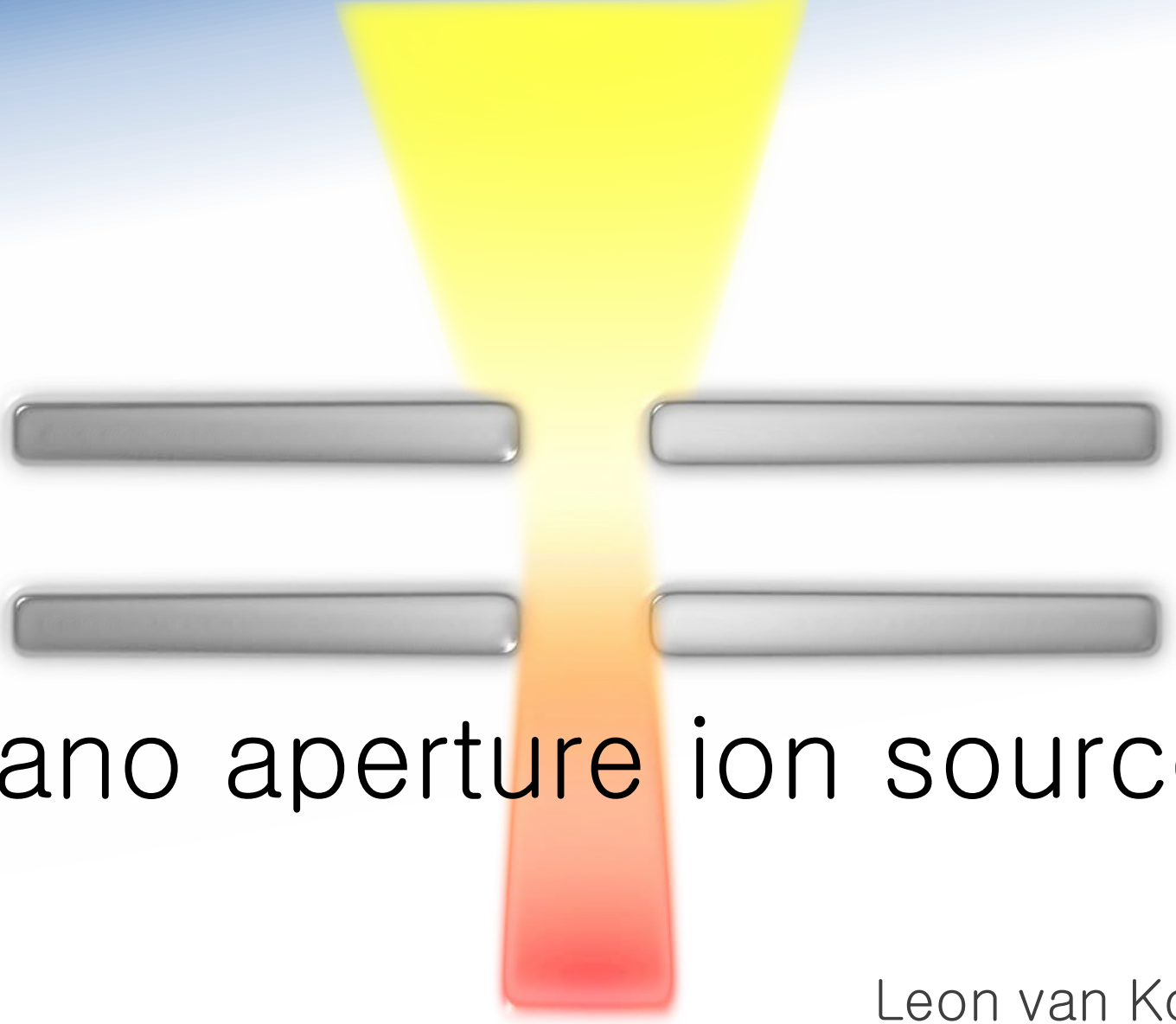


nano aperture ion source

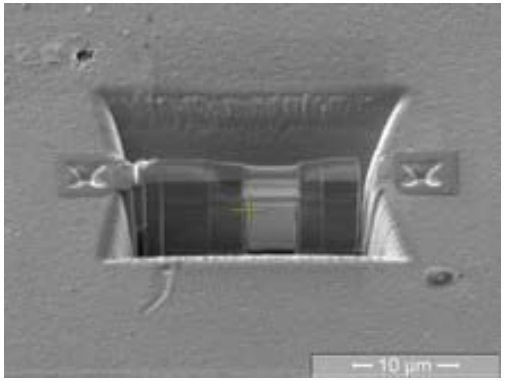
Leon van Kouwen
David Jun
Pieter Kruit

FOM TU Delft FEI

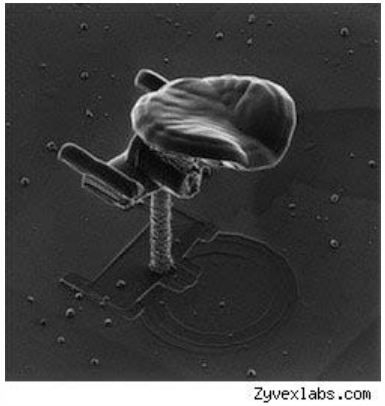
HR focused ion beams: applications

fabrication

cross sections

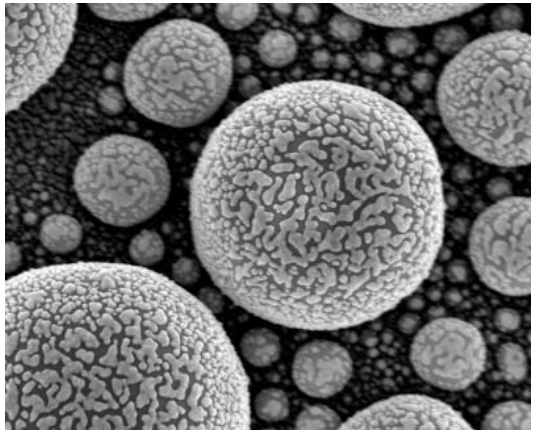


TEM lamella

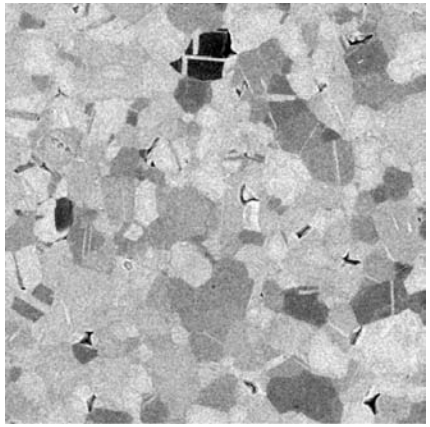


…

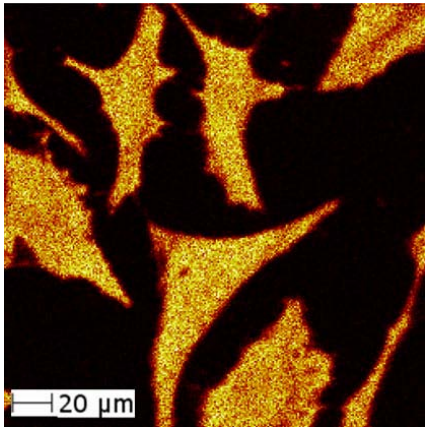
