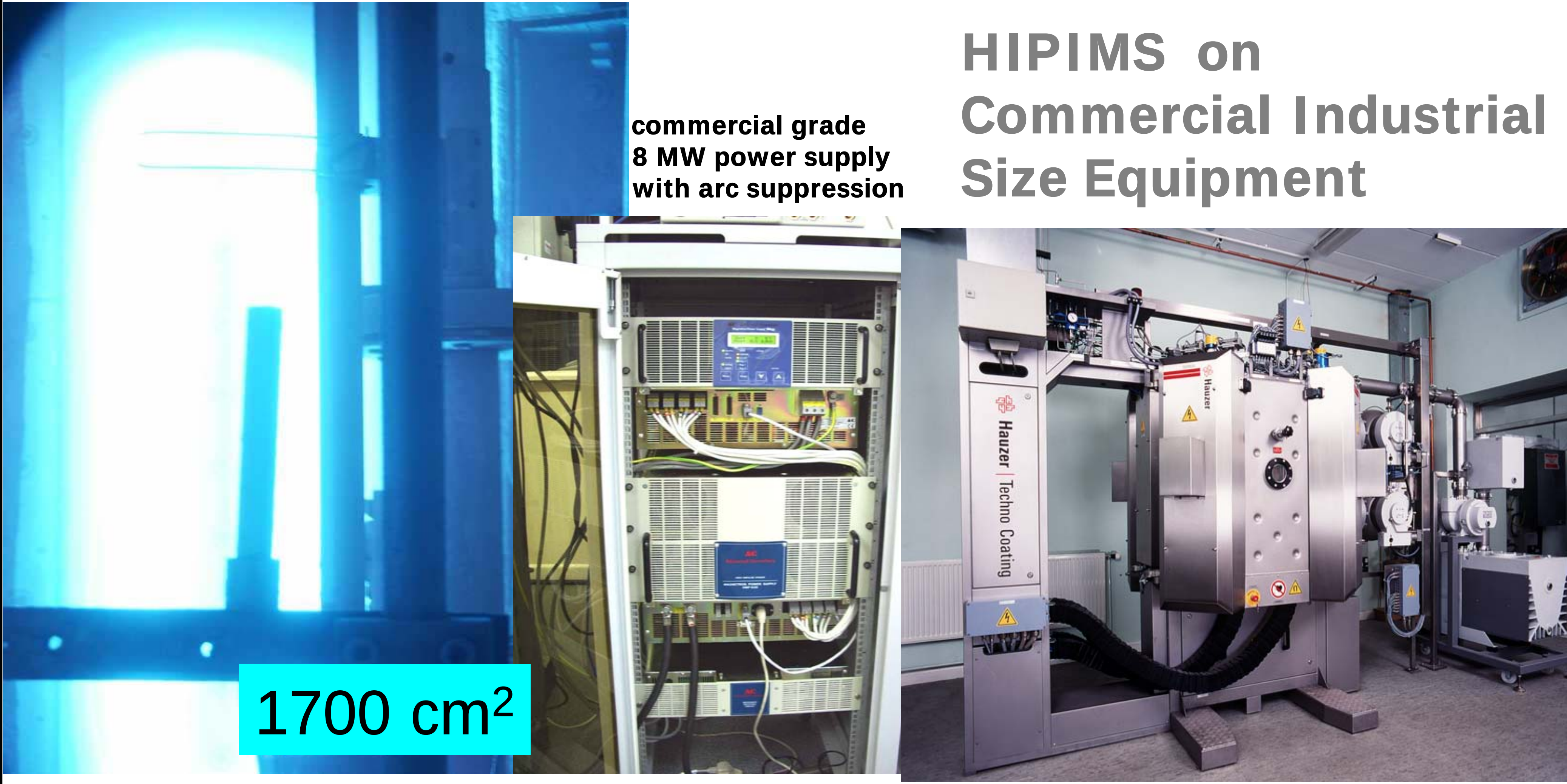
HIPIMS on Commercial Industrial Size Equipment



commercial grade
8 MW power supply
with arc suppression

1700 cm^2

MIICS 2008

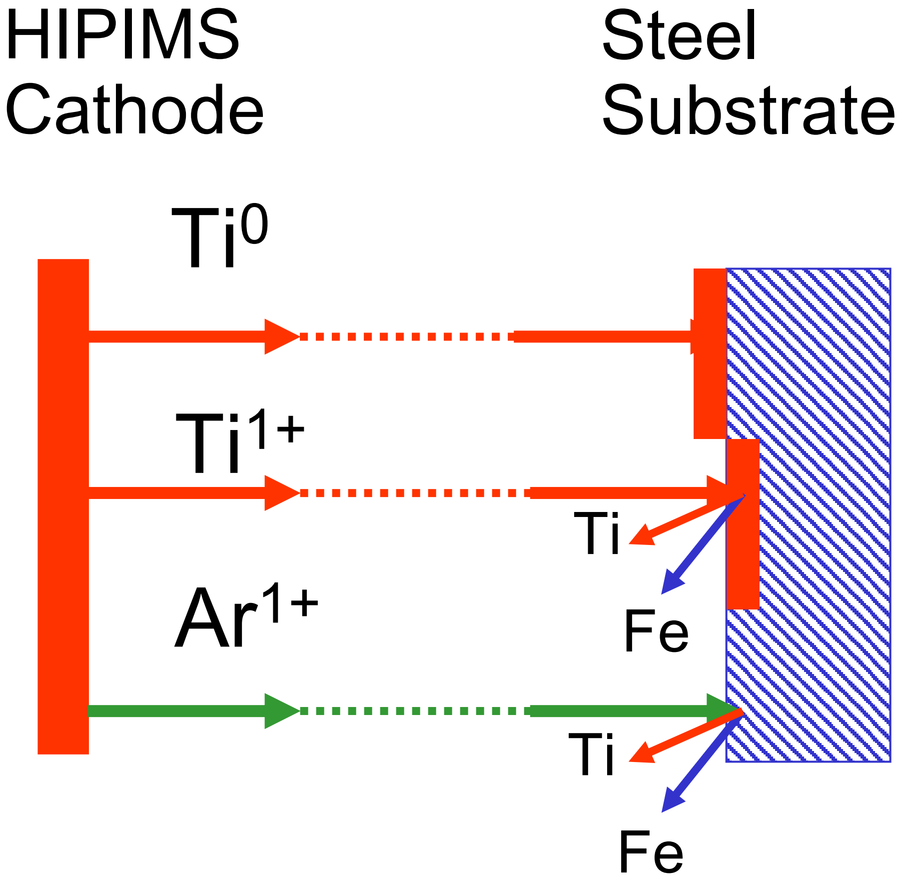
Mikkeli, 27 March 2008; 10:45

Current Progress and New Results in Characterising the HIPIMS Plasma

A.P. Ehiasarian, A. Vetushka, A. Hecimovic,
Sheffield Hallam University

S. Konstantinidis, Université de Mons-Hainaut, Belgium

Motivation



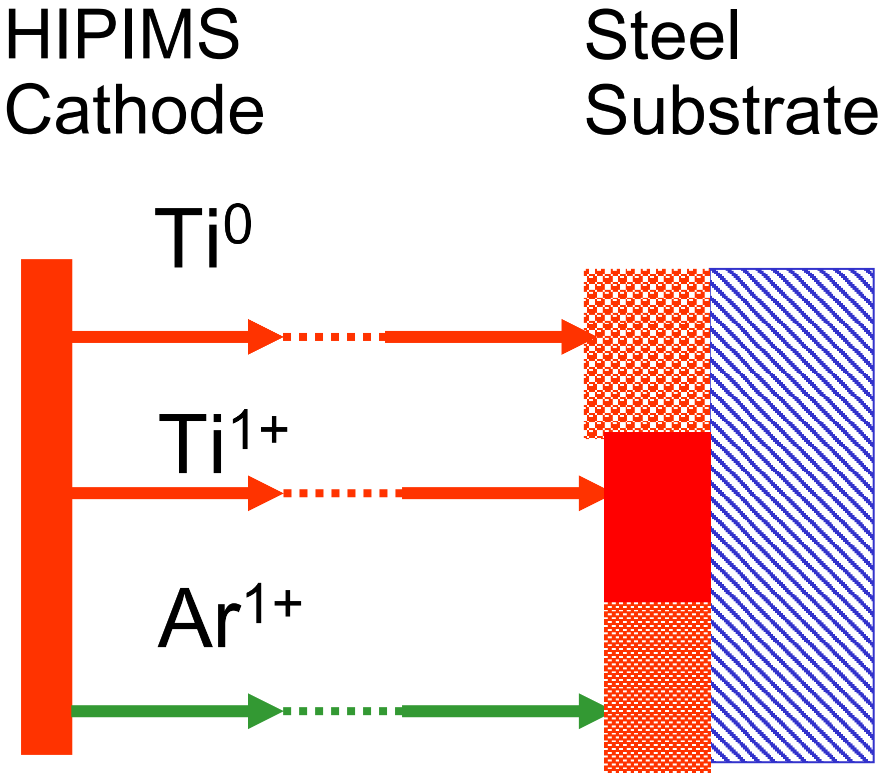
- **Pretreatment**

•Competing processes:

- •deposition -> J_n
- •etching + implantation + diffusion
- -Ji*SY + Ji*Ei + Ji*Q(T)
- •etching
- Ji*SY

