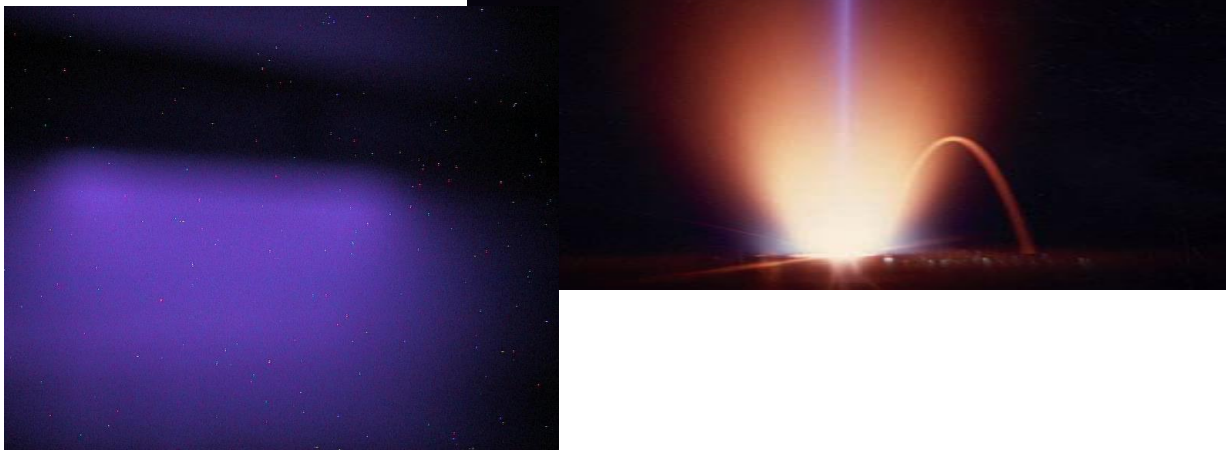
Novel very low Energy Electron Sources – an Overview

Customized Accelerators
The Basis of a successful Application Development

EuCARD-2 Workshop with Industry
8-9 December 2016
Warsaw, Poland

Frank-Holm Rögner
Head of Department
Electron Beam Processes



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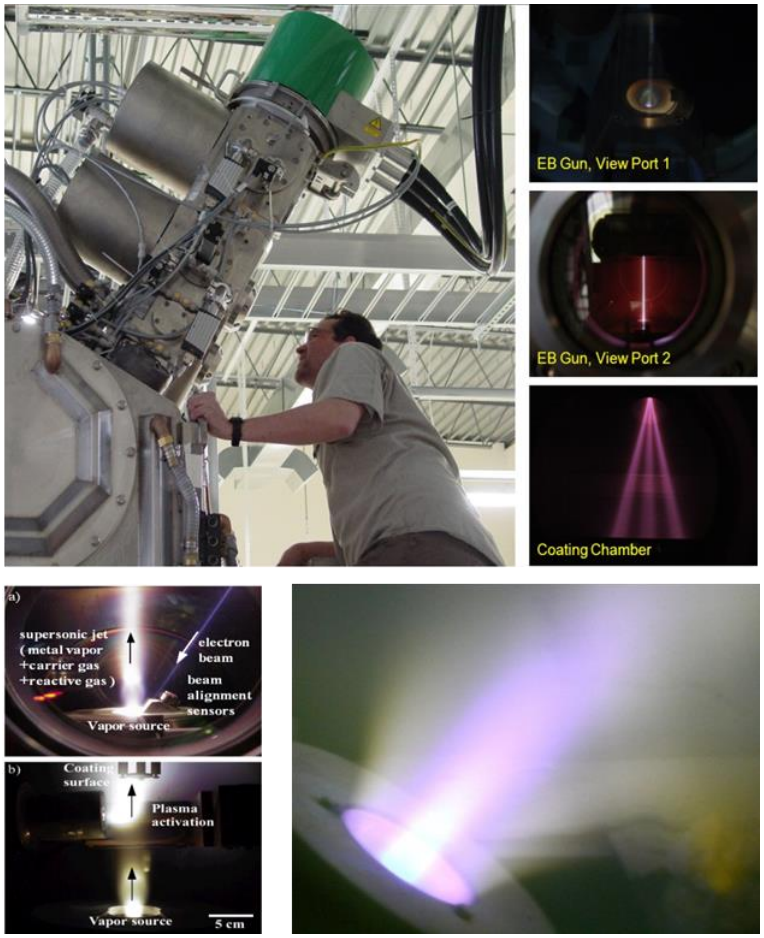
Outline

