Since 1968

Pushing the limits: 40µm Ion Beam Processing

NTG Neue Technologien GmbH & Co. KG, Germany
Dr. David Schäfer

Content

Company

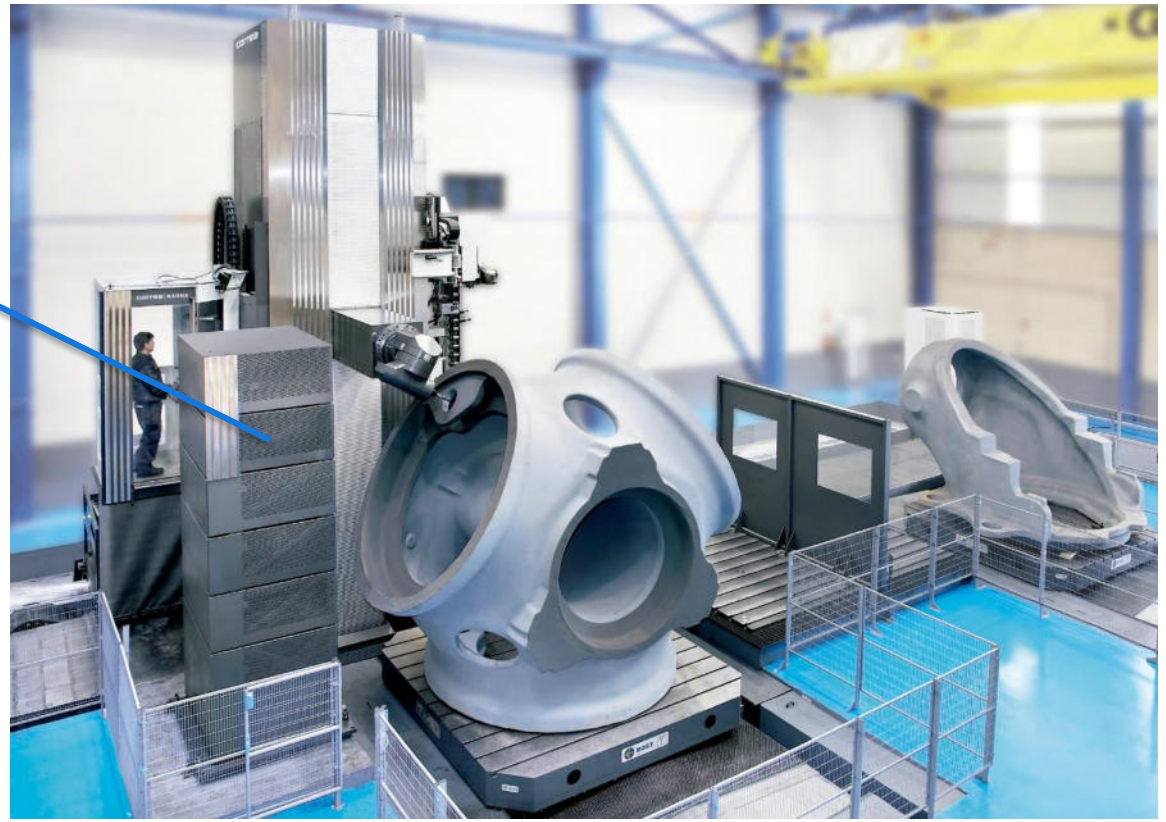
- **Founded 1968**
- **~ 100 employees**
- **~ 7500sqm. Production area**

2021: 5th Extension

- 12 x 24 m
  ~ 865 sqm Prod.-area

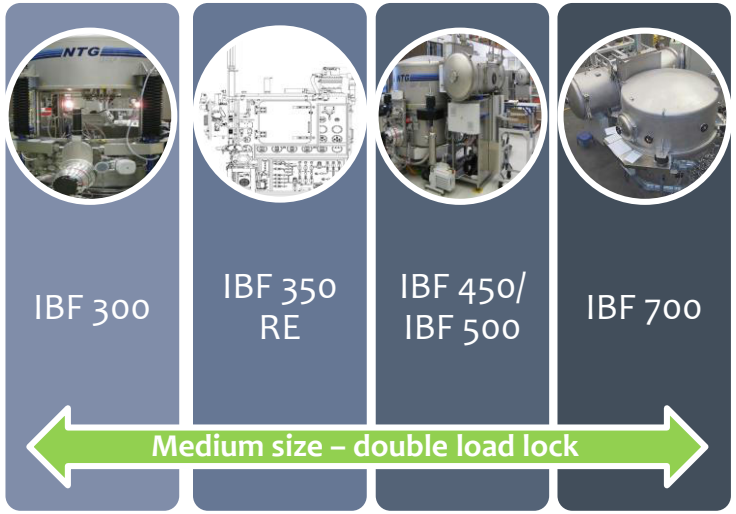
2010 IBF-Lab

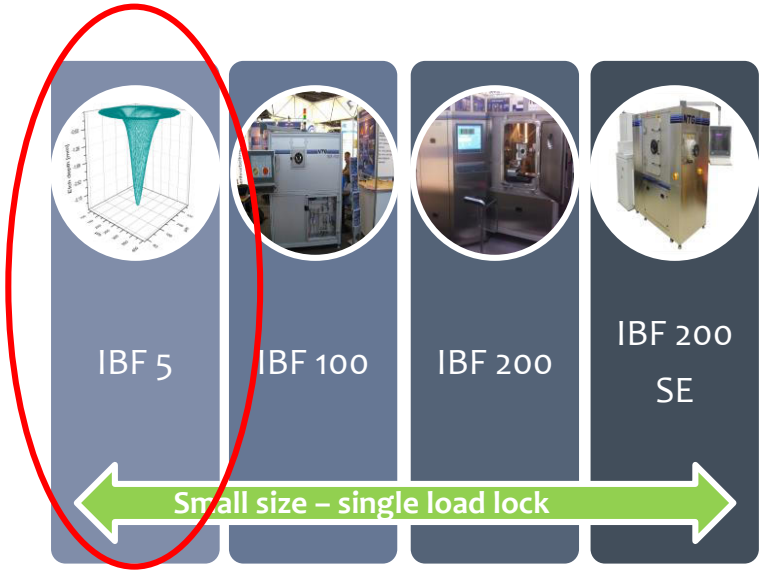
02/2019:
MAGNA-75 Fahrständerfräsmaschine, 5 Axis
Travel Range: (x,y,z): 7.500 x 1.500 x 4.000 mm

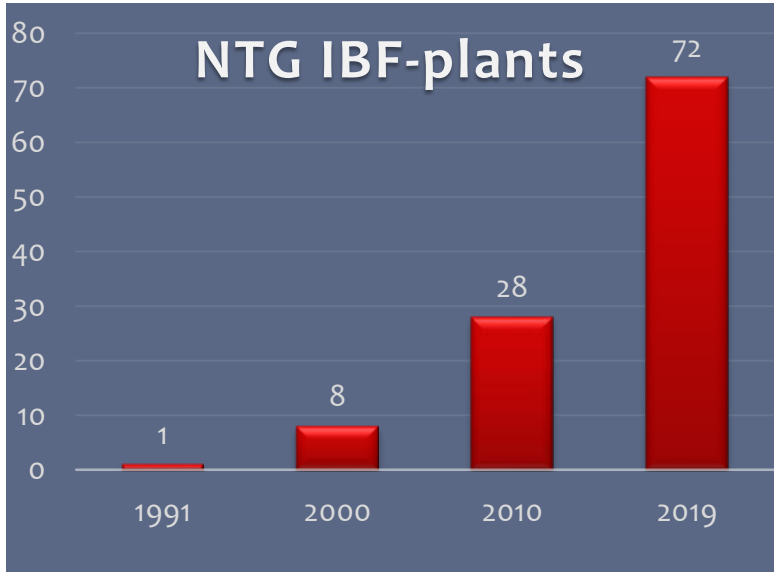


Ion Beam Machines

- ✓ >30 years IBF-experience
- ✓ Inhouse Lab (R&D, feasibility studies, job orders…)
- ✓ 100% inhouse competence
- ✓ Largest number of sold IBF-machines worldwide

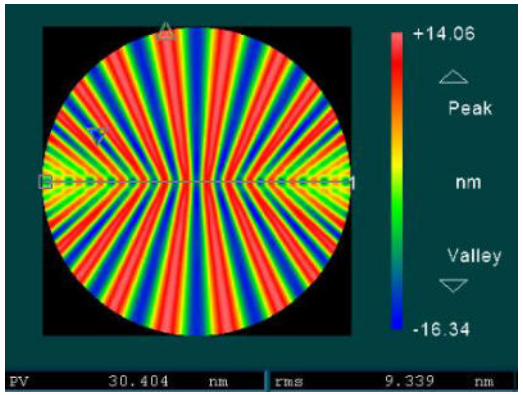


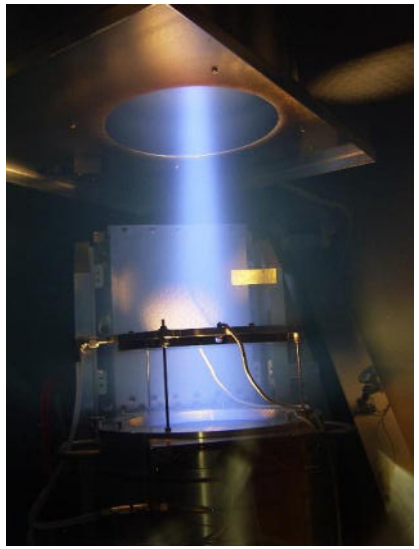




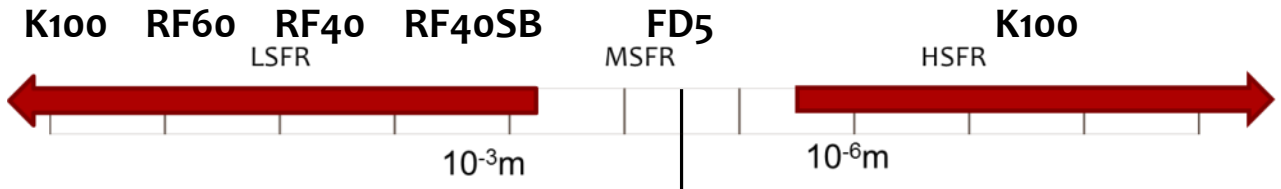
Ion Beam Figuring: New Ion Beam Sources

- Ion Beam Figuring – Mathematics
- Ion Beam Sources – Physics
- Ion Beam Sources – Overview
- Ion Beam Sources – Actual Developments