Motivation

- Deposition

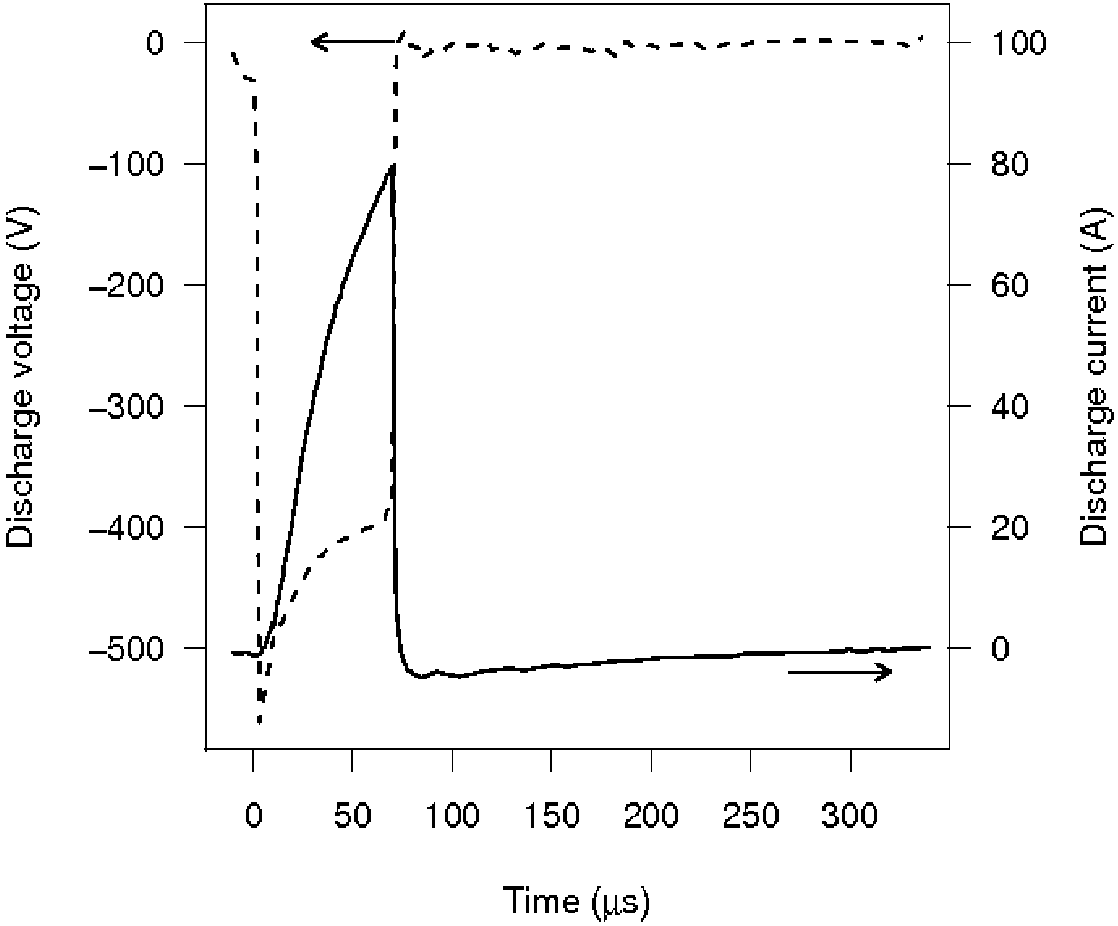


•deposition at 3 eV

•deposition at U_{Bias} + subplantation

•bombardment at U_{Bias}

HIPIMS Parameters

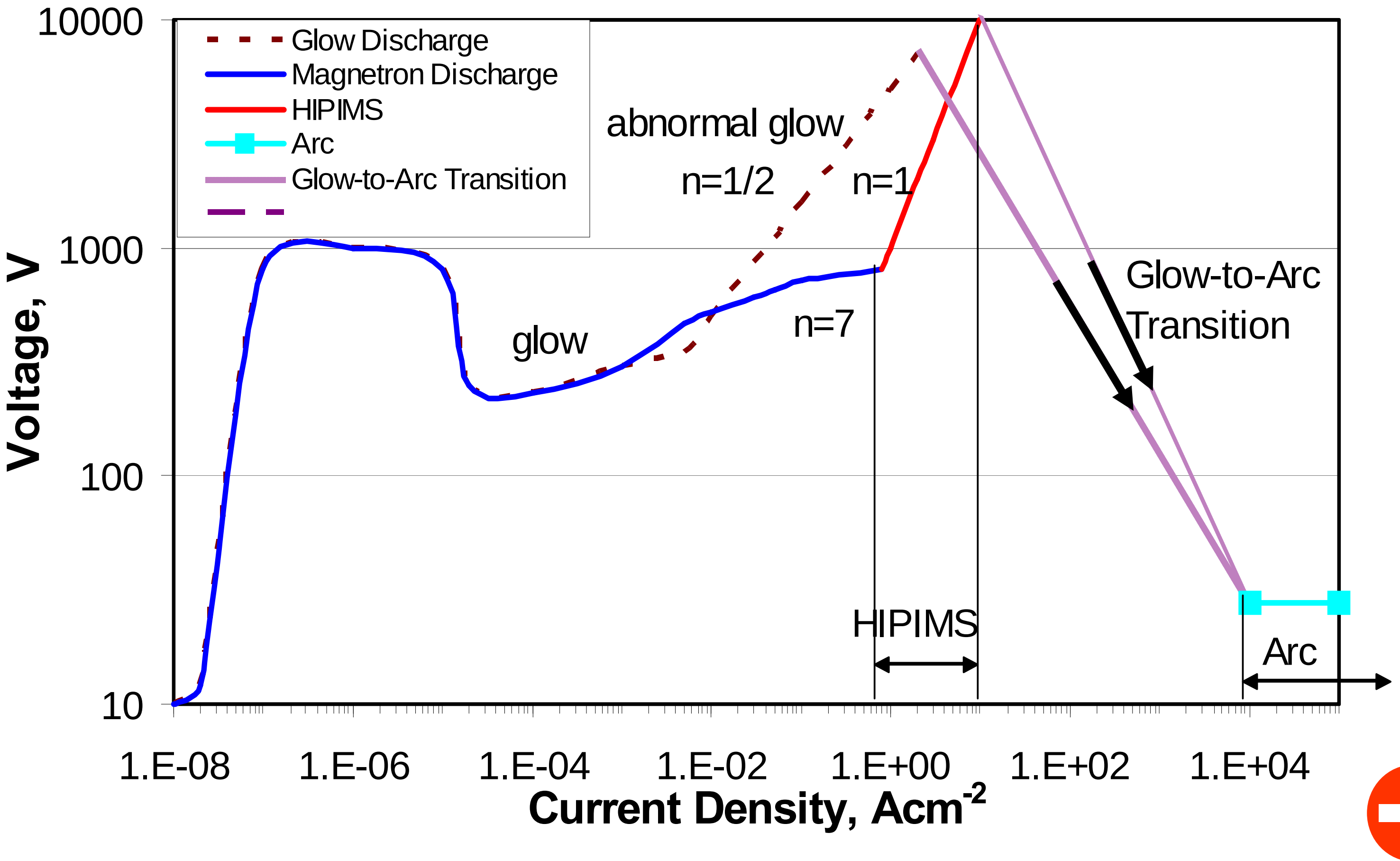


Current density = 1.6 Acm^{-2}
Power Density = 700 Wcm^{-2}

Pulse frequency = 500 Hz
Active Arc suppression

Target area = 48 cm^2

I-V Characteristic



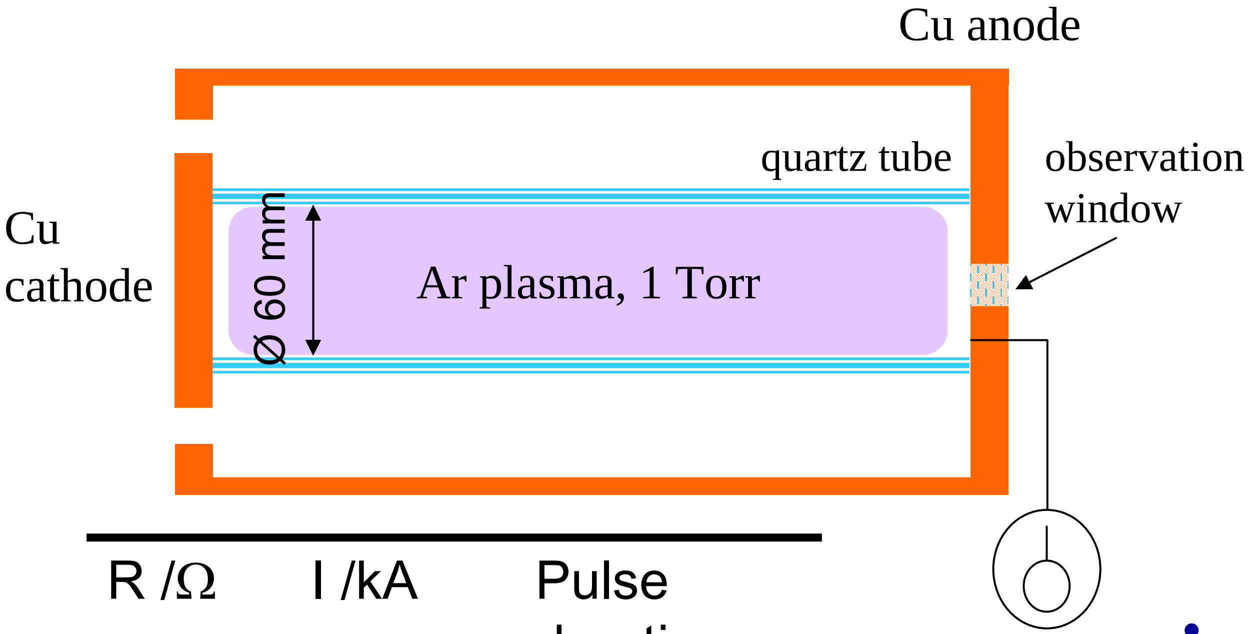
the defining parameter is Current Density, J