imaging



high surface contrast



channeling contrast



SIMS

HR focused ion beams: State-of-the-art

Helium ion microscope

LMIS (Galium)

HR focused ion beams: State-of-the-art

Helium ion microscope

LMIS (Galium)

Various gas species enable

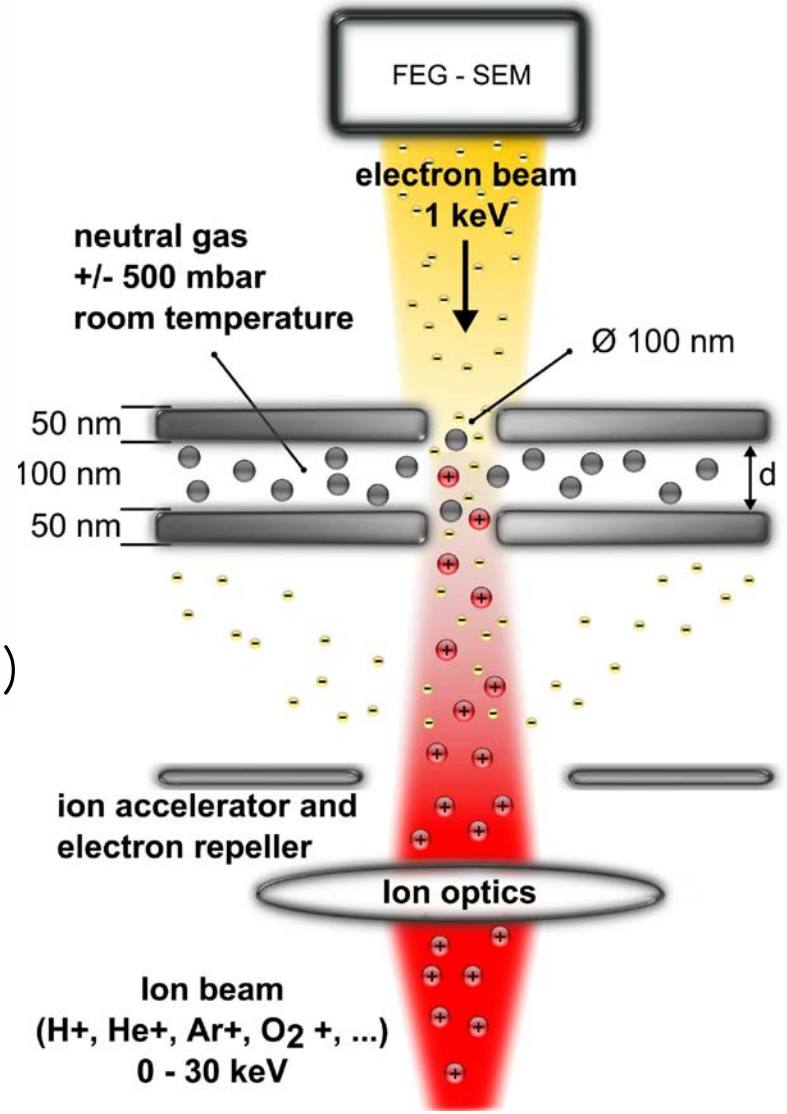
- no contamination in nano-structures
- efficient sputtering
- imaging with little sputtering
- Ion implantation