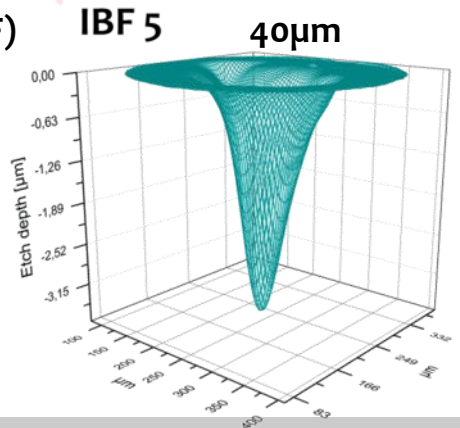


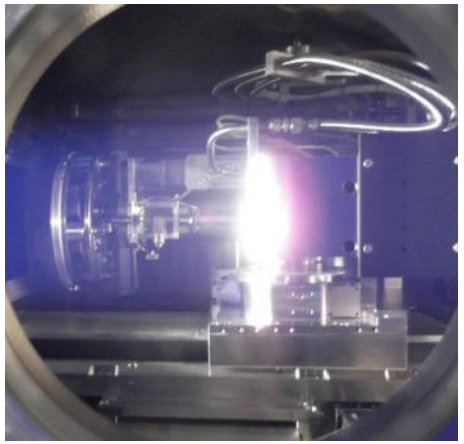
Ion Beam Guns / Feature Sizes



Deterministic
Ion Beam Figuring (IBF)

Statistical
Ion Beam Etching (IBE)





NTG

Ion Beam Figuring Mathematics

Dwelltime based Meander Processing

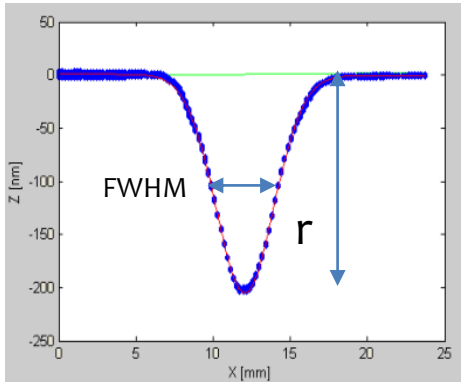
- Material removal: Relation to dwell time/speed and ion beam shape

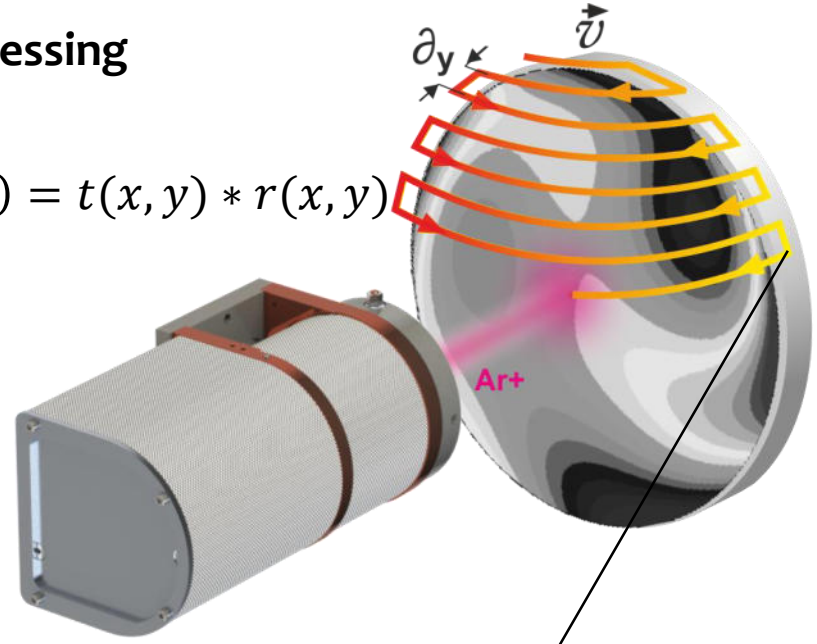
$$\Delta h(x,y) = t(x,y) * r(x,y)$$

Removal height — Rate — $FWHM = \sigma \cdot 2\sqrt{2ln2} \approx \sigma \cdot 2.35$ Ion Beam Size

$$H \cong \frac{\pi \cdot r \cdot \sigma^2}{\vec{v} \cdot \delta_y}$$

Speed — Row pitch (Resolution)





- Maximum speed of axis system defines „base removal“
- Smaller row pitch (higher resolution) ←→ higher base removal / longer treatment

Edge Extension:
Every Pixel is treated by the whole beam

$\delta_y \approx$ FWHM x 1/5 … 1/20

Coarse, fast low socket removal

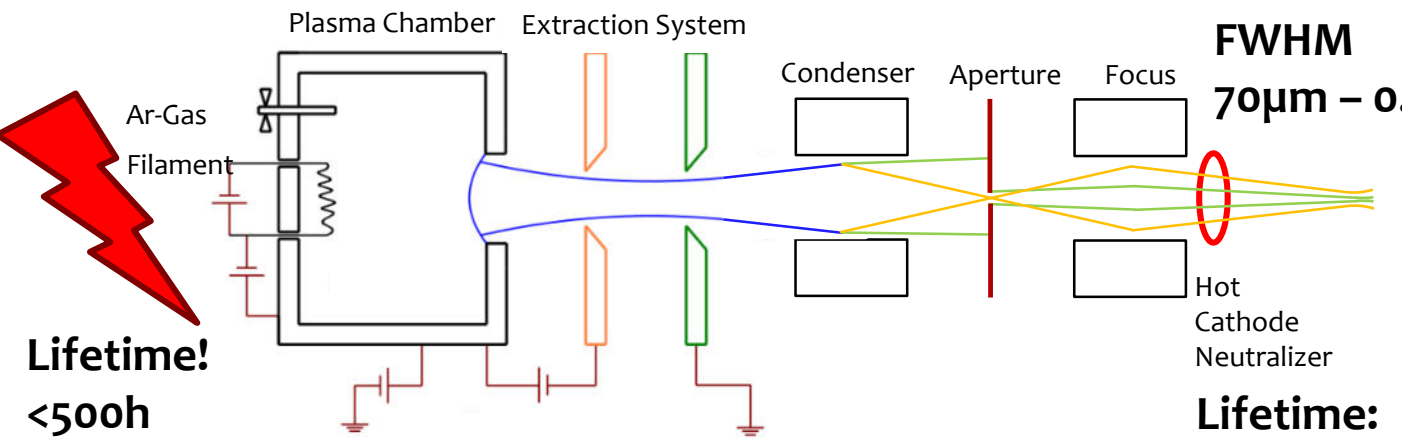
Fine, accurate high socket removal

➔ Position accuracy of ion beam <FWHM/20

➔40µm FWHM: 2µm precision [machine]
➔Long term stability of r(x,y) [IBS]

About maintenance intervals…

Filament Ion Beam Source (FD 5, single beam)

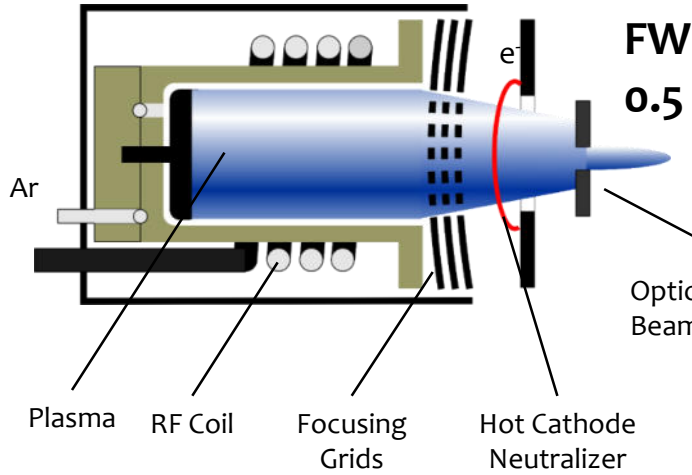


Lifetime!
<500h

FWHM
70µm – 0.3mm

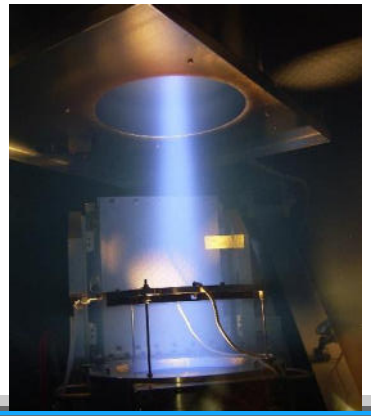
Lifetime:
>1000h

RF Ion Beam Source (RF40 & RF60, multiple beams)



FWHM
0.5 – 30mm

Lifetime!
100h – 1000h



Kaufman Ion Beam Source (K100, multiple beams)

Lifetime!
<50h

FWHM >60mm
Flat Top 100mm

Ion Beam Sources Overview

Name	Beam Size	Plasma	Beam Extraction	Neutralizer	Lifetime
FD 5	0.07 mm – 0.3 mm	Filament	Single Beam	Hot Cathode	Plasma 500h Neutr. >1000h
RF 5 (µB)	0.04 mm – 0.15 mm	RF	Single Beam	Hot Cathode	> 1000 h
RF 40	0.5 mm – 4 mm	RF	Multiple Beam + Aperture	Hot-Cathode	500 h – 1000 h
RF 40	5 mm – 20 mm	RF	Multiple Beam	Hot-Cathode	150 h – 500 h
RF 60	30 mm	RF	Multiple Beam	Hot-Cathode	100 h
K 100	60 mm (Gauss)	Filament	Multiple Beam	Hot-Cathode	<50 h (both)

RF 5 micro Beam
Established 12/2019

RF 5 mini Beam
Prototype
08/2020

More Vol.-Rem.
More Flexibility
Less Contamination

Life-Time

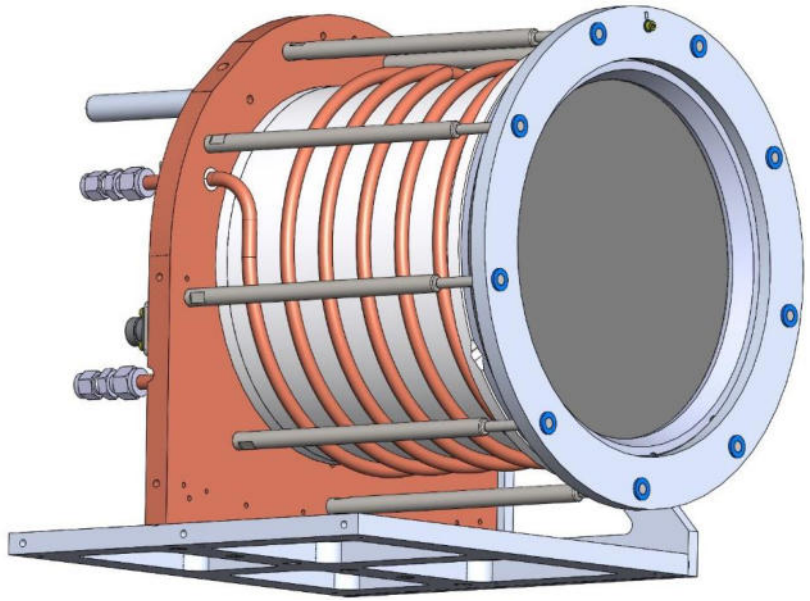
RF 200
Prototype end
of 2020

Life-Time,
Gas flexibility (RIBE)