J_{HIPIMS} < 1e2 Acm^{-2}

J_{Arc} >1e4 Acm^{-2}

⛔ Arc -> HIPIMS transition is impossible

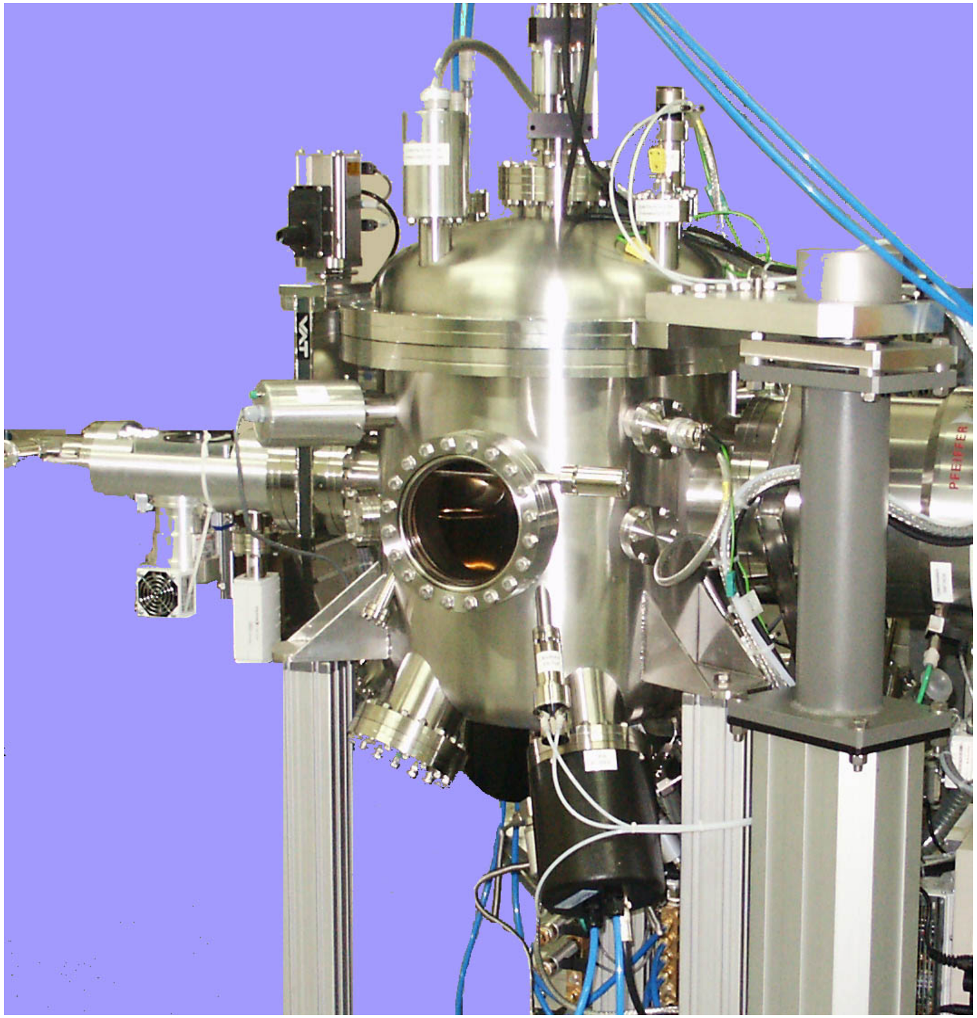
High Current Glow Discharges

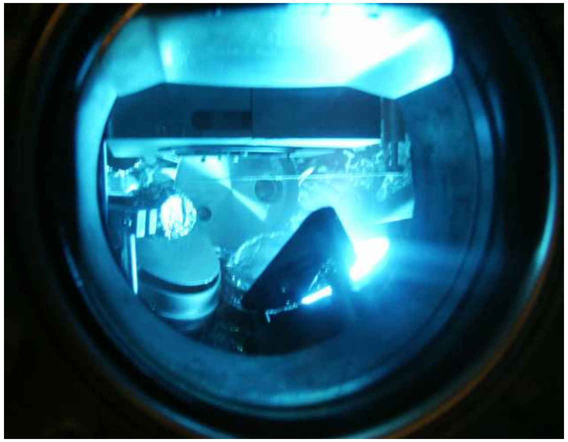


R /Ω	I /kA	Pulse duration /µs
3.0	2	666
1.0	6	220
0.5	12	106
0.23	24	50

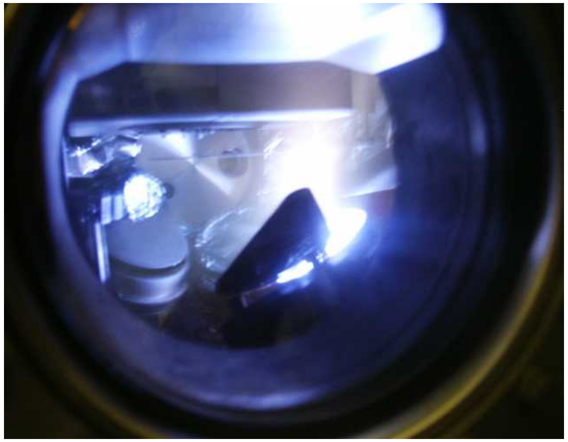
- No magnetic field
- High pressure of 1 Torr required
- Studies of gas plasmas (no deposition)

O.A. Malkin, 1972-76
Moscow Engineering Physics Institute
Book: Impulse Current and Relaxation in Gases