nano aperture ion source (NAIS)

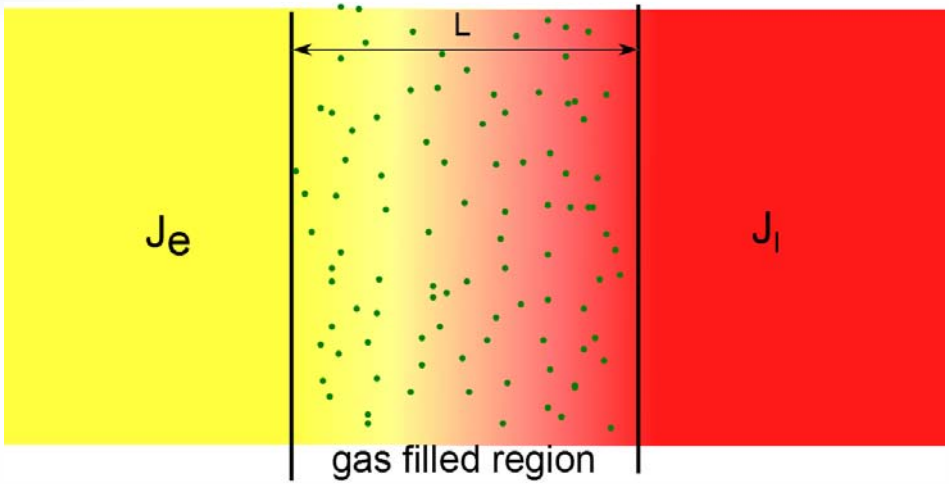
electron impact ionization
sub-micron gas chamber

- micromachined membranes
- high intensity e-beam (schottky)

any gas possible



optimizing the electron beam



reduced brightness

$$B_r = \frac{eJ}{\pi kT}$$

Ion current density

$$J = J_e(1 - e^{-\sigma_I nl}) \approx J_e \sigma_I nL$$

low ion–neutral interaction

$$L = \text{ion mean free path} = \frac{1}{n\sigma_C}$$

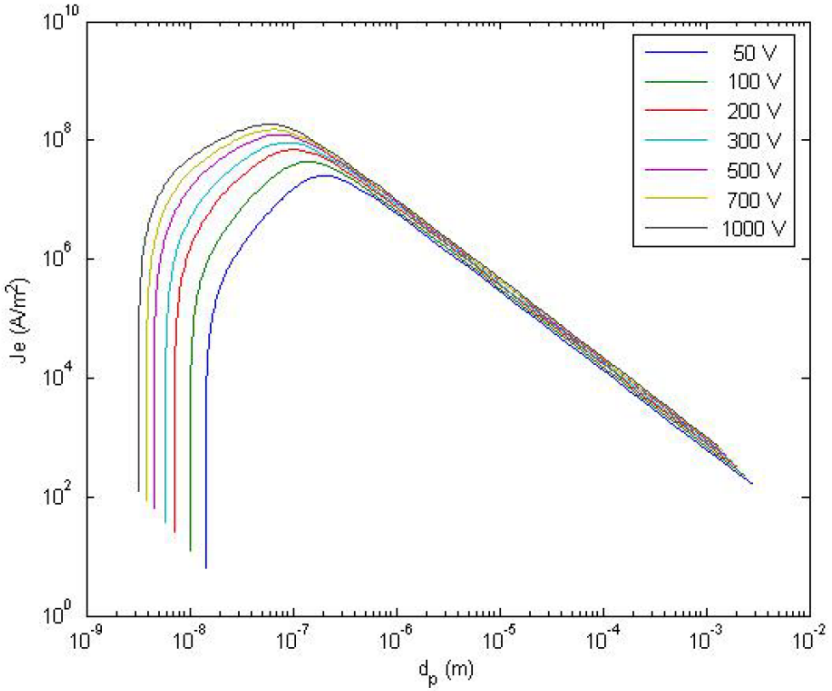
$$B_r = \frac{e}{\pi}\frac{\sigma_I}{\sigma_C}\frac{J_e}{kT}$$

max [(ionization cross section) x (electron current density)]