RF Neutralizer
Prototype 04/2020

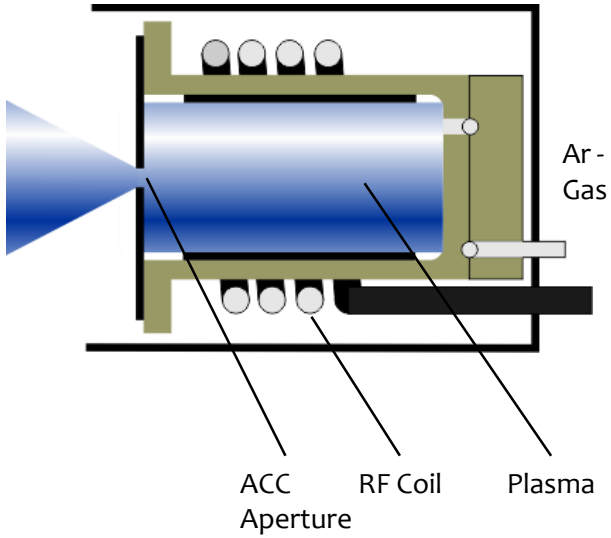
RF200 – under commisioning

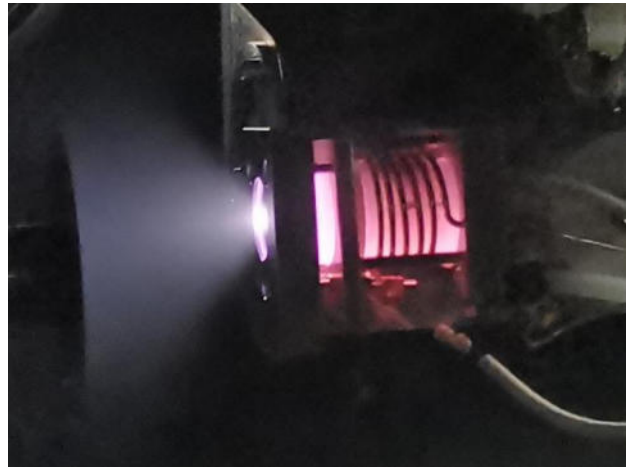
Extraction energy: 0.6 kV – 1.5 kV
Beam shape: gauß + flat top
FWHM: 150 mm – 200 mm
Gas: inert + reactive