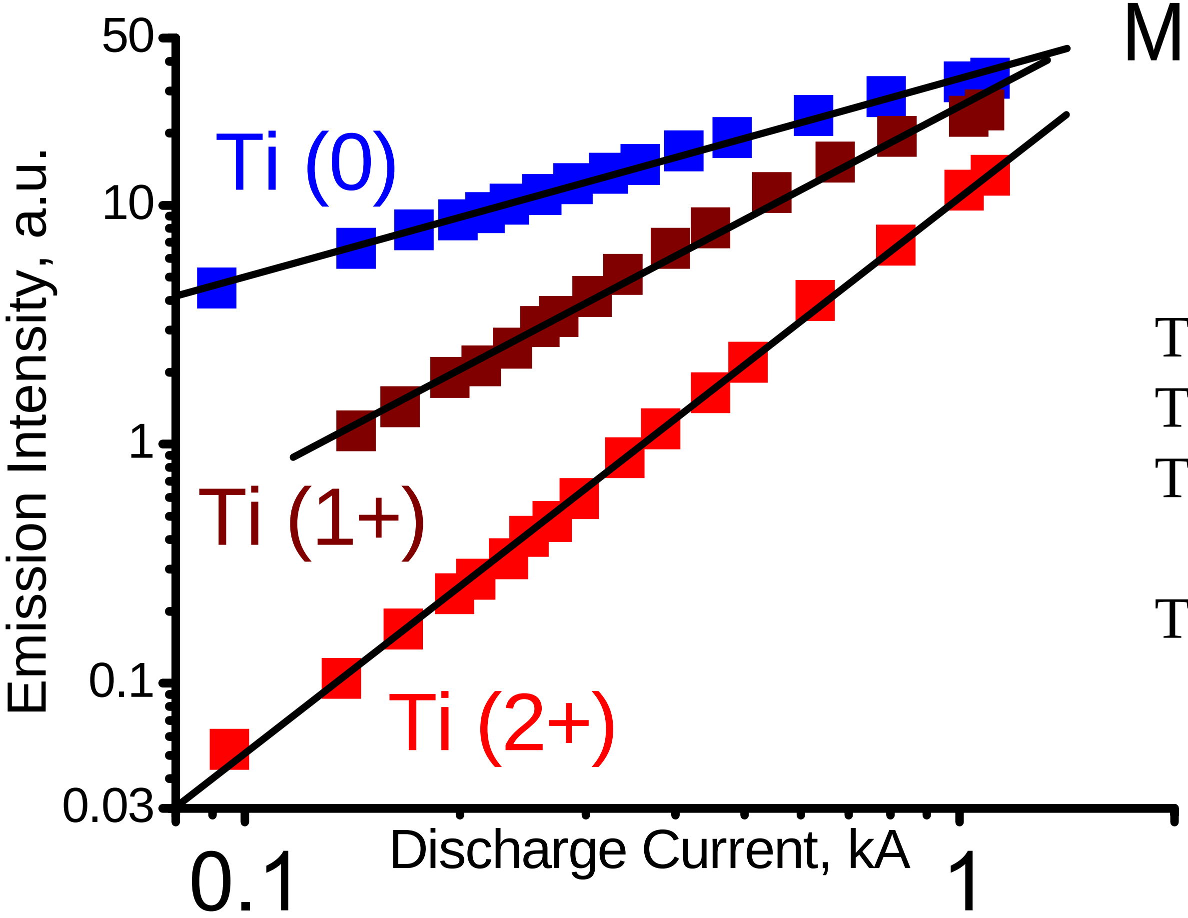


HIPIMS



conventional DC-sputtering

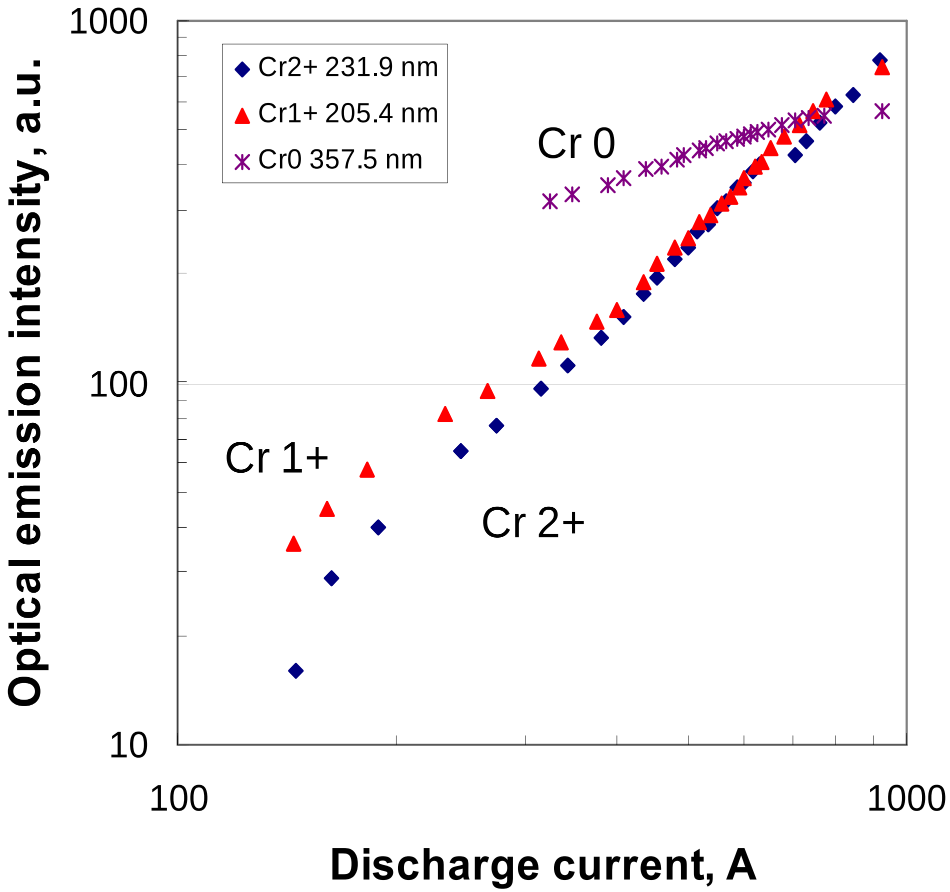
Metal Ionisation - OES



Ti 0 slope 0.8
Ti 1+ slope 1.5
Ti 2+ slope 2

Ti 1+ : Ti 0 slope = 2

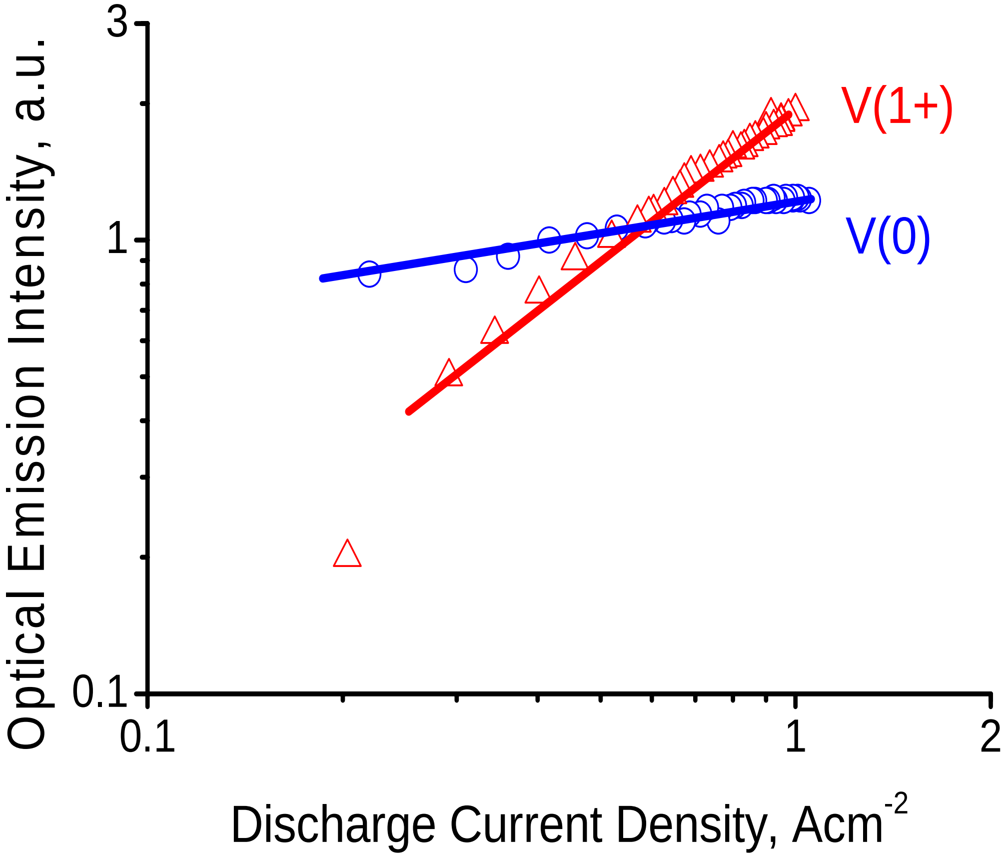
Metal Ionisation - OES

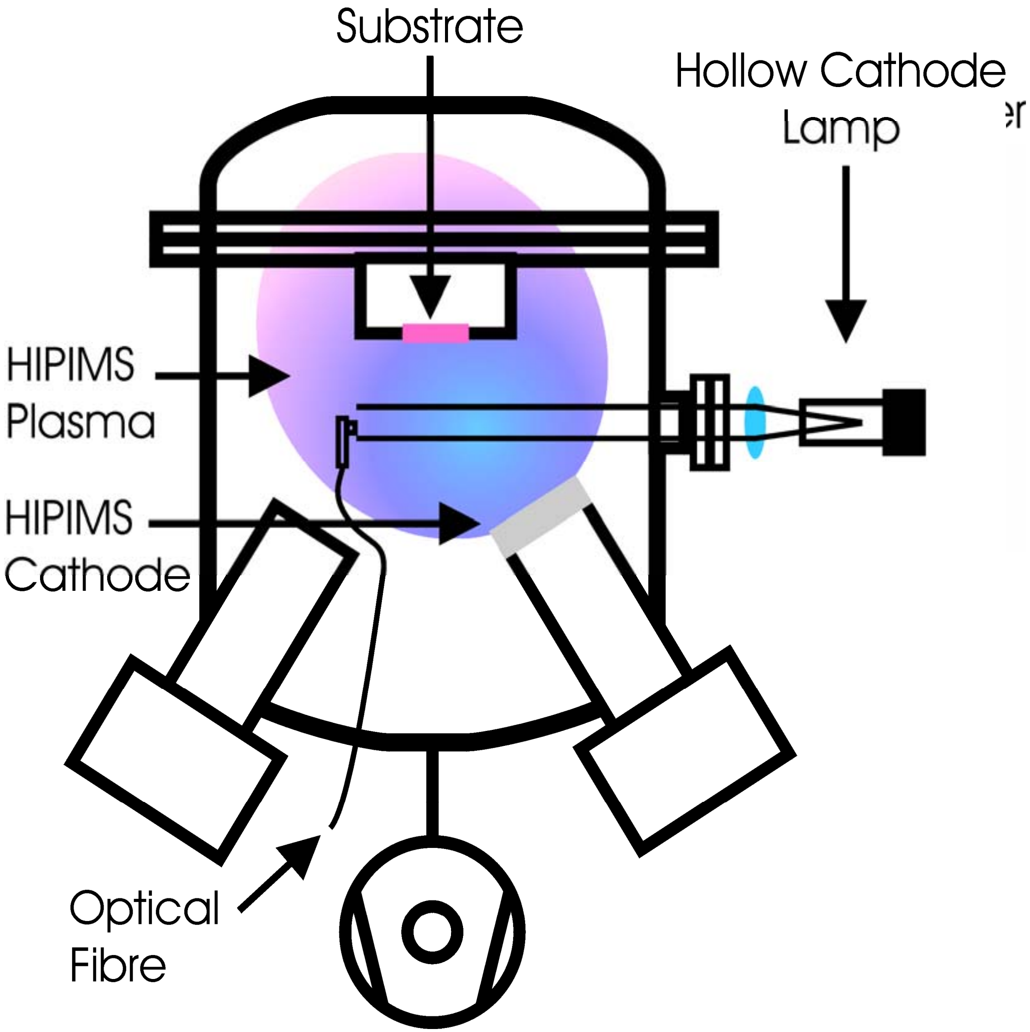


Cr 0 slope 0.56
Cr 1+ slope 1.8

Cr1+ : Cr 0 slope = 3

Metal Ionisation - OES

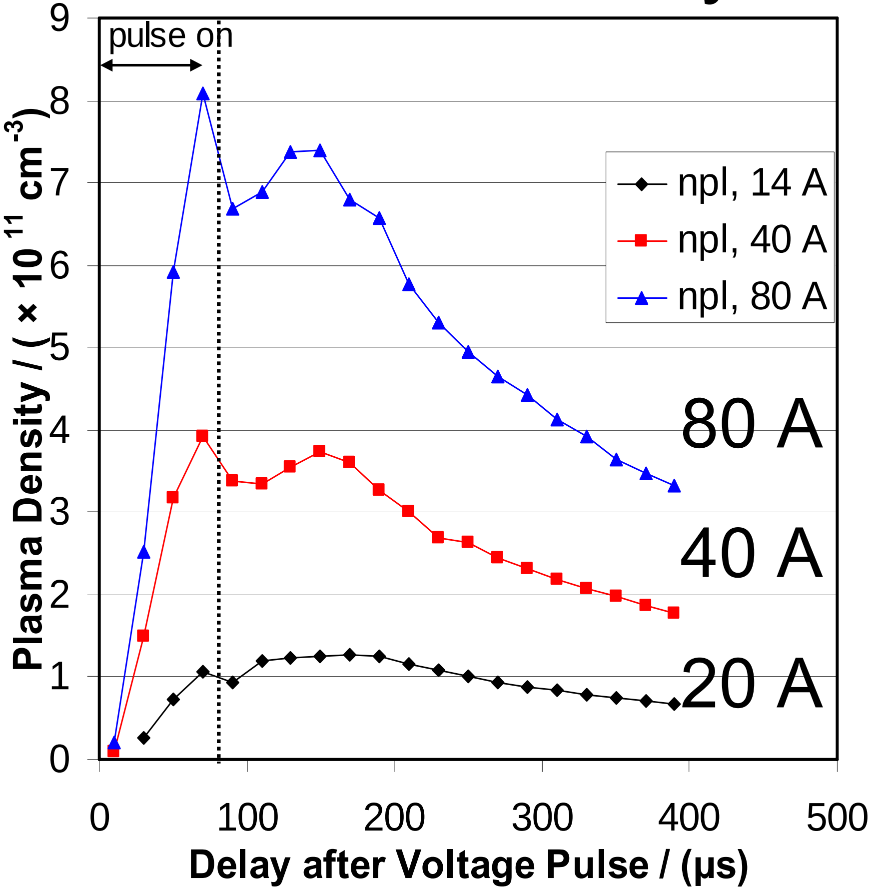




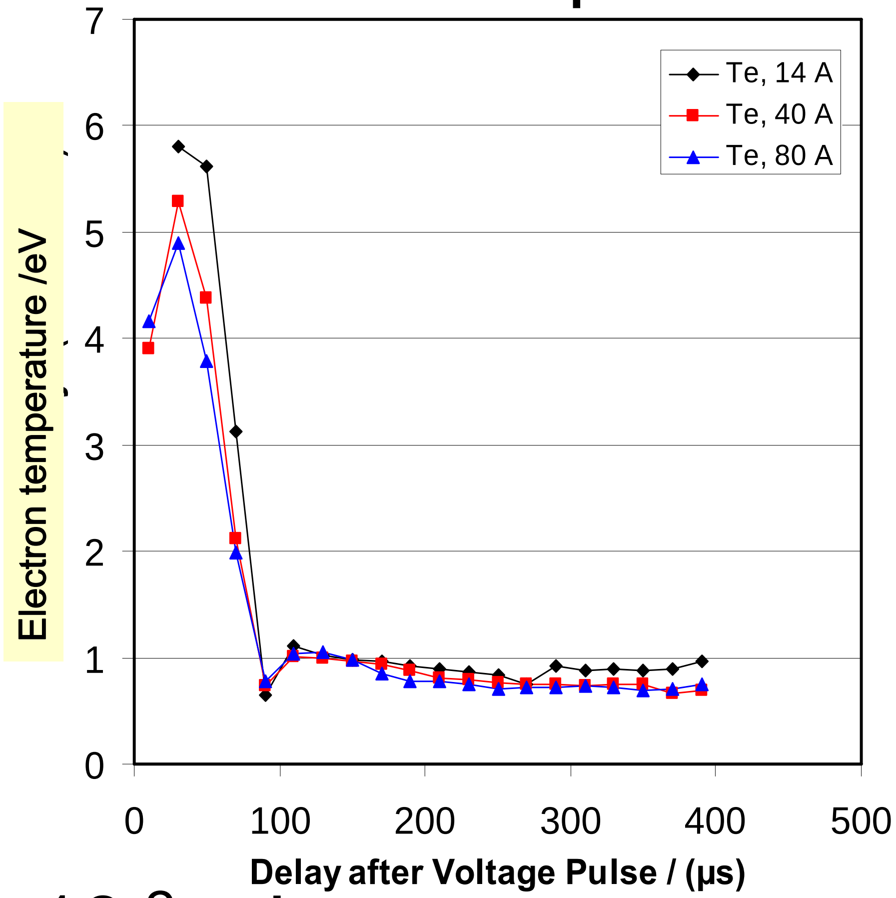
Plasma Diagnostics

- Ion Composition –
  Plasma Sampling Mass Spectroscopy (Hiden Analytical)
- Plasma Density –
  Langmuir Probe (Hiden Analytical)
- Ion to neutral ratio –
  Optical Absorption Spectroscopy