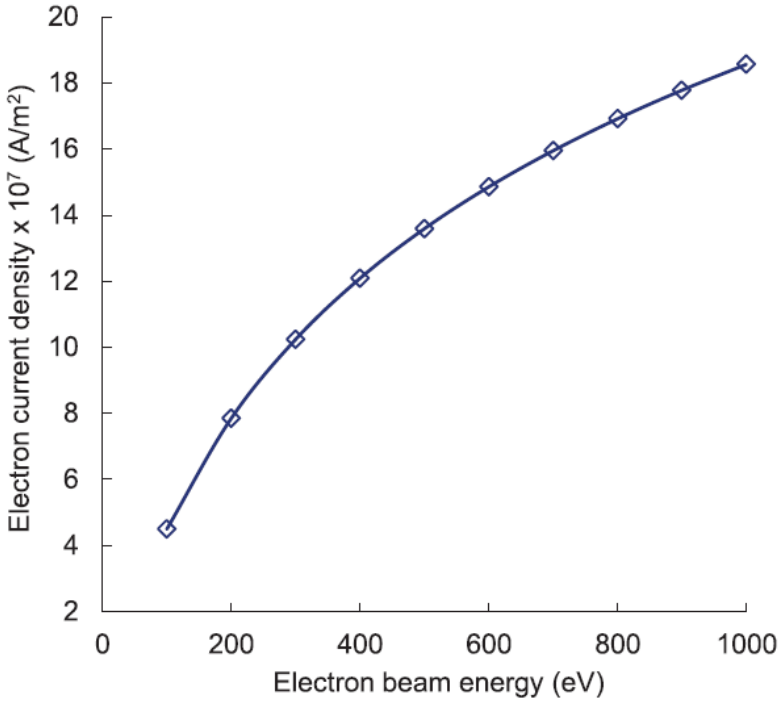
optimizing the electron beam

- Typical schottky and electron optical column specs:

electron current density*



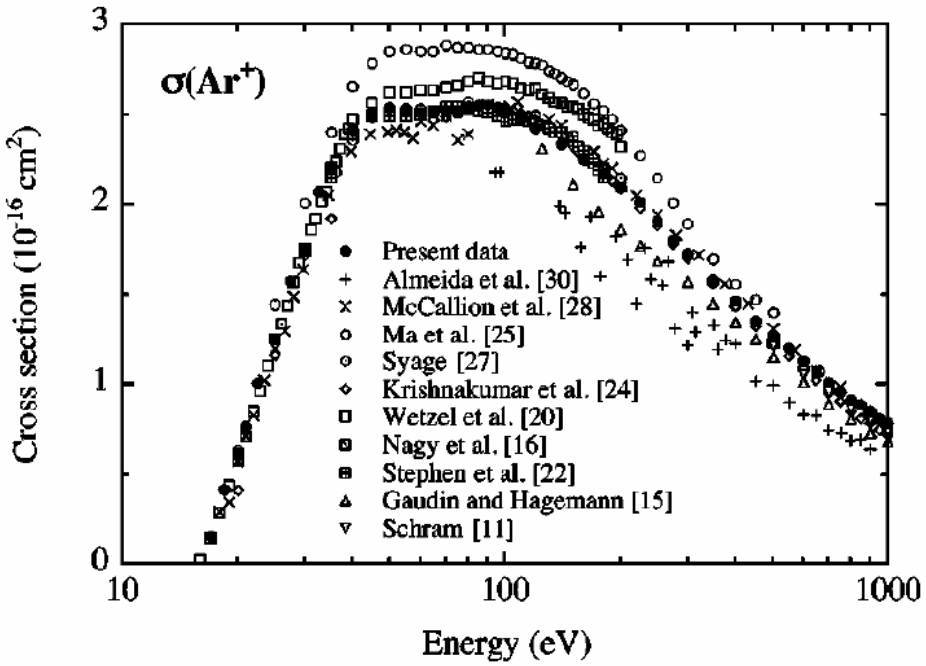
electron current density



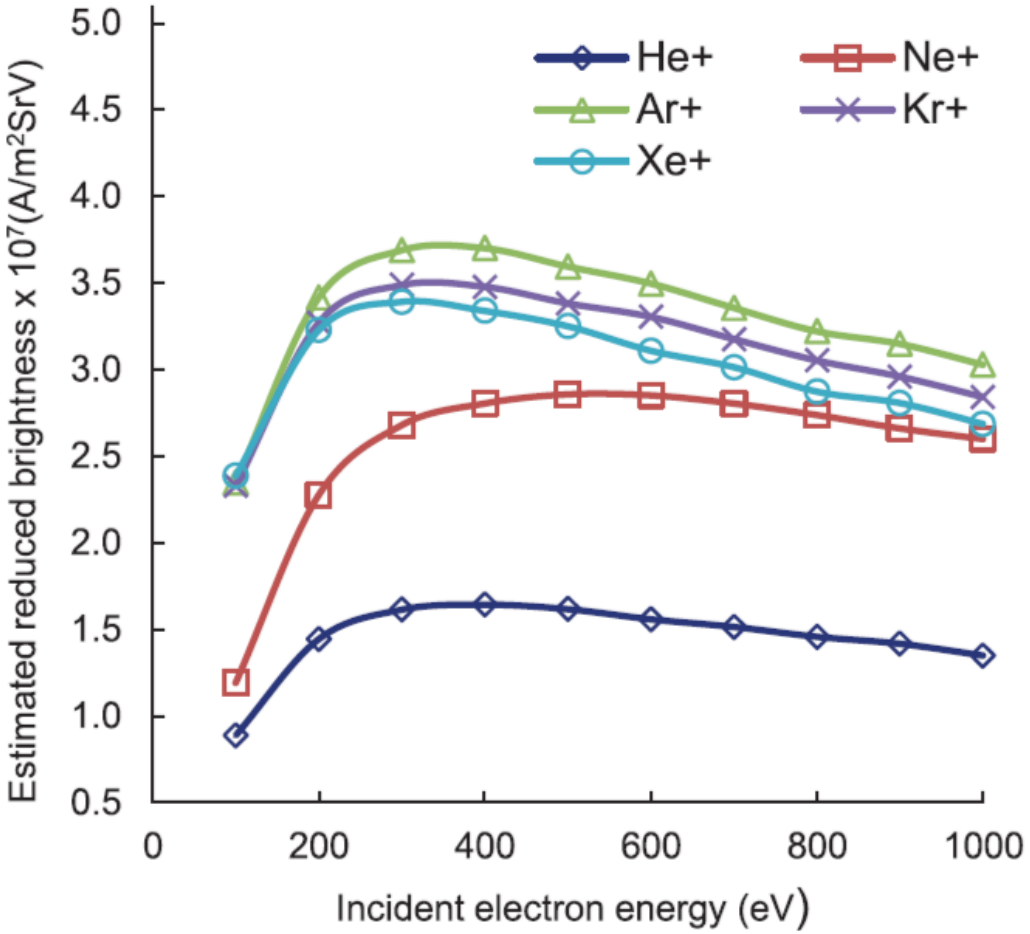
*V.N. Tondare

optimizing the electron beam

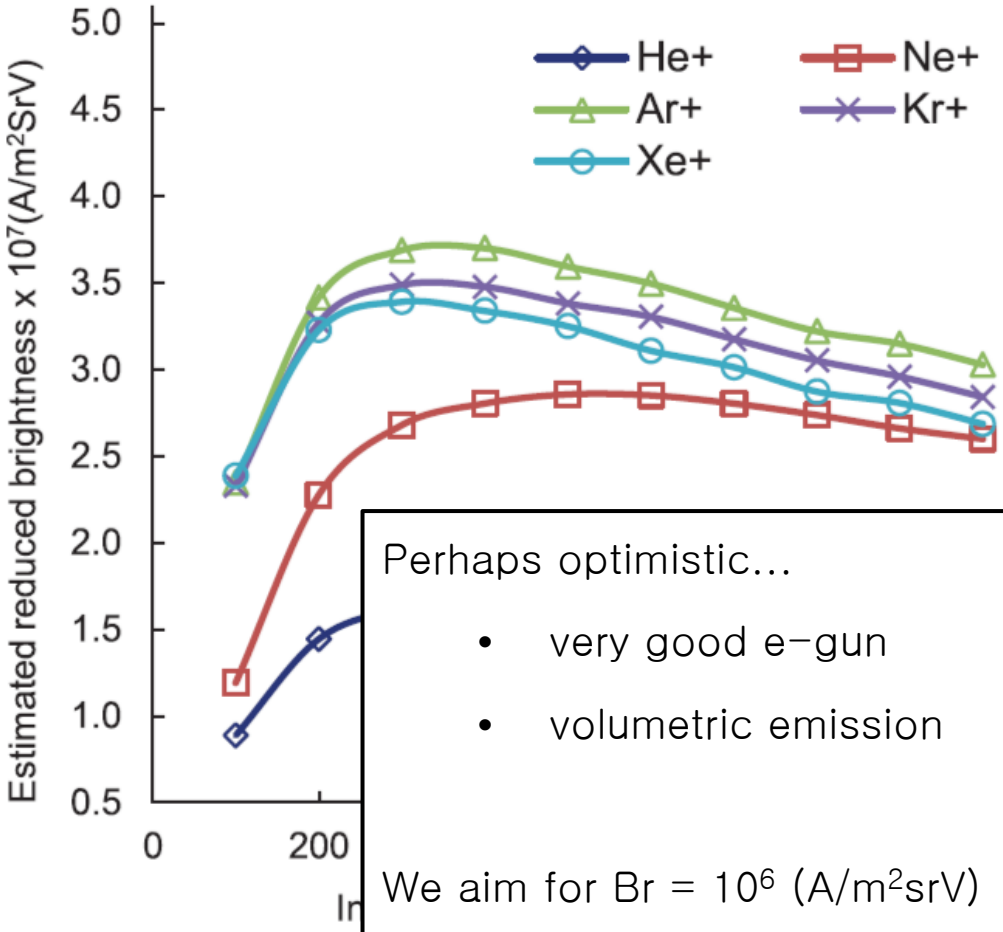
ionization cross section



estimated reduced brightness



estimated reduced brightness



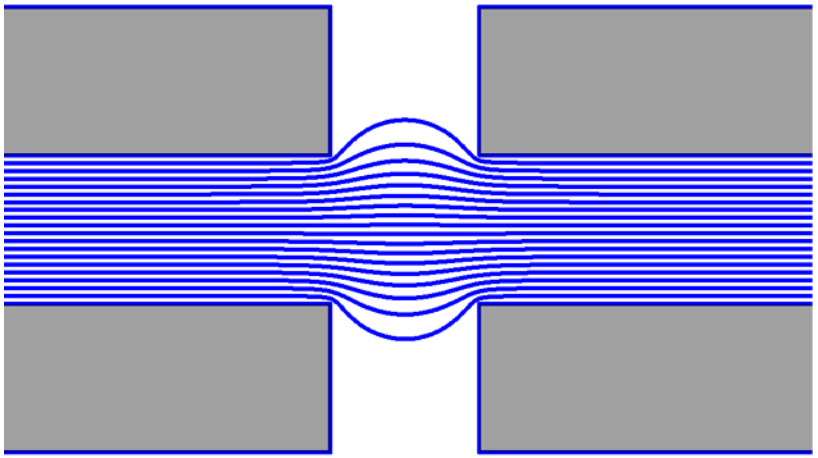