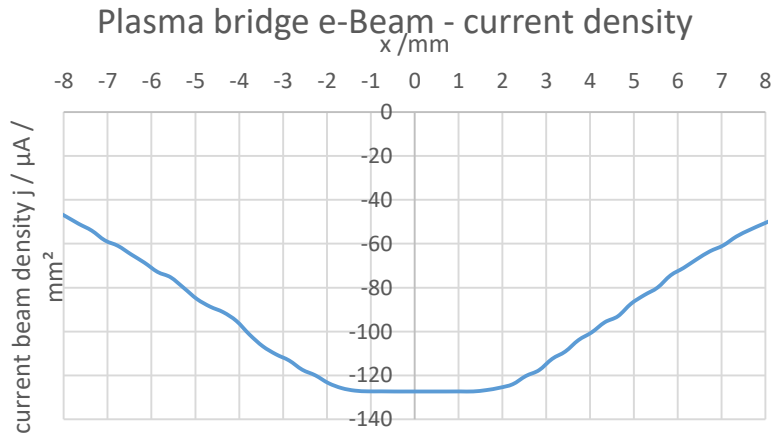


RF 200

RF Neutralizer – prototype

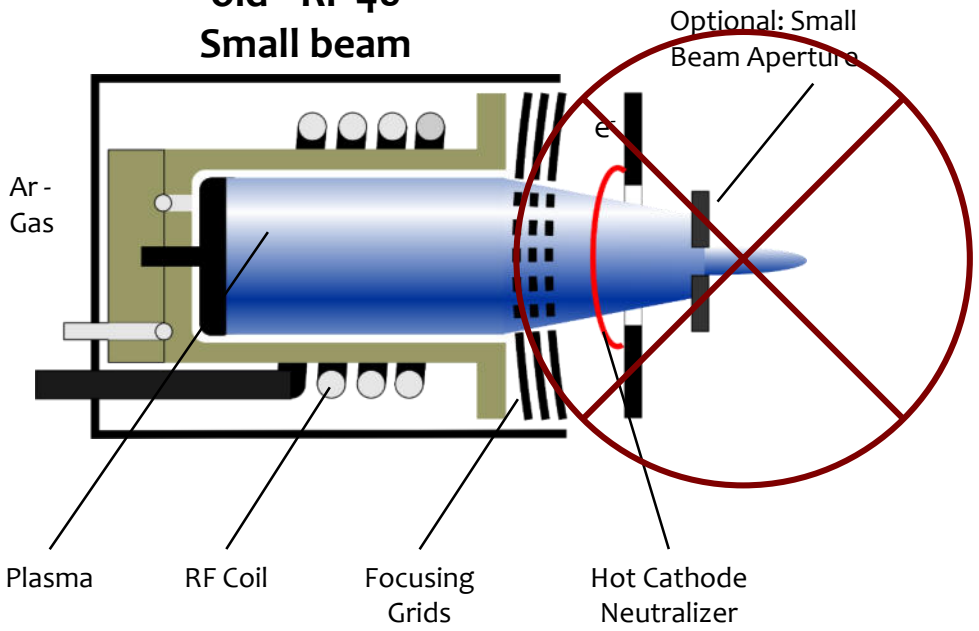




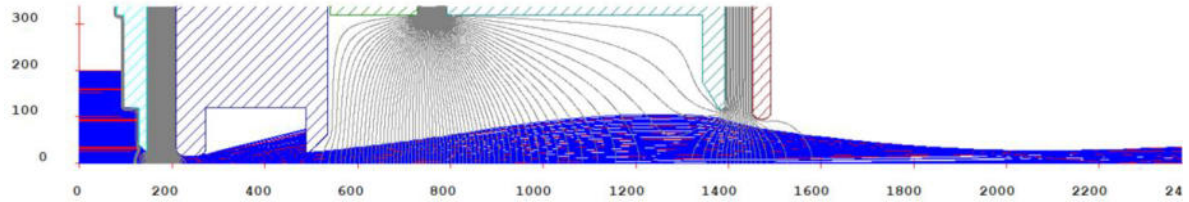


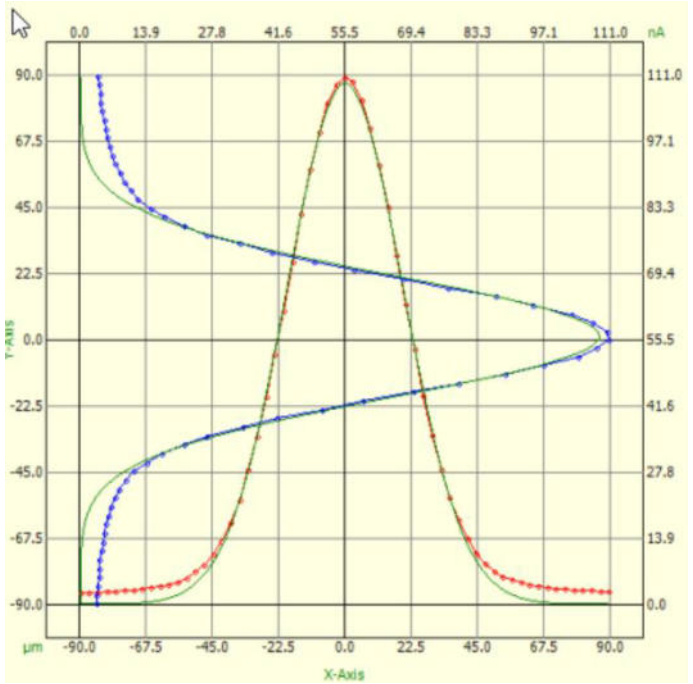
New Developement
RF 5 µB & mB

“old” RF 40 - Small beam

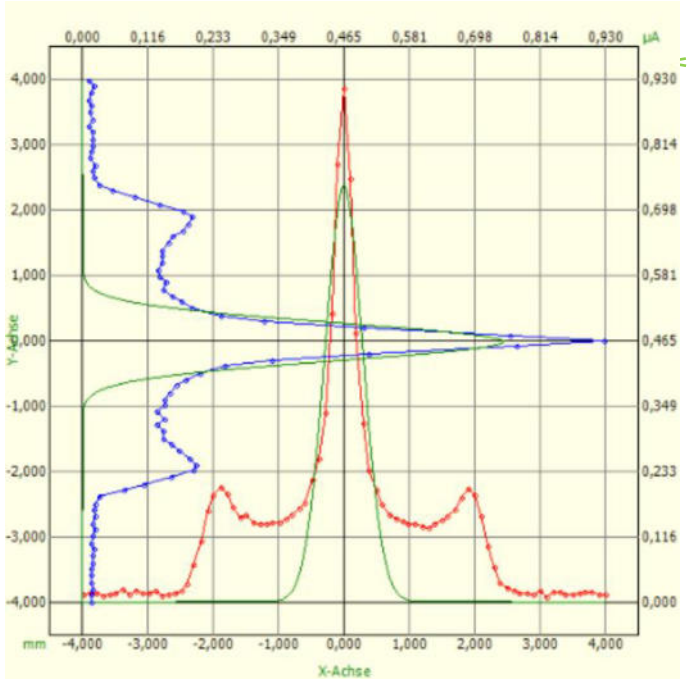


“new” single extraction system





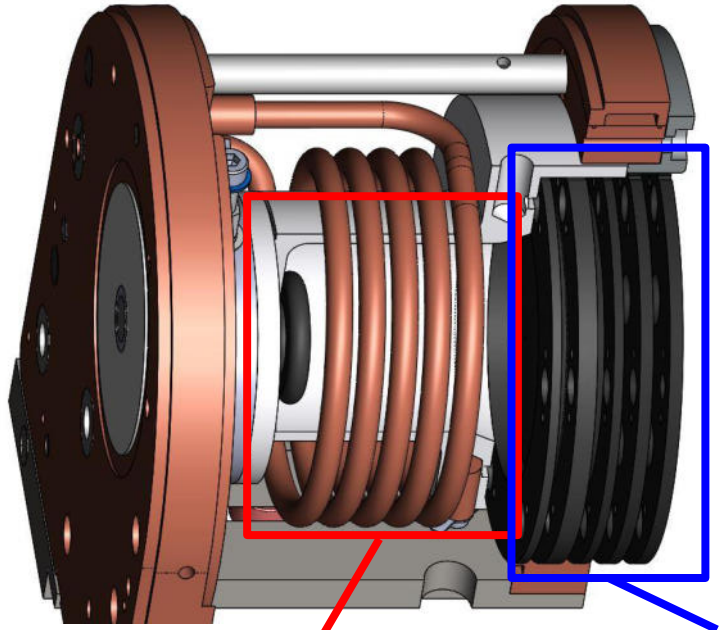
RF5 µB → 40-150µm



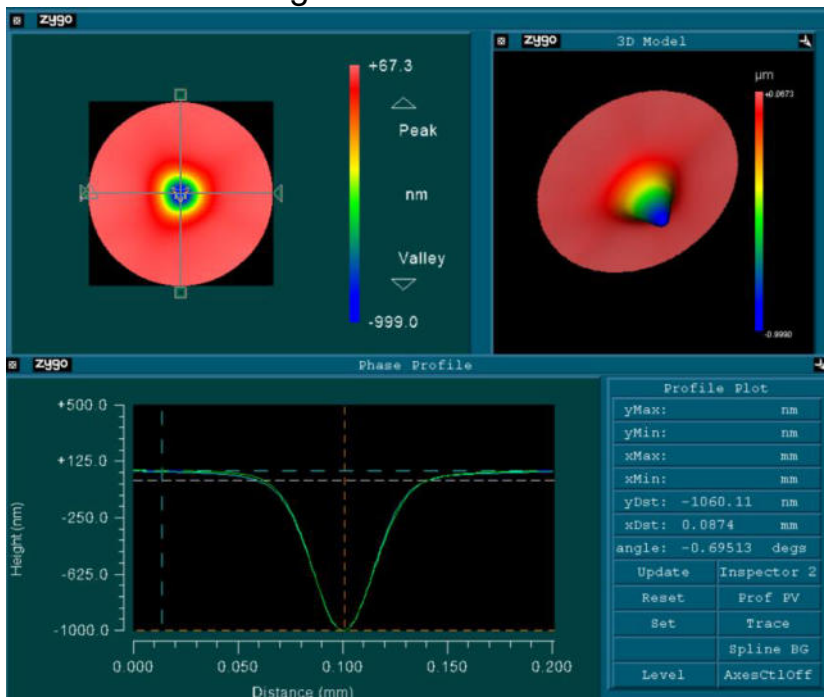
RF5 mB (under dev.) → ~1mm

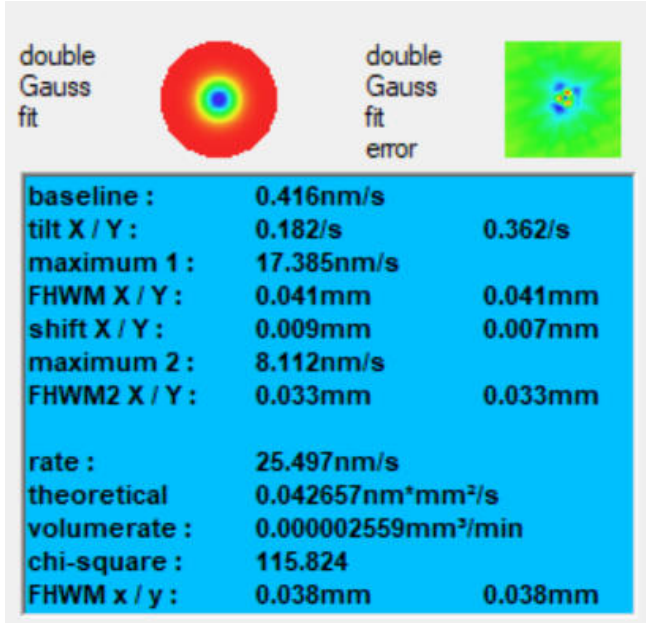
➔No Neutralizer for conductive materials necessary

New Ion source RF 5 µB



Material: Si
Etching time: 40 s
Working distance: 15 mm





Ion beam energy: <1 keV – 3 keV
Working distance: ~15 mm

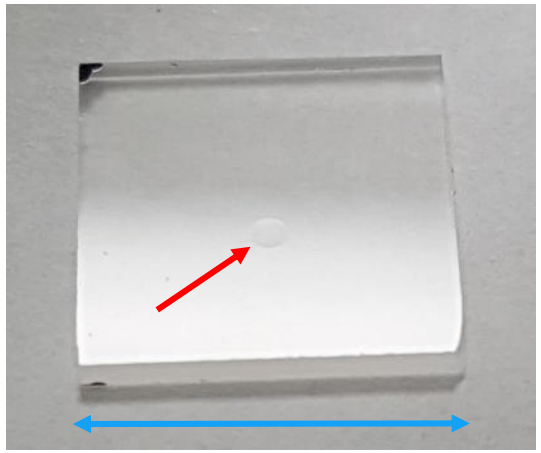
Beamparameter:
Beam energy: 2 keV
RF Power: 50W