Plasma density

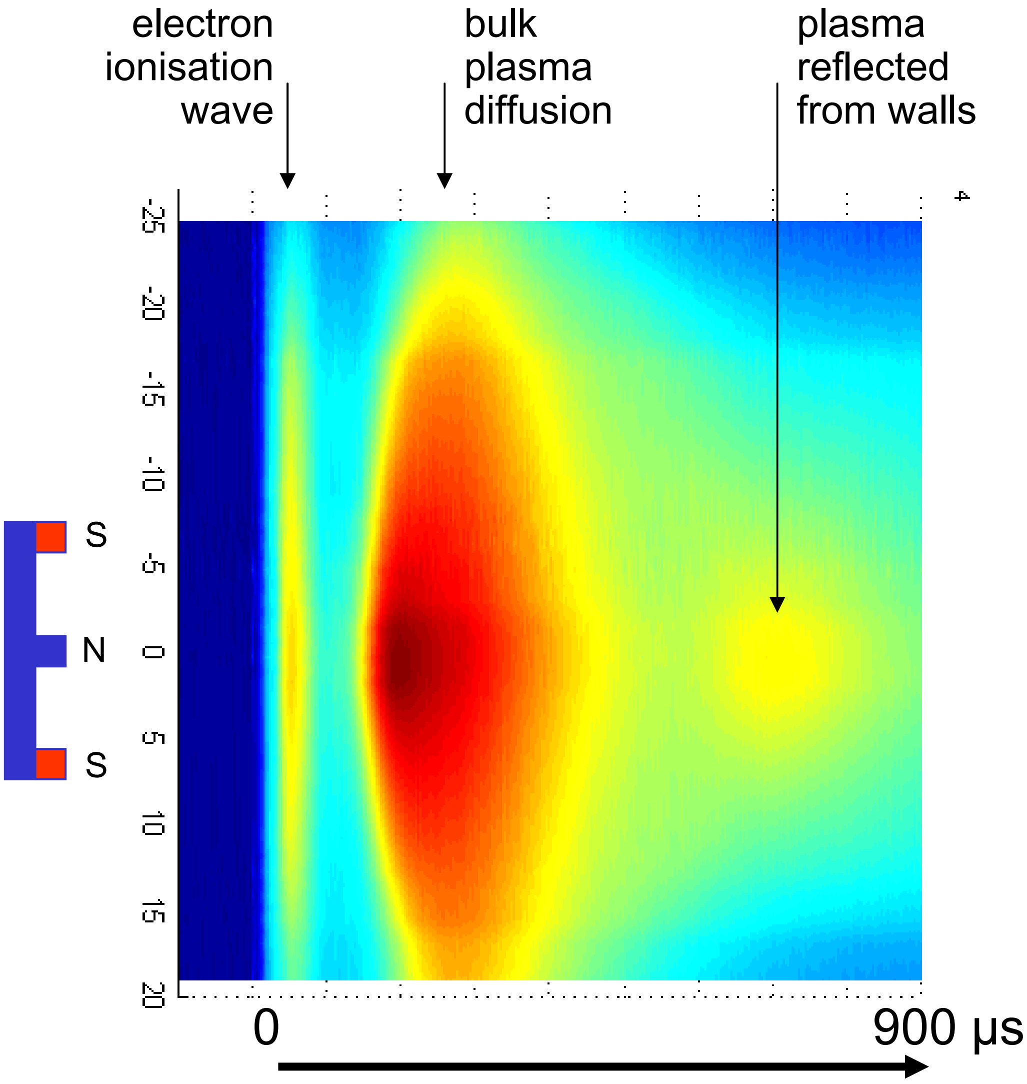


Electron Temperature



$P_{Ar} = 2\times10^{-2}$ mbar

Plasma Density Distribution at High Pressure



electron ionisation wave

bulk plasma diffusion

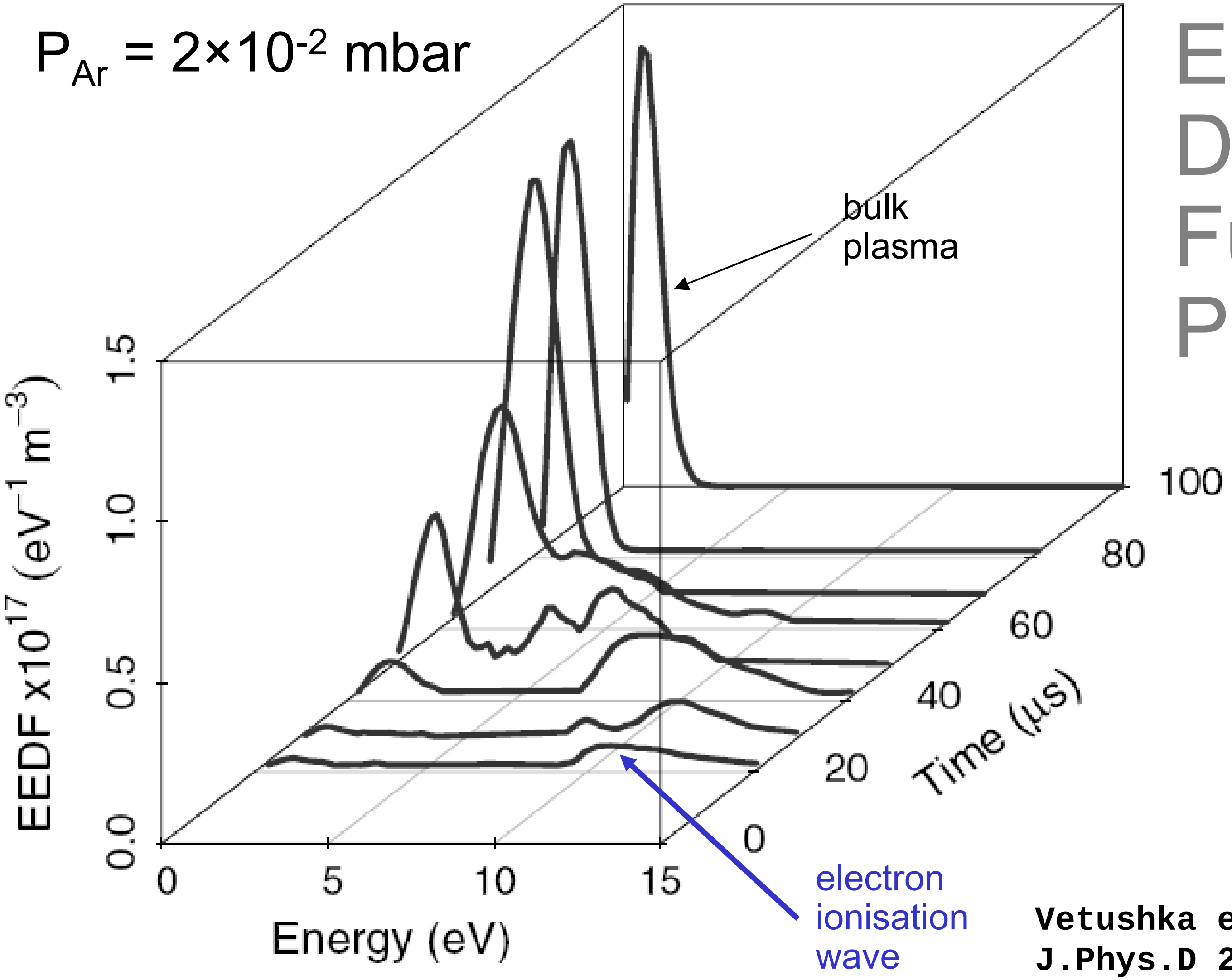
plasma reflected from walls

$P_{Ar} = 2\times10^{-2}$ mbar

Time

Electron Energy Distribution Function at High Pressure

$P_{Ar} = 2\times10^{-2}$ mbar

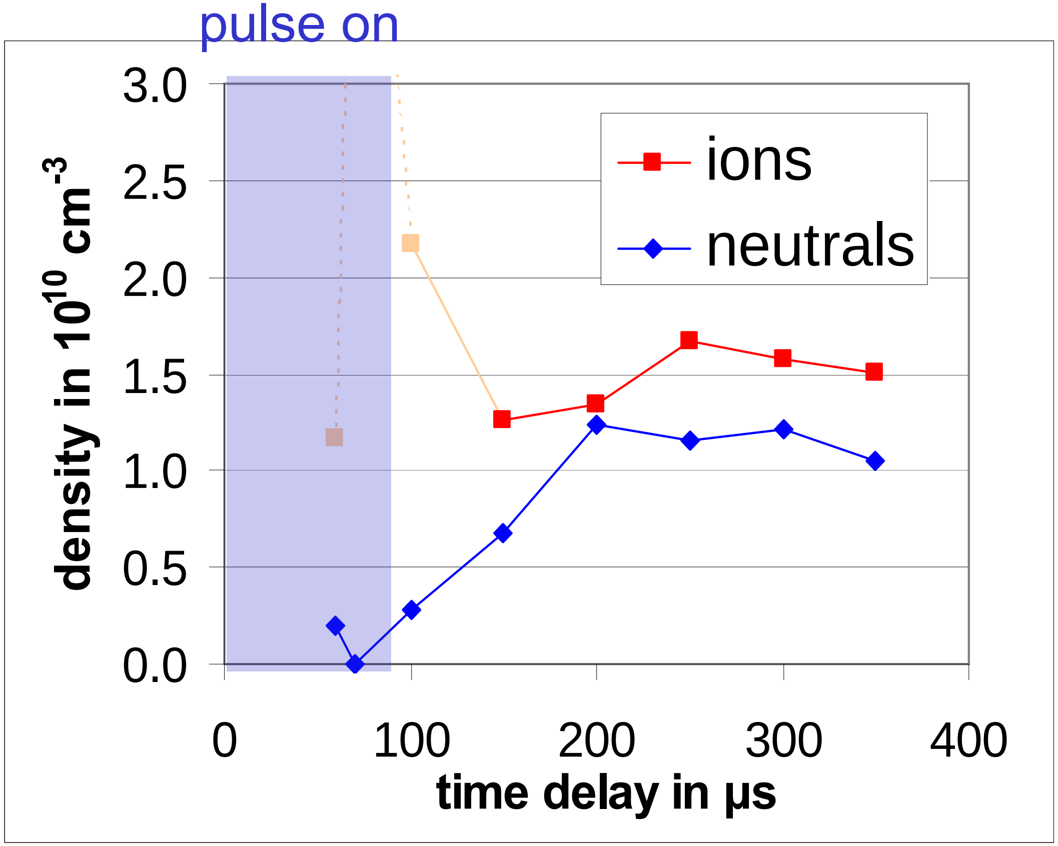


bulk plasma

electron ionisation wave

Vetushka et al, J.Phys.D 2008

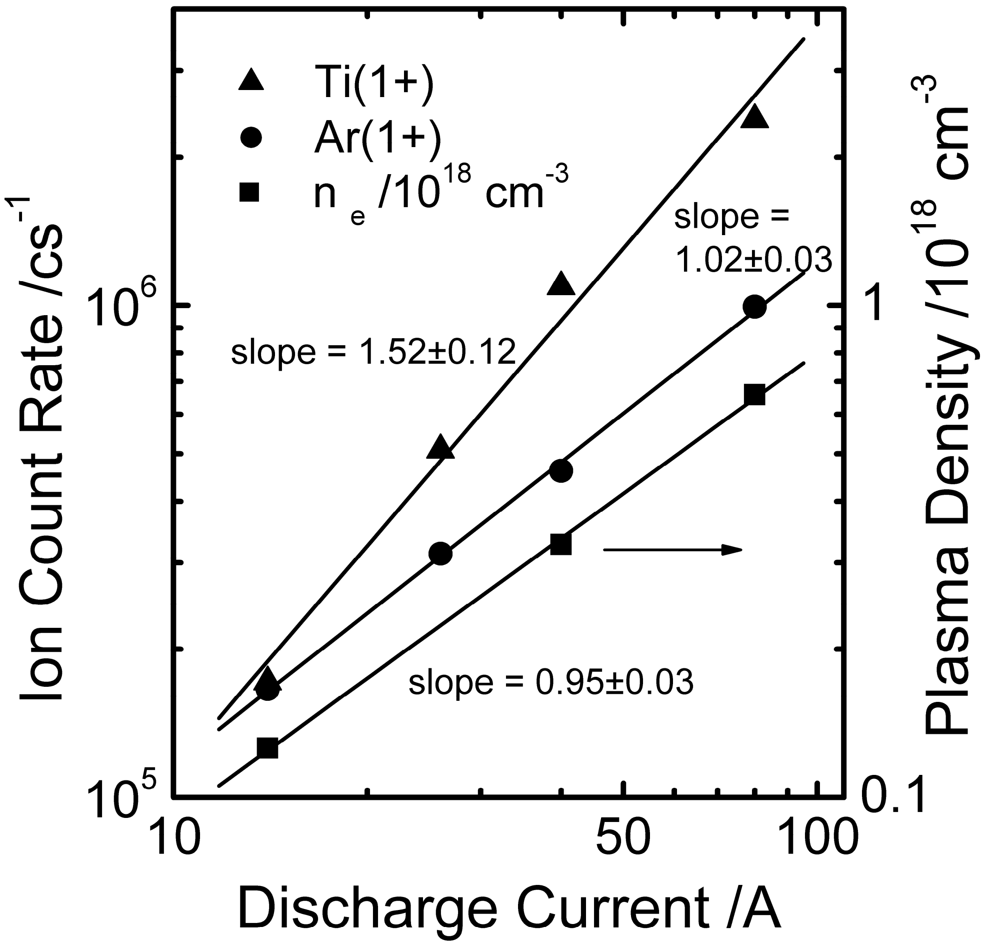
Optical Absorption Spectroscopy



- no Ti neutrals detected before 100 µs
- flight time to substrate volume ~ 100 µs – consistent with second peak in plasma density