Perhaps optimistic...

- very good e-gun
- volumetric emission

We aim for Br = 10^6 (A/m^{2}srV)

optimization: bias voltage

- Bias voltage
  - determines energy spread
  - prevents ion–ion interactions



optimization: bias voltage

- Bias voltage
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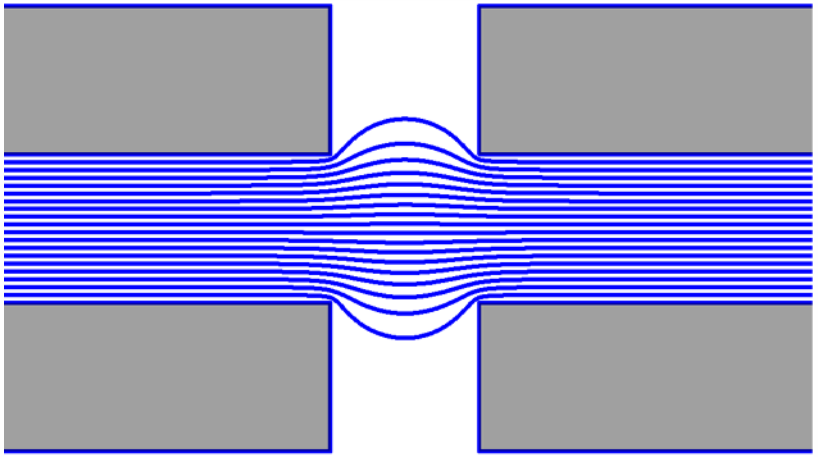