Results:
Etch rate: ~25.5 nm/s
volume rate: ~0.043 nm*mm²/s
FWHM: ~38 µm

„Old“ IBF systems upgradeable!
IBF 100…200, F40

IBF 5 - Example Sphere on Plane

Spherization



10 mm

Ion Beam Parameter

Ar+ Ion Energy: 3000 V

Beam Current: 0.7 µA

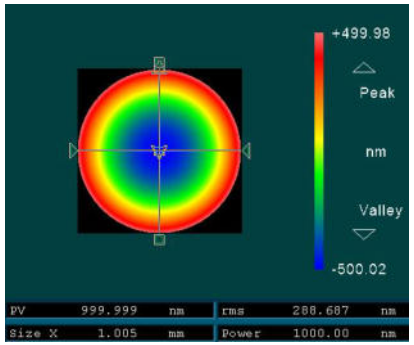
FWHM: ~80µm

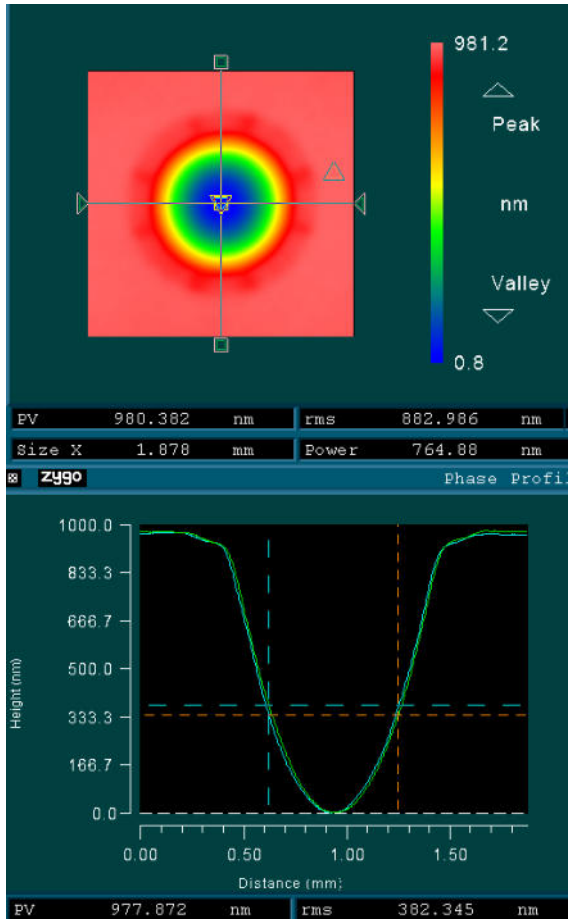
Sphere to generate

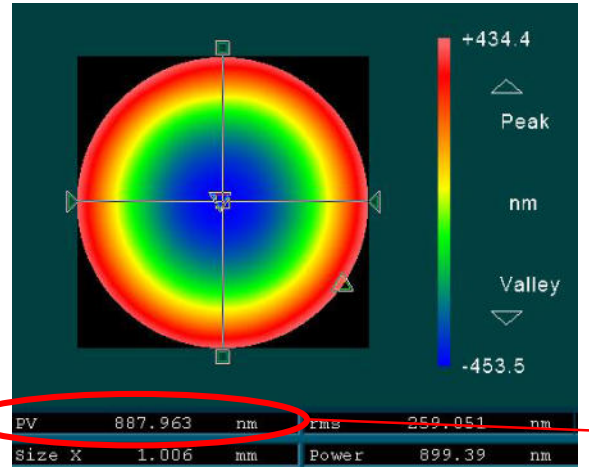
Diameter: 1 mm

Central removal: -1 µm

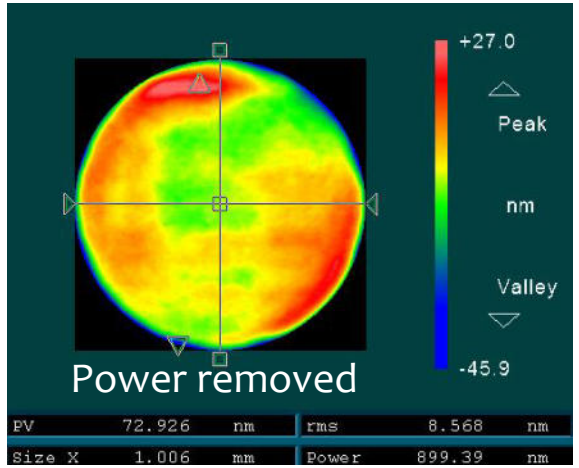
→ Radius: 125 mm

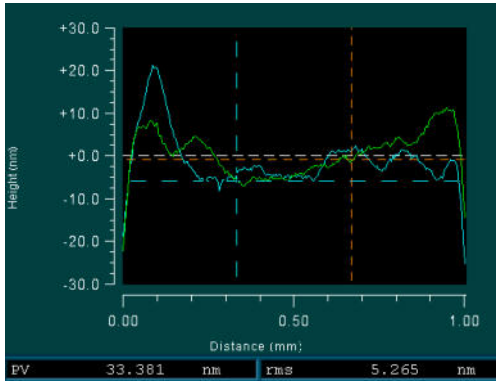






~900 nm of
1 µm Power
→ R=139mm





Application: Mirrors, Laser Optics, Wavefront manipulators

Residual error Ø 100% ~ λ/10

Ø 95% ~ λ/20

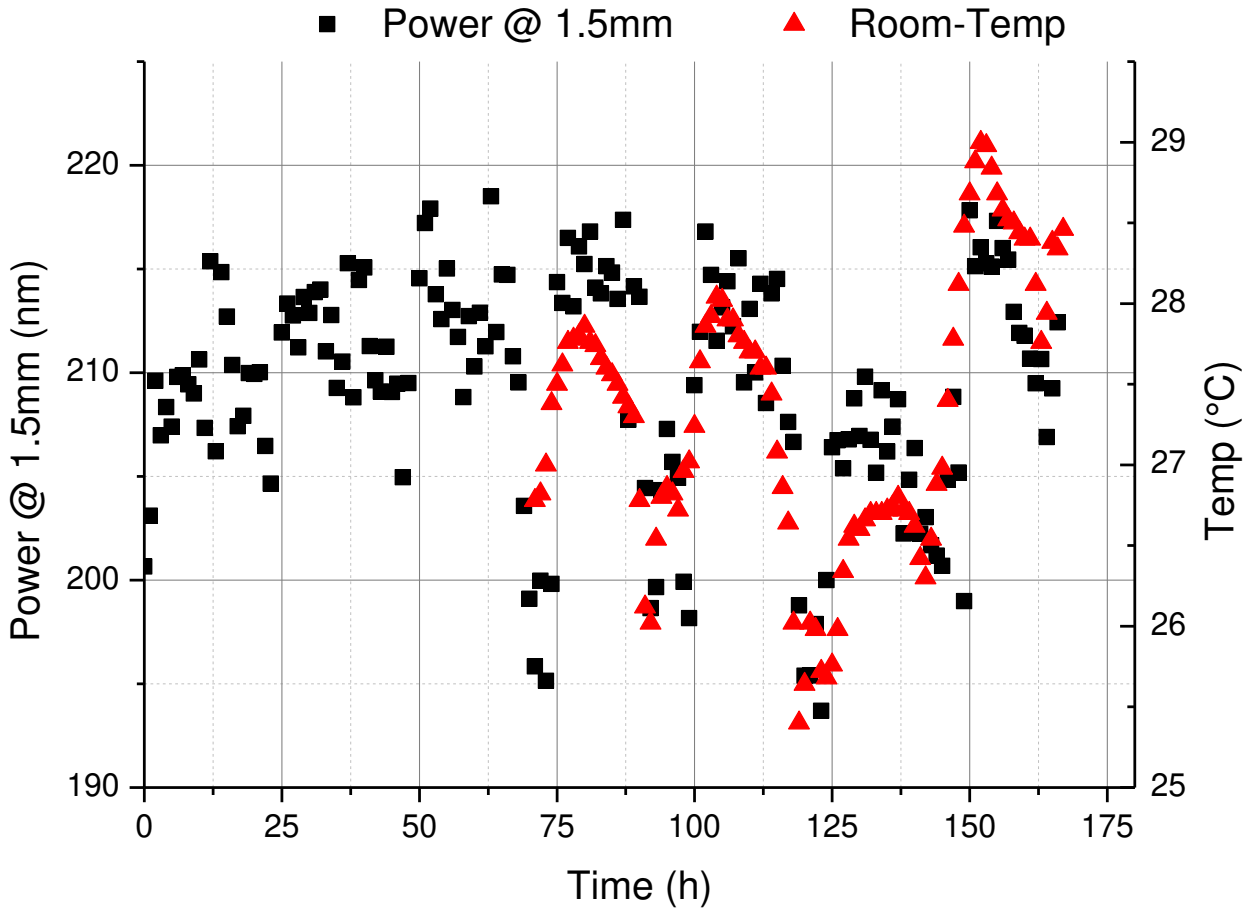
Any shape possible

Long term Sphere etching test

Multiple Spheres: 6.5 rows, 25 each → 166 spheres
Material: Si-Wafer, 14mm working distance
Shape: D = 1.5mm, Power = 200nm → 24min
Process: 1 sphere in 1 hour
total ~166hours (7days)
Evaluation: Power value of etched sphere

Result Power (d=1.5 mm):

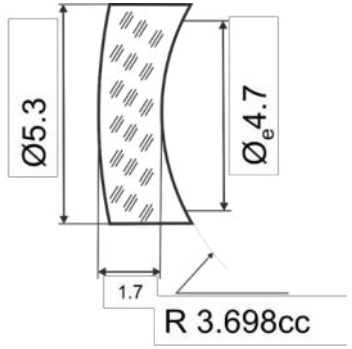
Mean = 209.4 nm
PV = 24.8 nm (11.8%)
σ = 5.4 nm (2.6%)

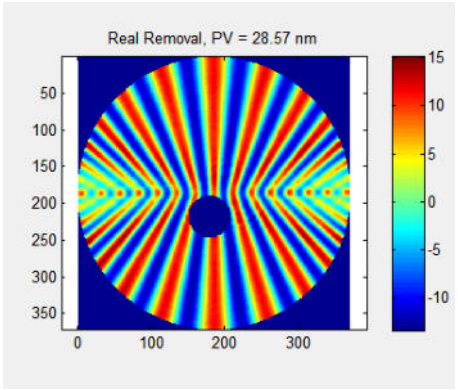


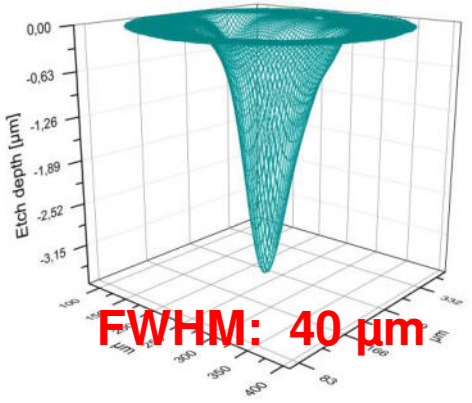
➔ It seems roomtemperature mainly defines the error budget
(NTG IBF 5 lab machine)

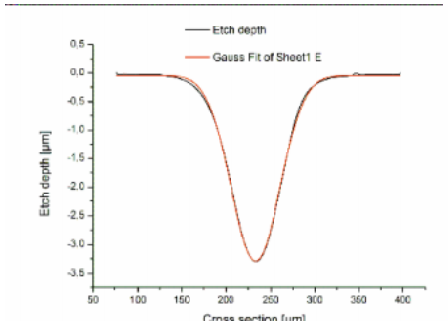
IBF 5 – New possibilities for smaller optics

- IBF 5 – IBF for Micro Optics
- Examples









IBF 5 Machine Design

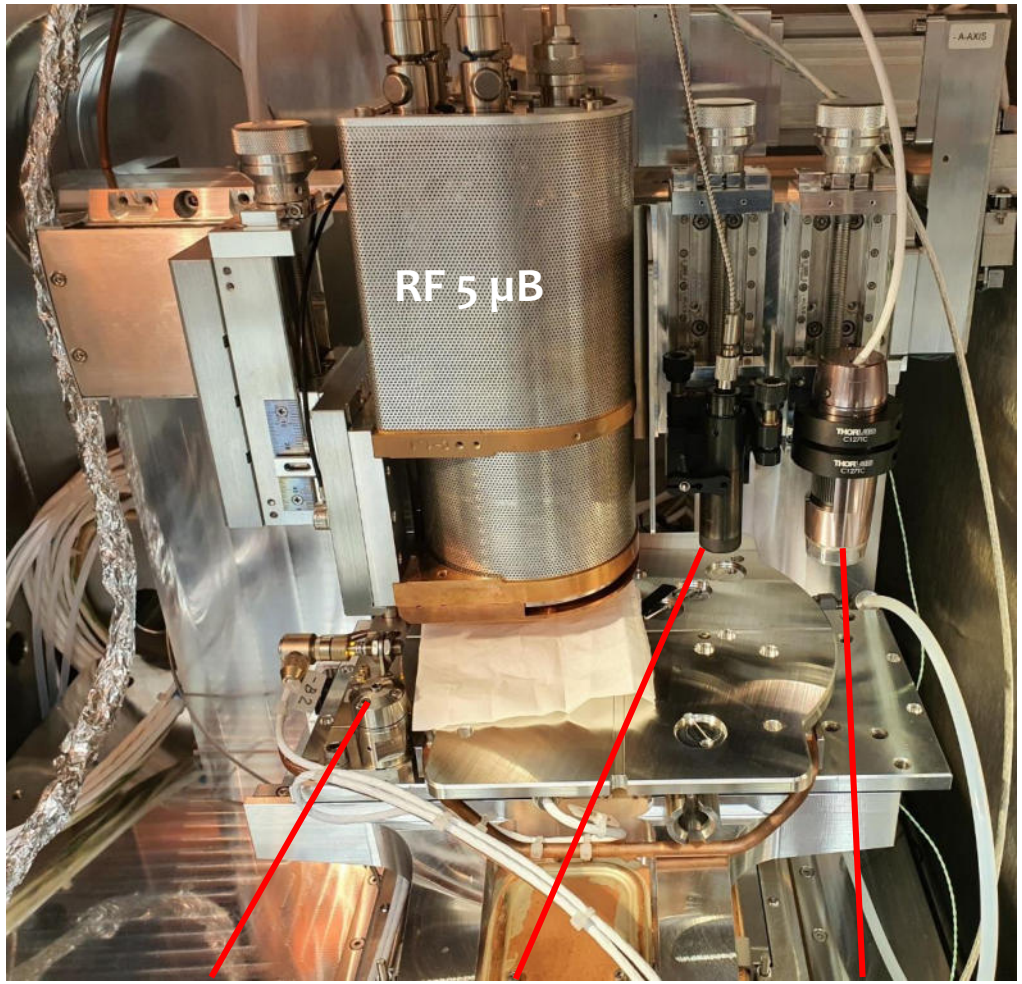
NEW 2020 !

Water cooled axis system + workpiece holder
Position precision <2µm @ 100 x 100mm²

Technical data:

Optics Size:	<Ø5mm <Ø0.2 inches
Contact angle:	max. 72°
Shape:	freeform
Working Travel range:	100 x 100 mm²
Thickness:	<50mm (20 inches)
Weight:	max. 2kg (4.4 lb.)
Alignment system: (vacuum use)	µ-Faraday Cup Confocal Sensor Vision System
Load lock system:	no load lock, batch processing load lock optional available

IBF 5 Alignment System

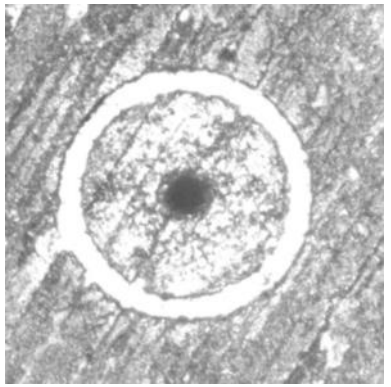


µ Faraday Cup Confocal Camera

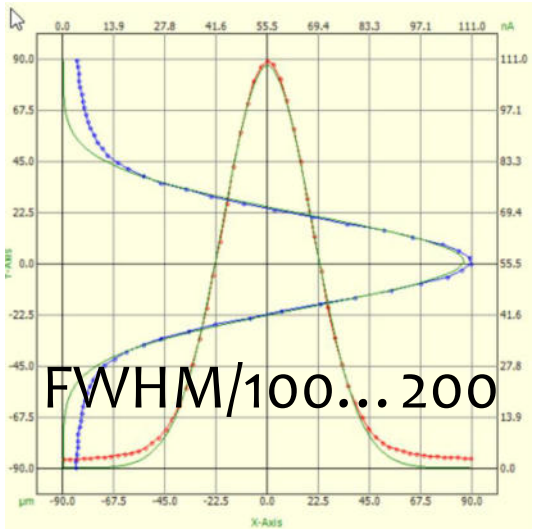
Camera System:
- Variable camera zoom (FoV ~1.5mm… >20mm)
- Confocal illumination vizualize test etchings

Confocal System:
- Measurement range: 2.5mm
- Height measurement + ROC scan of sample