Ti ion : Ti neutral ratio

- in the range 0.5-1
- stable near the substrate

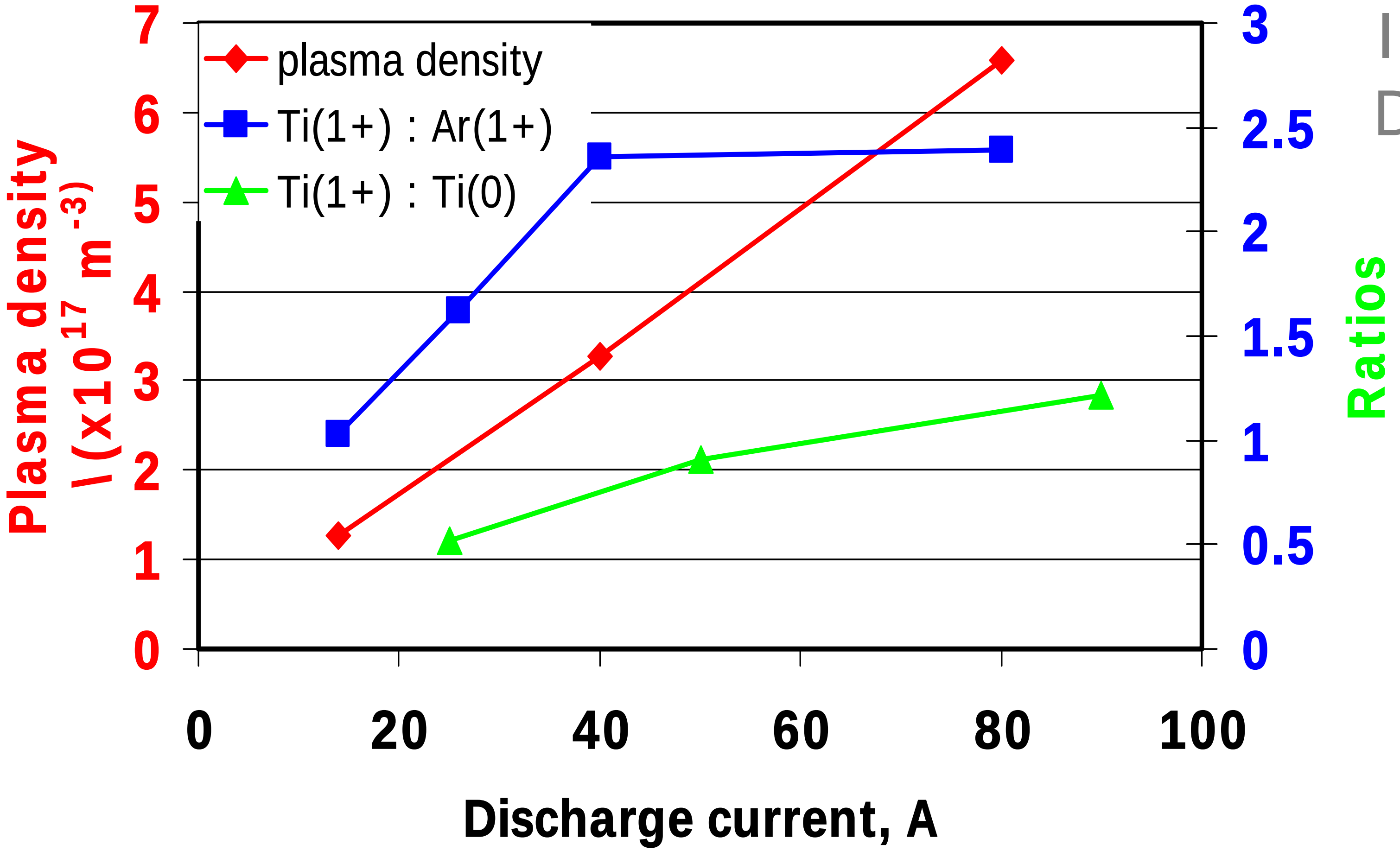


Ion Composition

Experimentally:

- $n_{pl} \sim I_d$ predicted from Bohm criterion
- $n[Ar^{1+}] \sim I_d$ slope predicted 0.5
- $n[Ti^{1+}] \sim I_d^{1.5}$ slope predicted 2

Influence of Discharge Current



$n_{\mathrm{pl}} \sim I_{\mathrm{d}}$

$\frac{\mathrm{Ti}(1+)}{\mathrm{Ar}(1+)}$ saturates

$\frac{\mathrm{Ti}(1+)}{\mathrm{Ti}(0)} \sim I_{\mathrm{d}}$

$n_{pl} \sim I_d * u_{BOHM}^{-1}$

$n_{pl} \sim I_d$

[Ti(0)] = Id * sputter yield

Ti(1+):

Ti(0) + e -> Ti(1+) + 2e

$[\,\mathrm{Ti}(1+)\,] = [\,\mathrm{Ti}(0)\,] * ne \sim Id^2$

$$\frac{[\,\mathrm{Ti}(1+)\,]}{[\,\mathrm{Ti}(0)\,]} \sim I_d$$

$$\frac{\mathrm{Ti}(1+)}{\mathrm{Ar}(1+)}$$

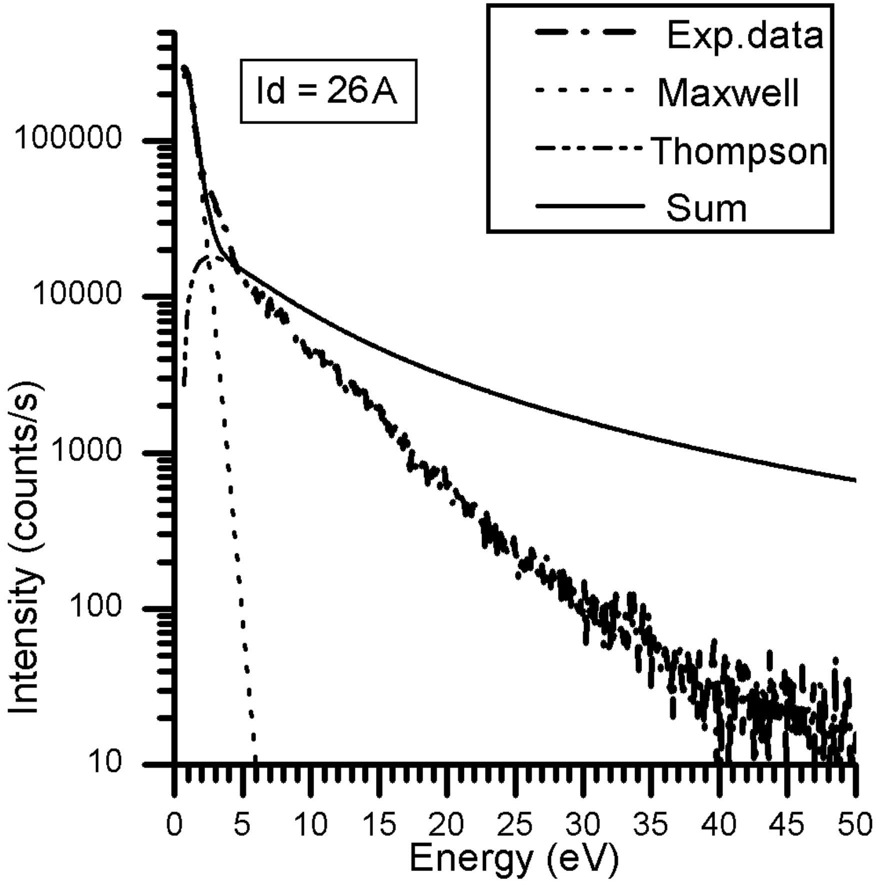
$[\,\mathrm{Ti}(1+)\,] = [\,\mathrm{Ti}(0)\,] * ne \sim Id^2$

$[\,\mathrm{Ar}(1+)\,] \sim I_d - [\,\mathrm{Ti}(1+)\,]$

$$\frac{[\,\mathrm{Ti}(1+)\,]}{[\,\mathrm{Ar}(1+)\,]} \sim \frac{I_d}{1 - I_d}$$

saturates

Ti^{1+} Ion Energy Distribution Function



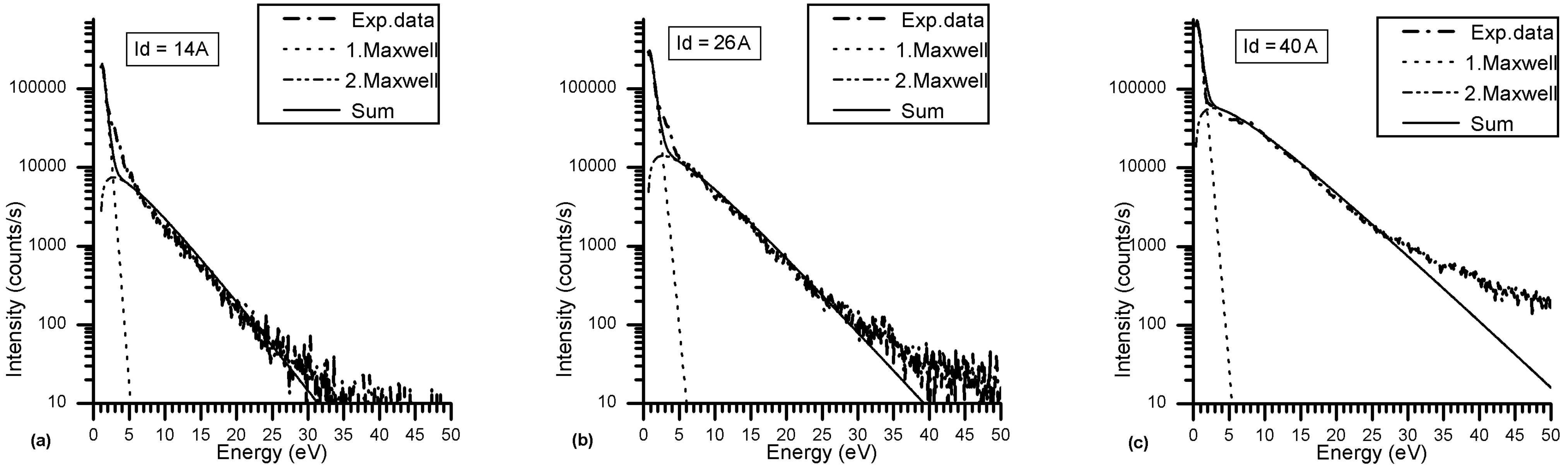
Hecimovic et al, J.Phys.D 2008

Time-averaged measurements:

- Measured data not described by Thomson
- Described well by two Maxwellians

$P_{Ar} = 4\times10^{-3}$ mbar

Ti^{1+} Ion Energy Distribution Function



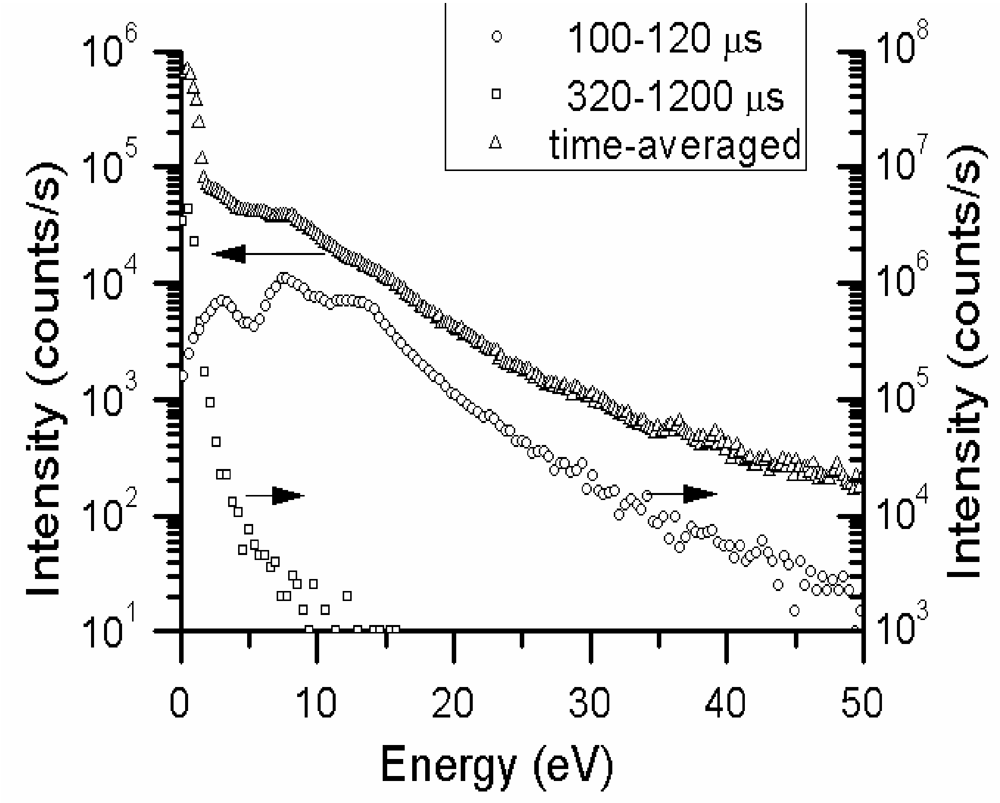
Time-averaged measurements:

- High energy tail related to sputtering but partly cooled
- Increased with discharge current

Hecimovic et al, J.Phys.D 2008

$P_{Ar} = 4 \times 10^{-3}$ mbar

Ti^{1+} Ion Energy Distribution Function



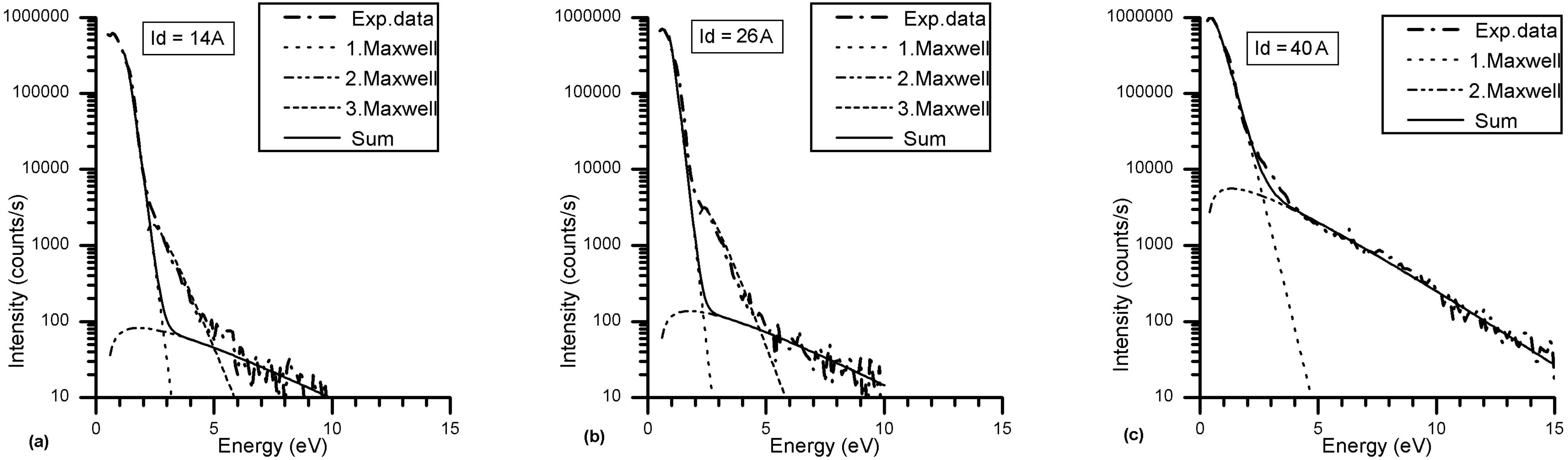
Hecimovic et al,
J.Phys.D 2008

Time-resolved measurements

- Highest number of ions detected in afterglow
- High energy ions during pulse on-time

$P_{Ar} = 4\times10^{-3}$ mbar

Ar^{1+} Ion Energy Distribution Function



Time-averaged measurements:

Significantly lower energy due to charge exchange

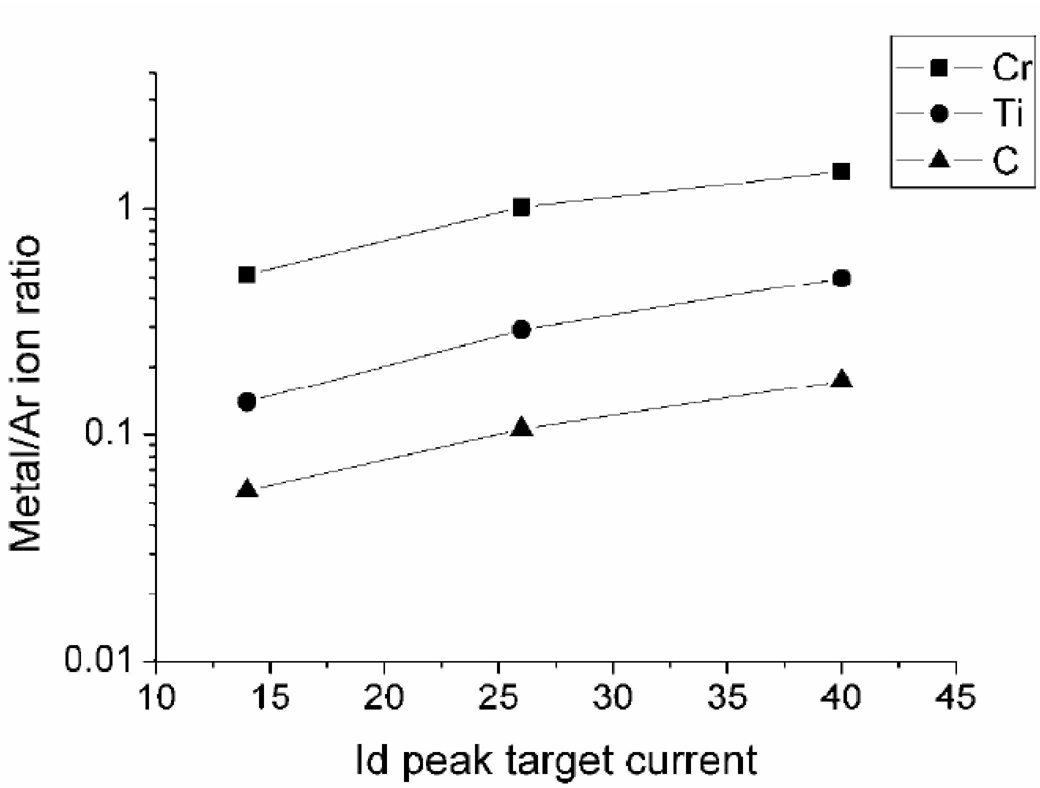
Energy imparted by collisions with metal (gas rarefaction)

Intermediate energy group could be attributed to a shockwave from gas rarefaction