membrane spacing: 100nm
bias voltage: 0.3 V
Argon gas

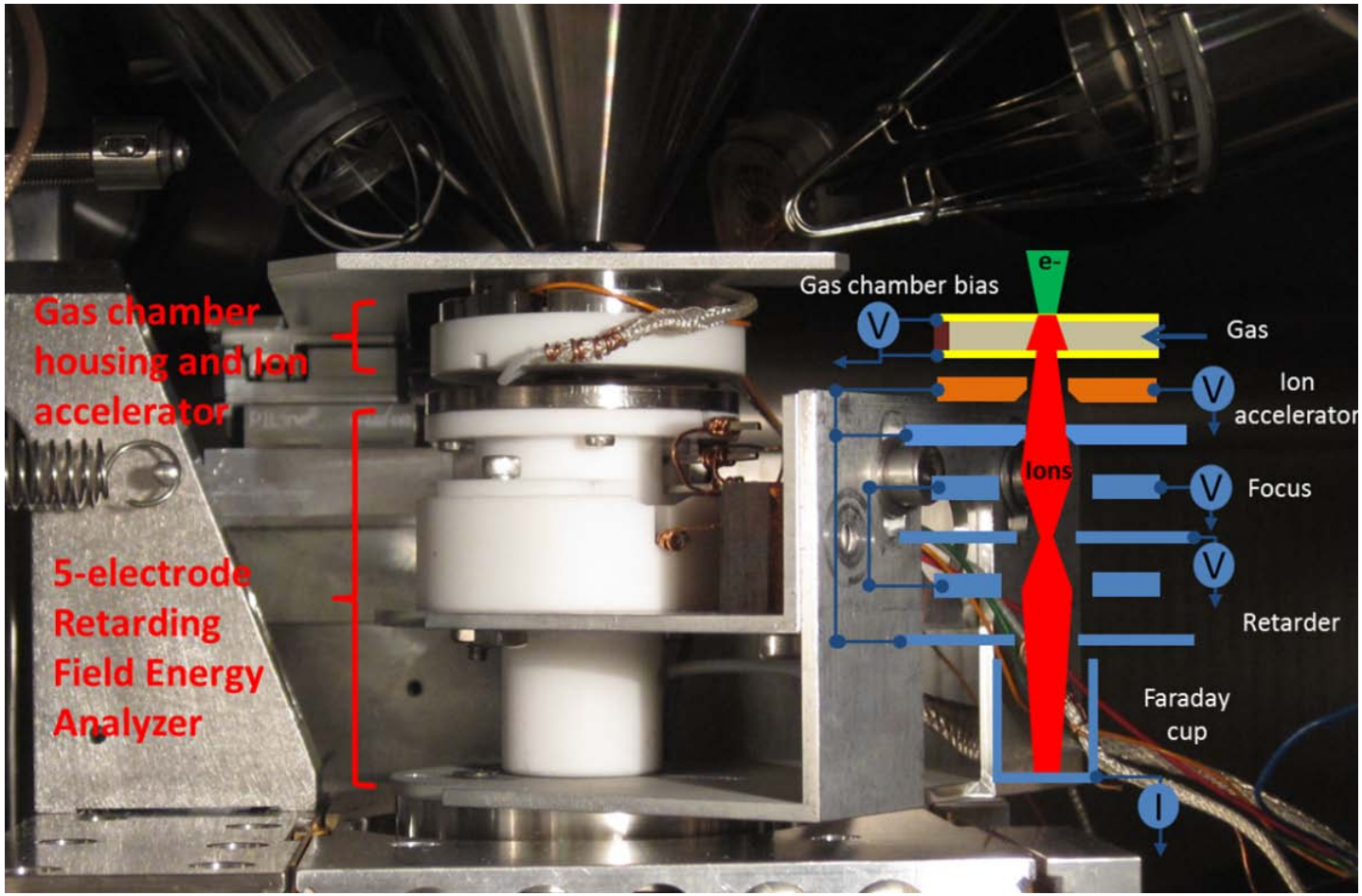
→ average ion residential time: 111 ps

total emission current: 1nA

→ average ion interval = 160 ps

typically only one ion in the source at a time!