One Common reference:
- µ Faraday Cup



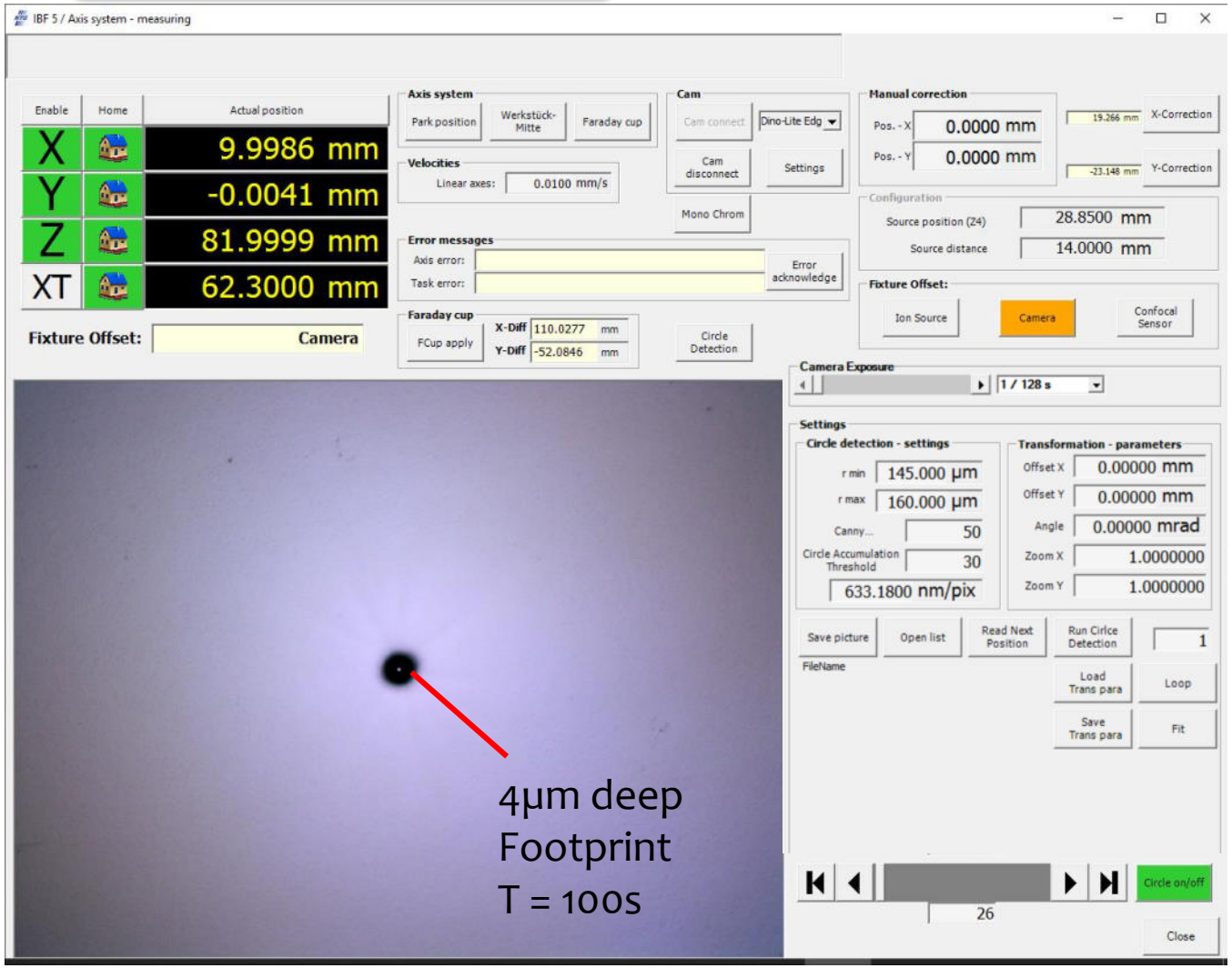
50µm aperture
500µm + Contrast groove



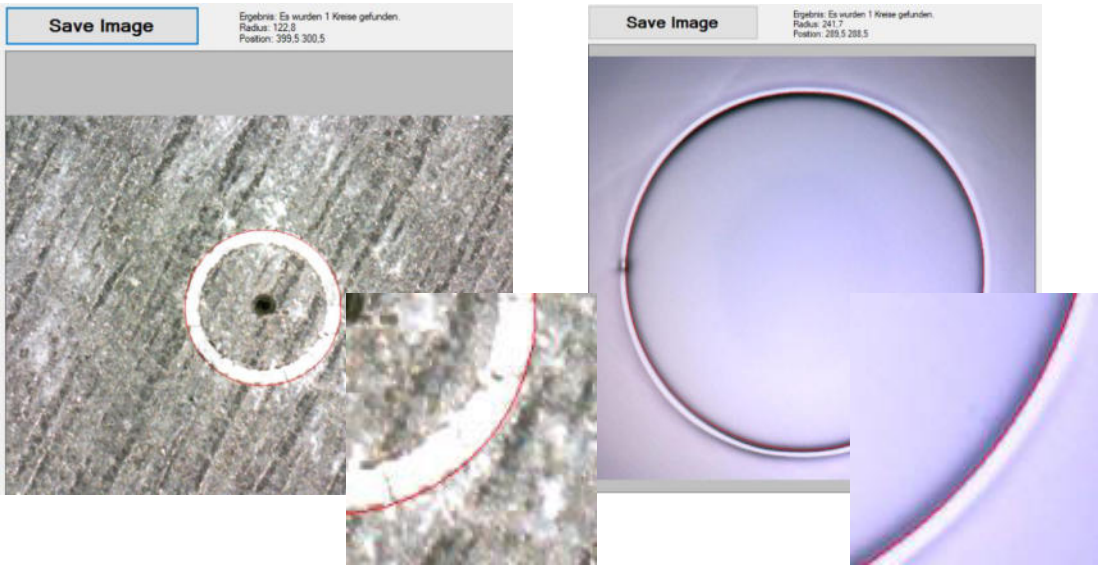
Ion Beam distribution
Measurement (TCP)

IBF 5 Camera system

GUI for Camera Measurement



- Circle Autodetection
- Automated Measurement loop for several fiducial measurement

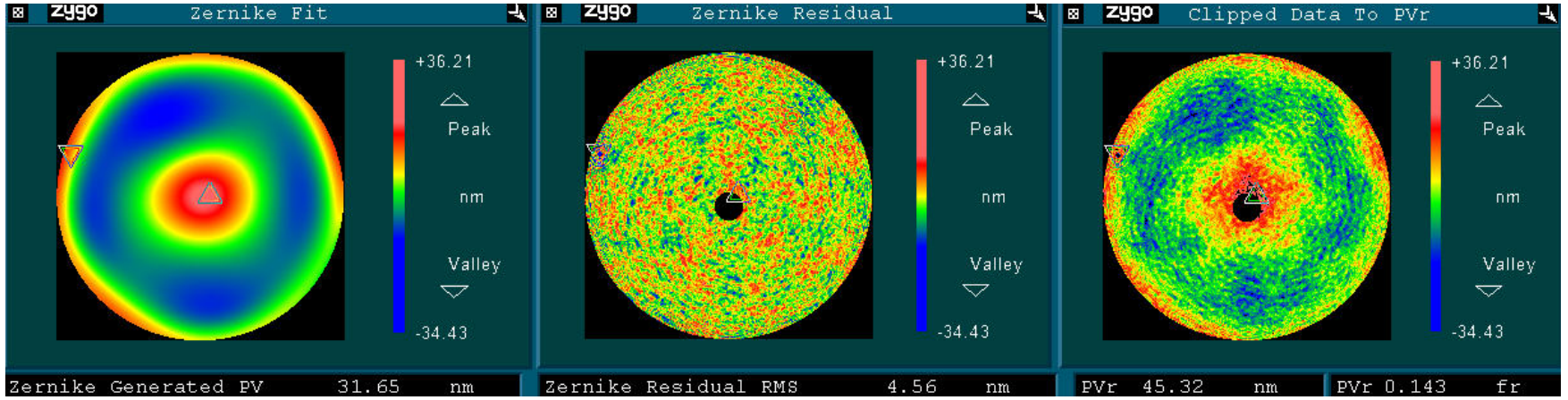


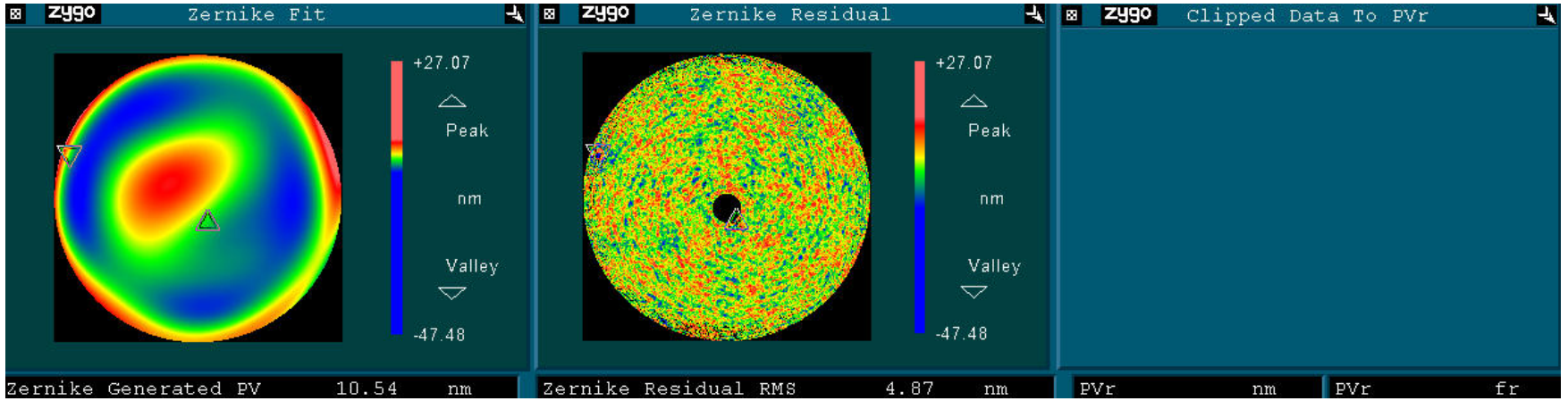
→ Finally evaluate sample position in relation to µ Fcup (Δx, Δy, Rot, Zoom)

IBF processed „ring“:
500µm groove, 1µm deep
T=60min

IBF 5 - Example
Tungsten Carbide Mold

Form Correction: Mold Ø 2.36mm





Sample
Ø 2.36 mm, R 1.35 mm (f/0.572)
Material: Tungsten Carbide
Treatment @90%:
Measurement using f0.75 (Ø1.62mm)

Ion Beam Parameter

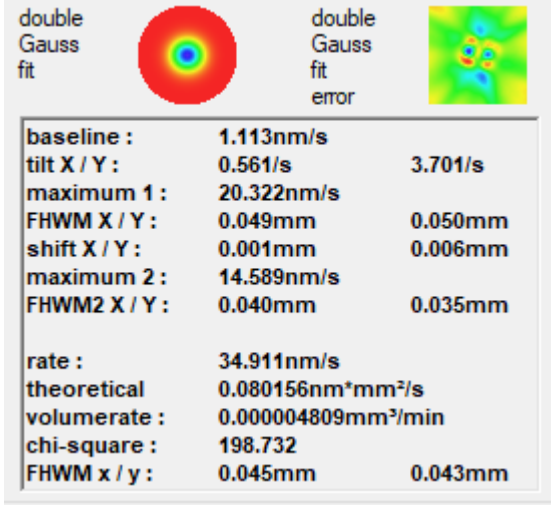
Ar+ Ion Energy:	3000 V
FWHM:	70 µm
Vol.-Rate:	0.1 mm^2nm/s