**Hecimovic et al,
J.Phys.D 2008**

$P_{Ar} = 4\times10^{-3}$ mbar

Dependence on Target Material

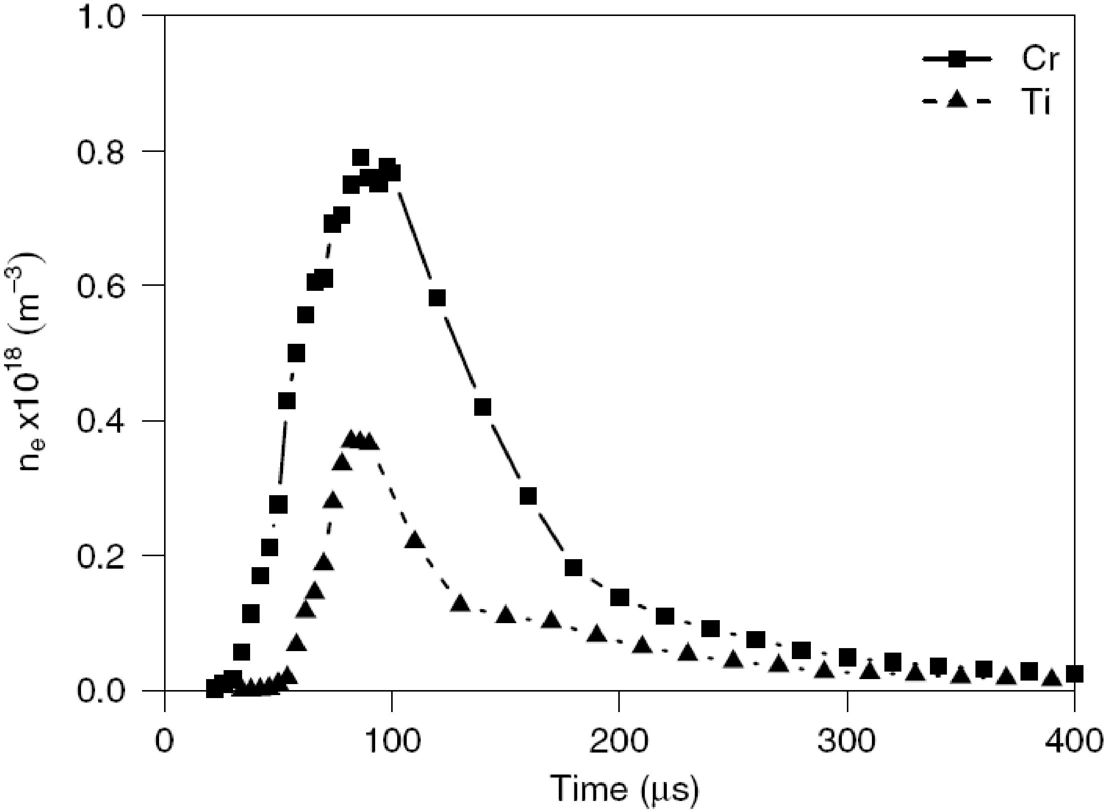


- Metals with high sputter yield exhibit higher metal ion-to-gas ion ratio

$P_{Ar} = 4\times10^{-3}$ mbar

Hecimovic et al, J.Phys.D 2008

Dependence on Target Material

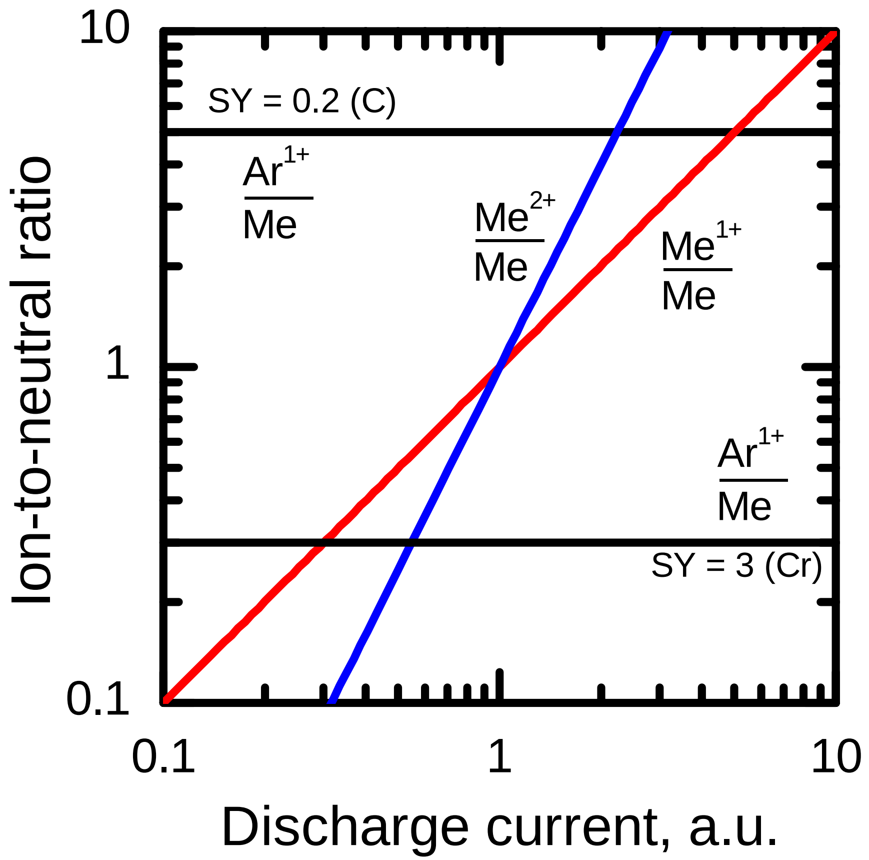


- Metals with high sputter yield exhibit higher overall plasma density for the same discharge current

$$P_{Ar} = 4\times10^{-3} \text{ mbar}$$

**Vetushka et al,
J.Phys.D 2008**

Dependence on Target Material

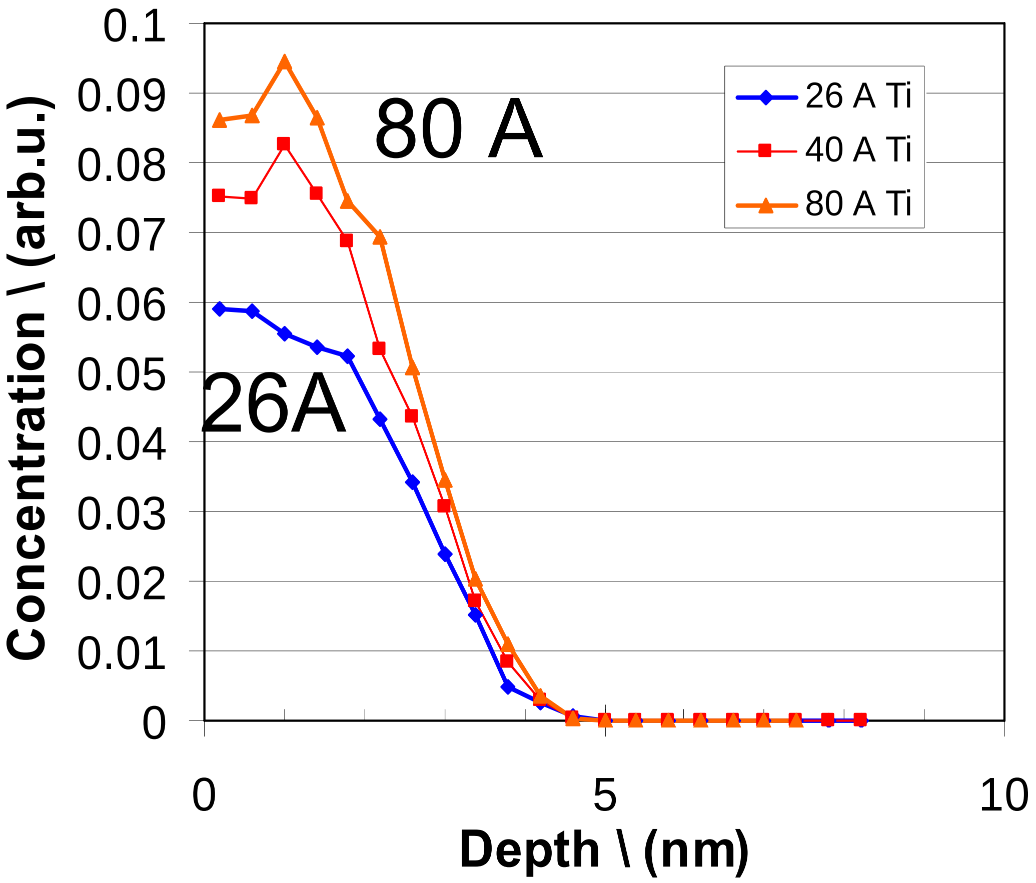


- gas ion-to-neutral ratio is constant
- metal ion-to-neutral ratio can be controlled
- materials with high sputtering yield generate metal-rich plasmas at lower currents.
- materials with low sputtering yield generate a high content of doubly charged ions before reaching the level of gas ions

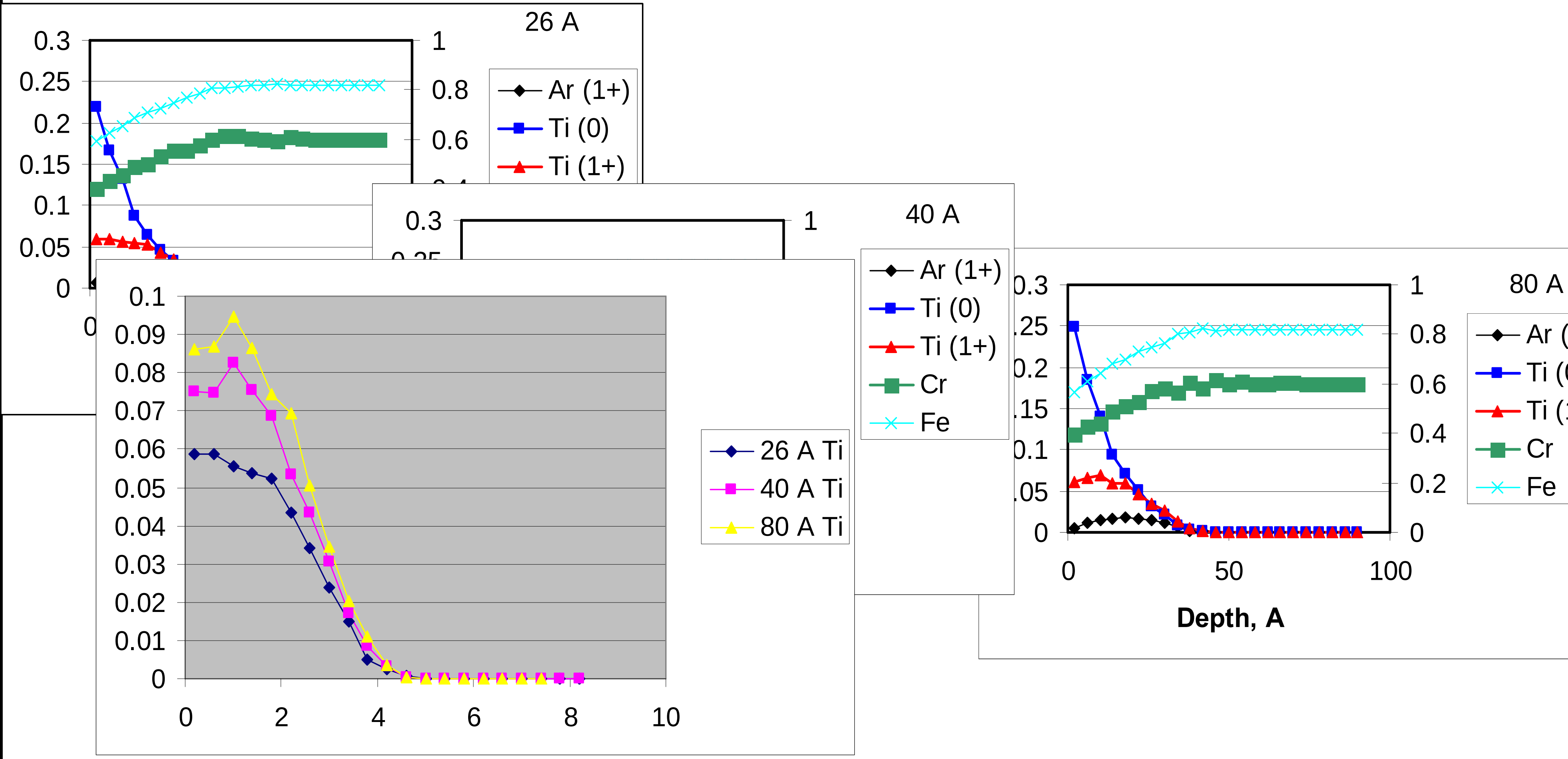
Conclusions

- Metal degree of ionisation increased with discharge current
- Metal ion–to-gas ion ratio increased as function of discharge current
- High energy metal ions generated during pulse on-time
- Metals with high sputter yield produce higher plasma density at the substrate
- Metals with low sputter yield produce plasmas with greater proportion of double charged metal ions.

Ti Implantation



- Retained Ti ion amount increases with Discharge current


26 A
0.3
0.25
0.2
0.15
0.1
0.05
0
1
0.8
0.6
Ar (1+)
Ti (0)
Ti (1+)
40 A
0.3
1
Ar (1+)
Ti (0)
Ti (1+)
Cr
Fe
80 A
0.3
.25
0.2
.15
0.1
.05
0
1
0.8
0.6
0.4
0.2
0
0
50
100
Depth, A
Ar (
Ti (
Ti (
Cr
Fe
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
2
4
6
8
10
26 A Ti
40 A Ti
80 A Ti