prototype testing

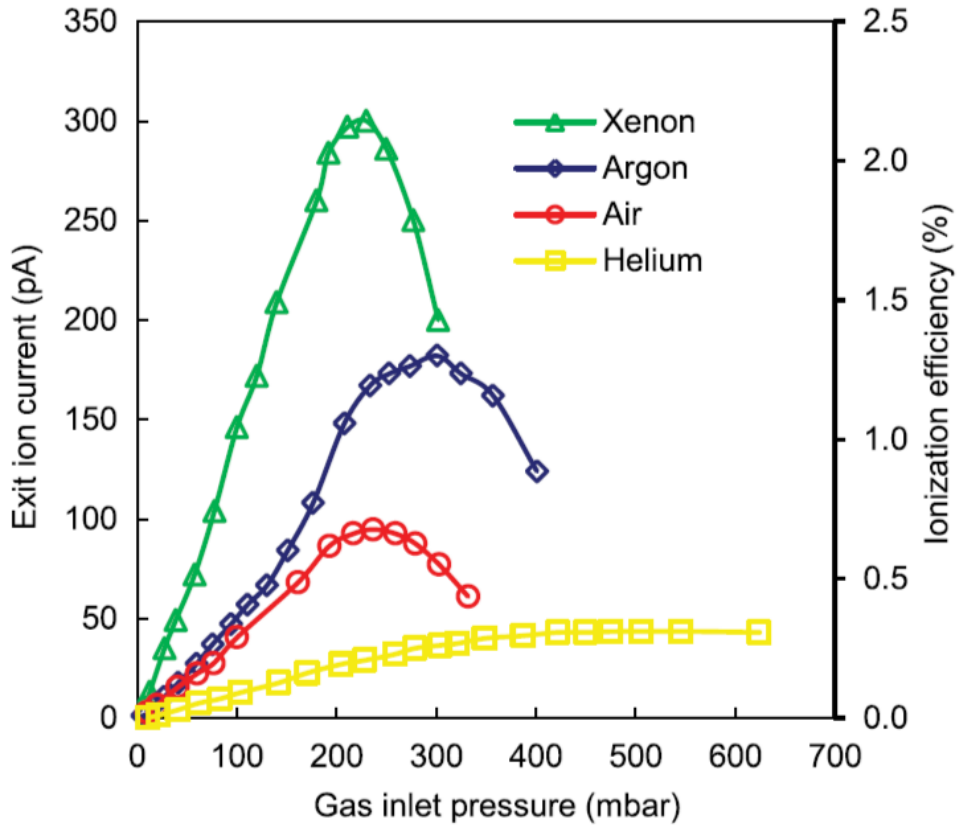


prototype testing: ion currents

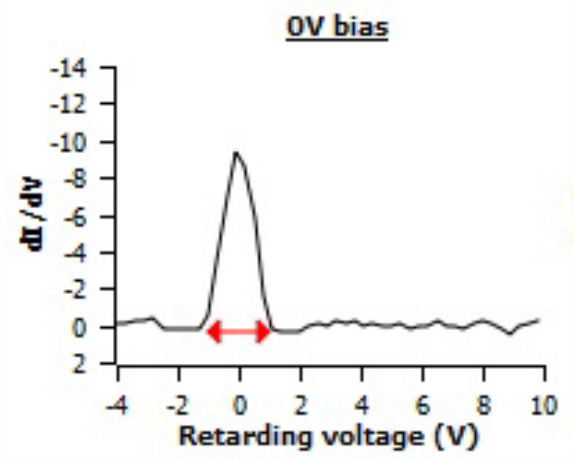
electron current: 14nA

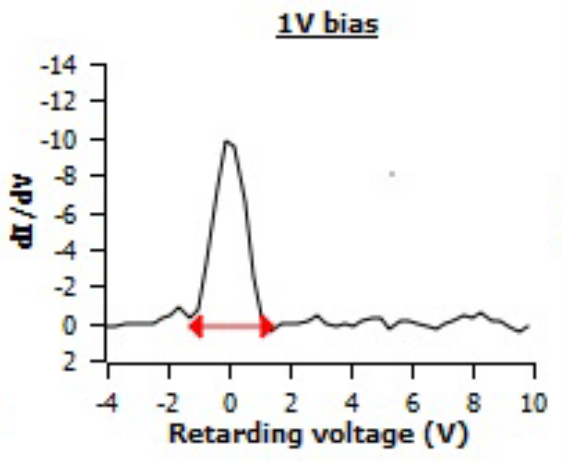
membrane spacing: 2.3um

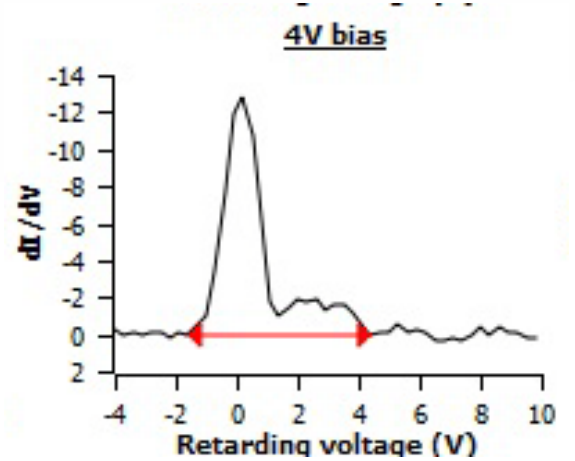
aperture diameter:1.5 um

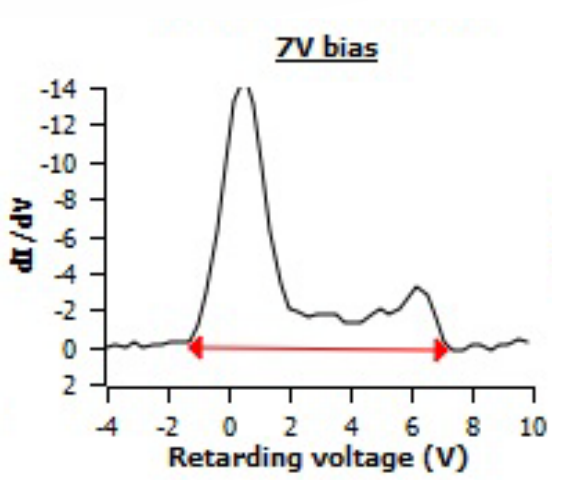


energy spread measurements









FOM TU Delft FEI

ultra cold???

$$B_r = \frac{e}{4\pi}\frac{\sigma_I}{\sigma_C}\frac{J_e}{kT}$$

Cooling down the gas chamber:

- Brightness improved
- Energy spread unaffected ($kT << eV_b$)

Cooling with liquid helium or nitrogen: same device

Cooling by LASERs: alternative design

final slide

Conclusions

- Source for HR FIB systems: the **Nano aperture ion source**
- First tests inspiring

Outlook

- Replace Ga on a FEI DualBeam
- Measure brightness
- Explore applications
- Optimize by improved physical model
- Cool down ?