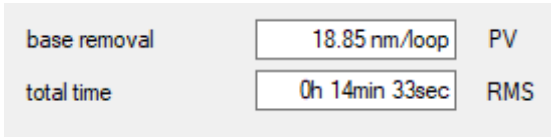
Processsing Time: 0:06h

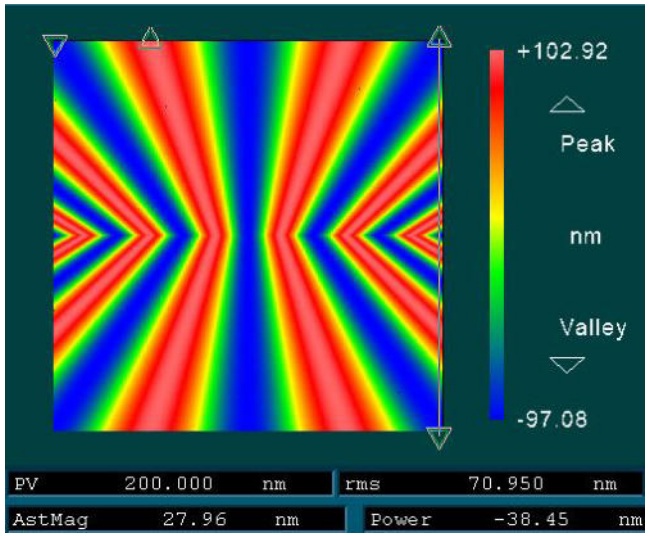
NTG lab machine

IBF – New State-of-the-art Resolution Limit

Ion Beam:
Energy [eV]: 2000



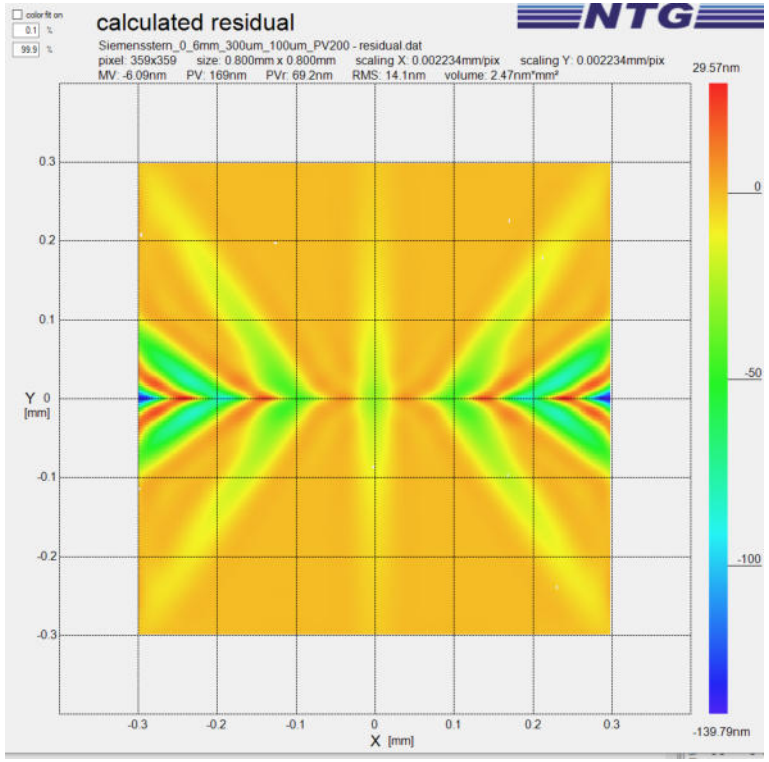




Simulation

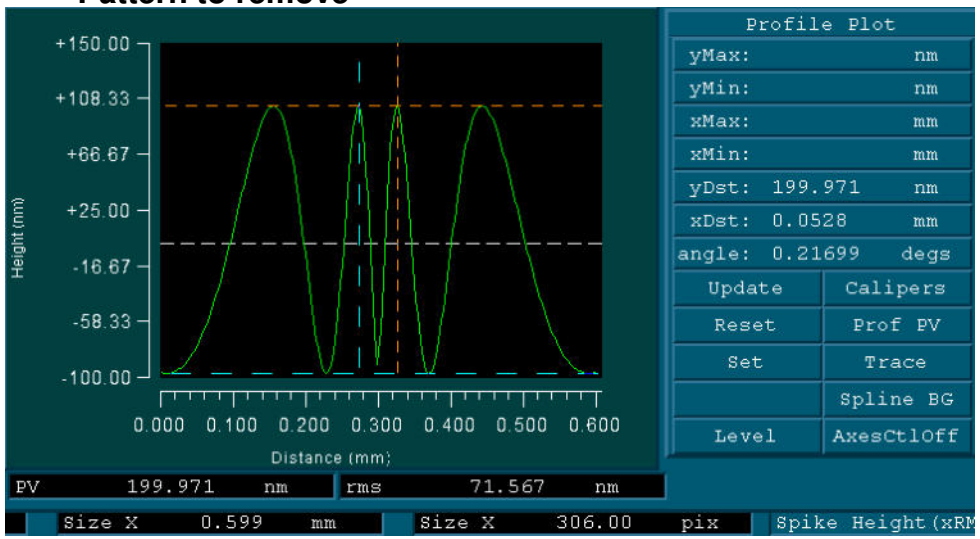
Modified Siemensstar:

PV: 200nm
Spatial wavelengths
V: 300µm to 100µm
H: 50µm to inf.



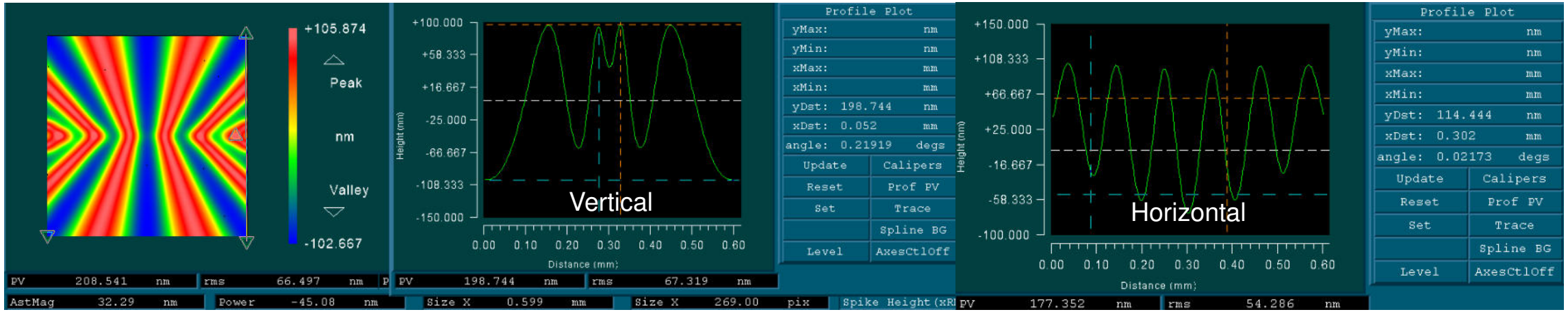
Calculated residual

Pattern to remove



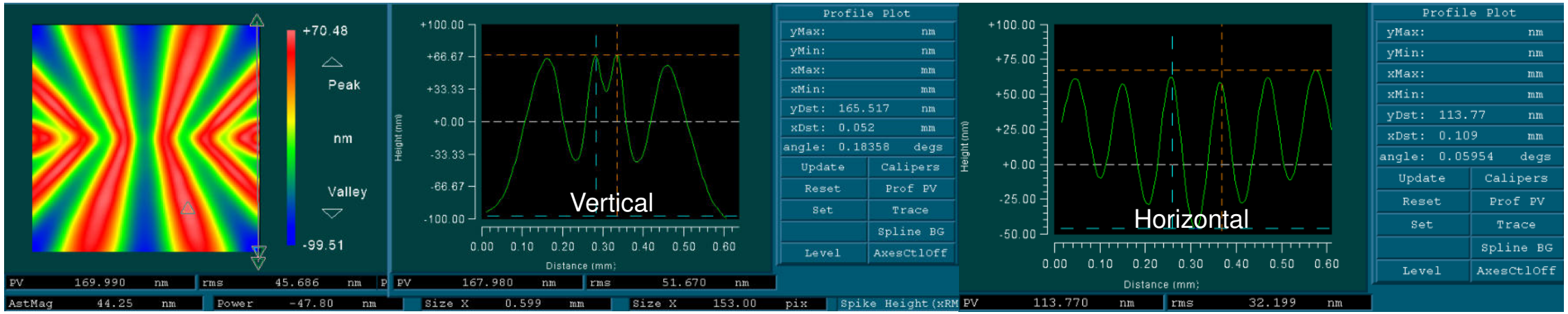
IBF – State-of-the-art Resolution Limit

Simulated removal:

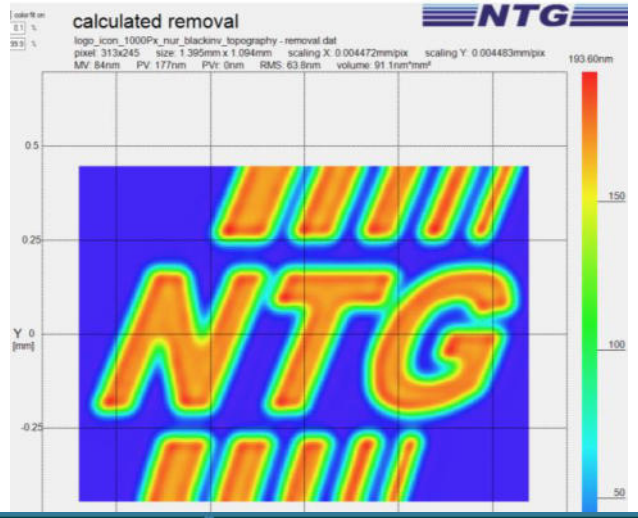


→Full modulation @ l=100µm

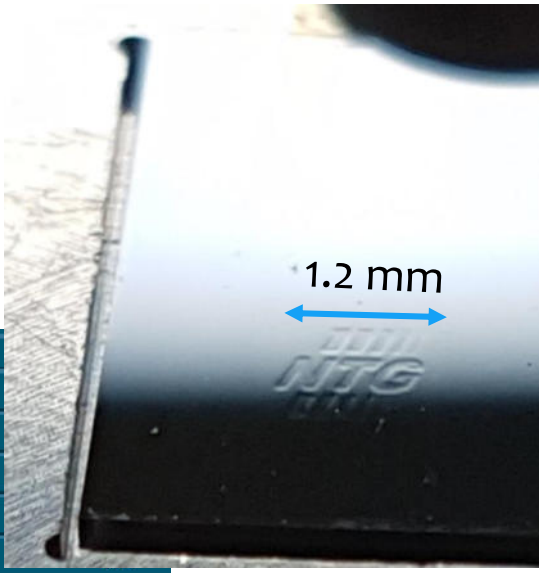
Real removal:

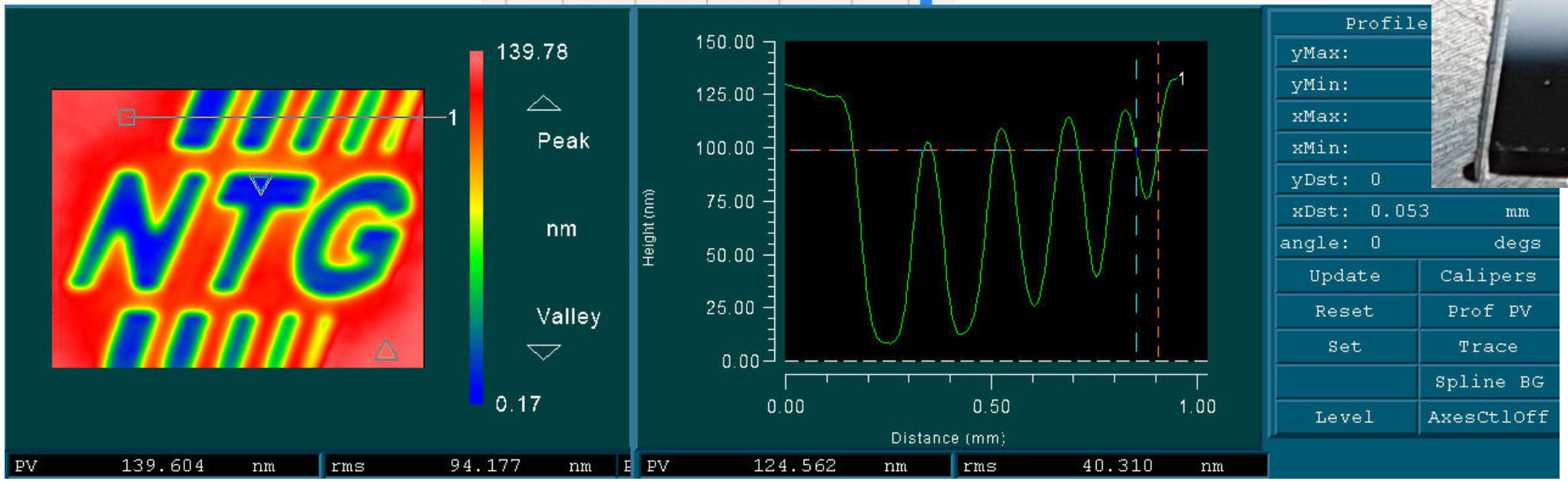


Name/Barcode Marker

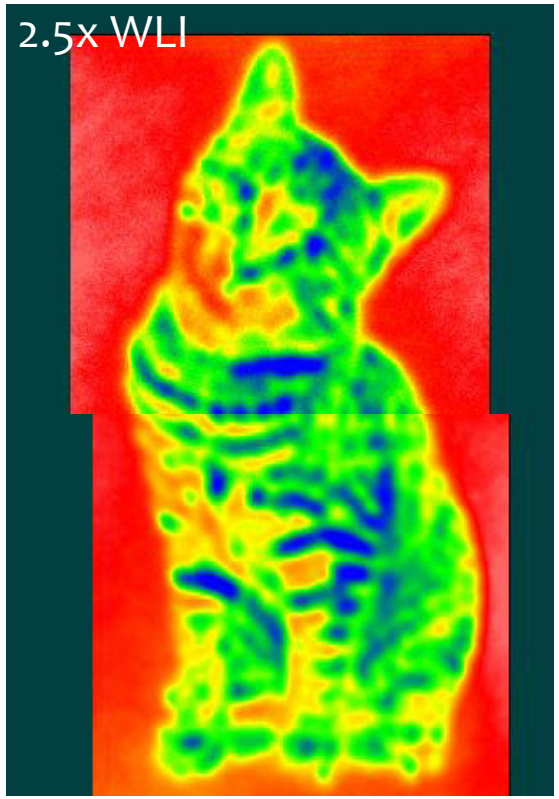


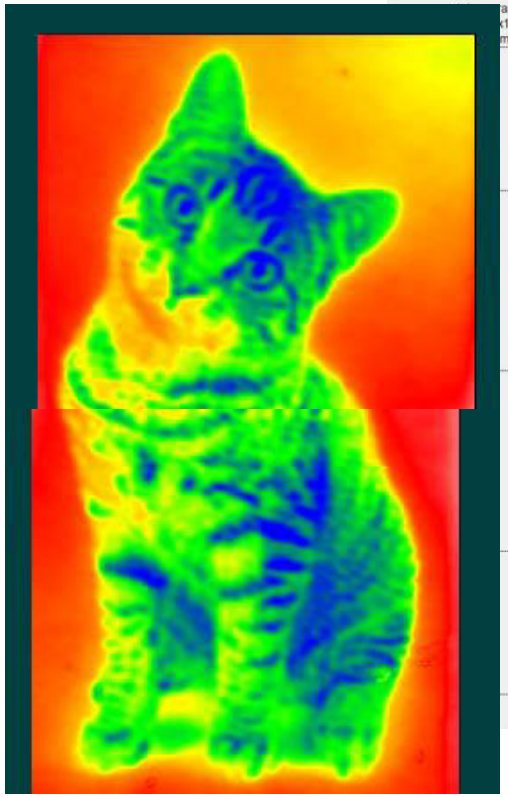
PV: 200nm
Beam size: 50µm
Processing Time: 0:24h

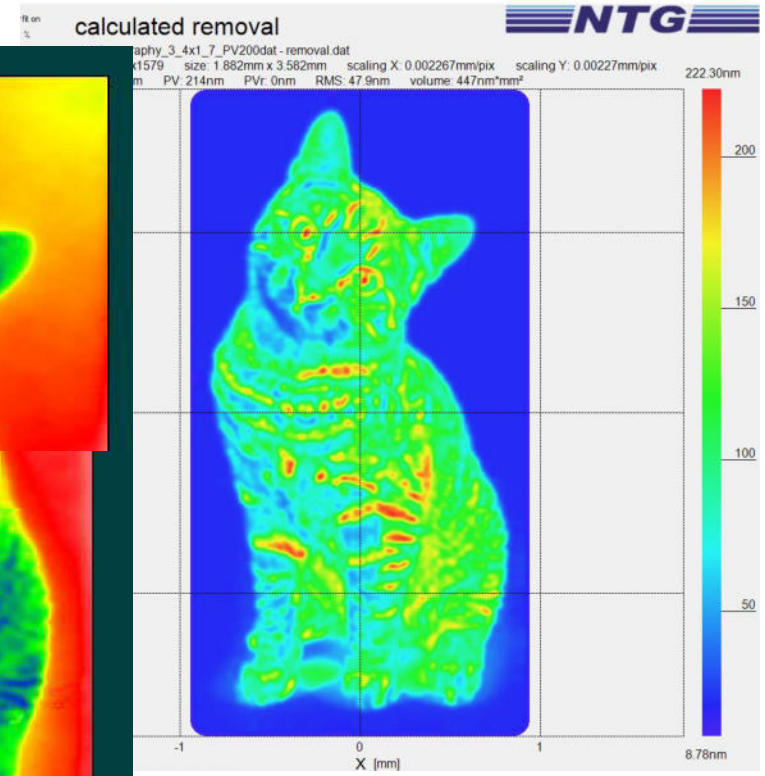


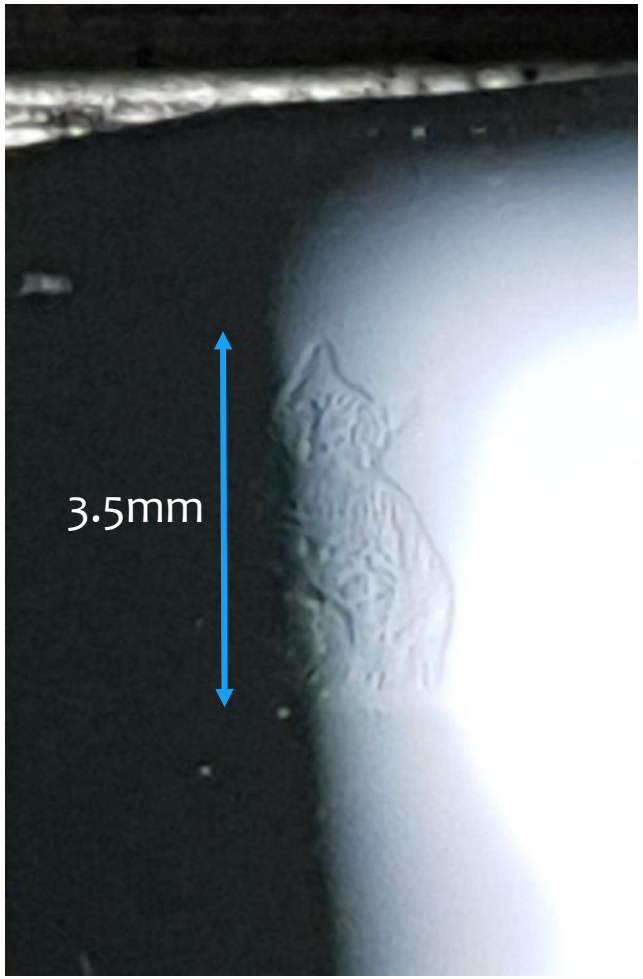


Schrödinger‘s Cat found on Silicon Wafer!!!









FD 5 Ion Beam Source

PV:	100nm
Beamsize:	70… 90µm
Processing Time:	0:48h

RF 5 µB Ion Beam Source

PV:	200nm
Beamsize:	45µm
Processing Time:	1:34h

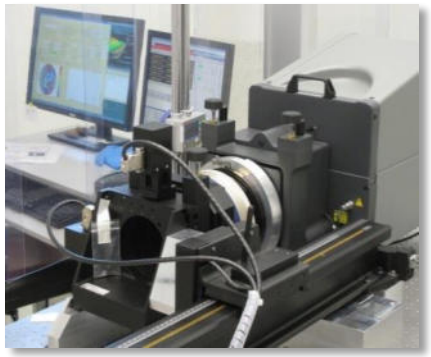
Summary

- IBS: Physics, mathematics, new gun developements
- IBF 5: Pushing the limits
- Examples: Form correction, spherization, markers

NTG Laboratory

- Surface Measurements (Interferometer, WLI, AFM) → PSD
- Process Simulation, Process Development
- Feasibility Studies
- Reference-Optics (PtB certified)
- IBF / IBS / IBE
- IBF 5, IBF 200S
- Measurements internal/external

Thank you!



Materials

- Schott / Ohara,...
- WC, SiC, NiP...
- Zerodur, ULE,...
- Clearceram, TiN, AlN,...
- SiO_2, CaF_2,...
- Nd:YAG, KTP, BBO,...
- ... tbt