- Electron Beam Basics
- Customized eBeam-Sources
- Summary



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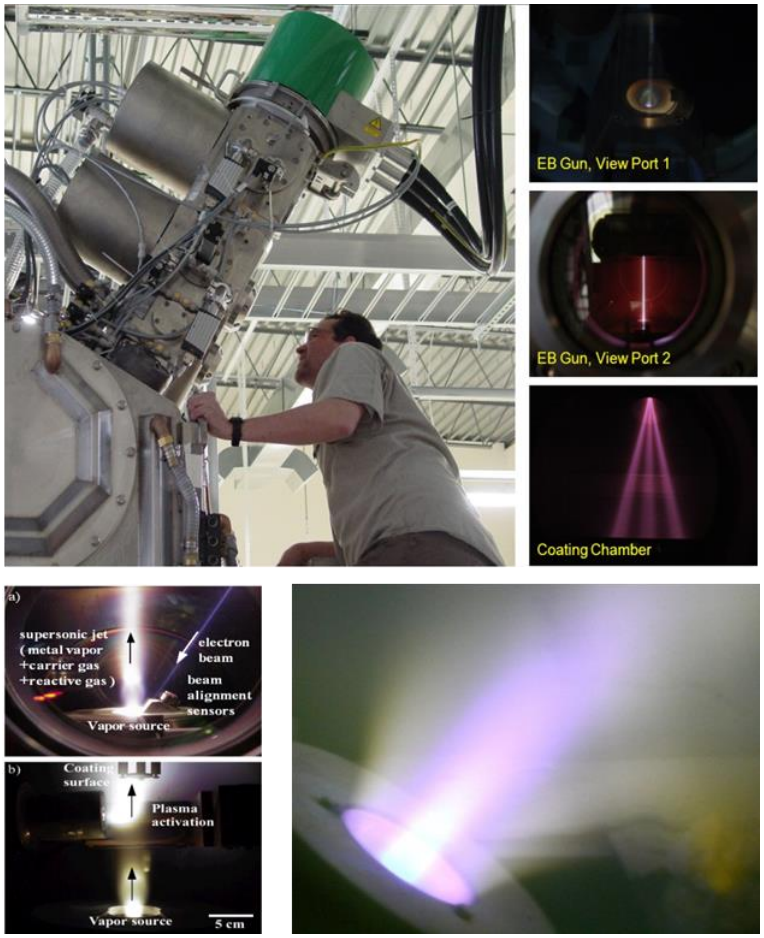

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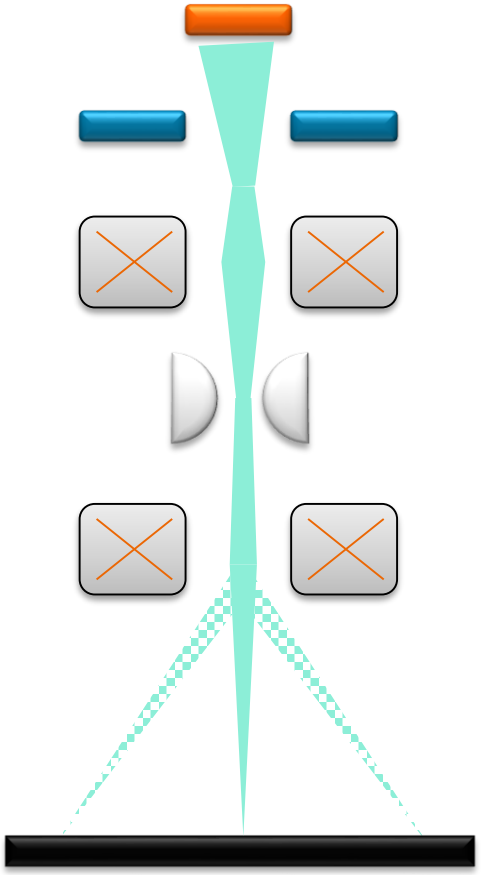
Electron Beam Technology - Basics

Principles of electron beam generation and processing



Cathode, emits electrons

Acceleration anode

Electromagnetic beam shaping, centering and stigmatic correction

Pressure decoupling between electron generation and processing

Electromagnetic beam focussing and fast deflection

Workpiece

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Electron Beam Technology - Basics

Effect of Electron Beam Interaction

Thermal Processes	Non-thermal Processes	
Heat Production	Chemical Reactions	Biocidal Effects
Vacuum	Atmosphere	Atmosphere
- Evaporation - Melting - Welding / Joining - Hardening - Micro- structuring	- Curing - Crosslinking - Drying print-inks - Surface modification (Grafting)	- Disinfection - Seed treatment - Sterilisation - Inactivation - Cell-modification

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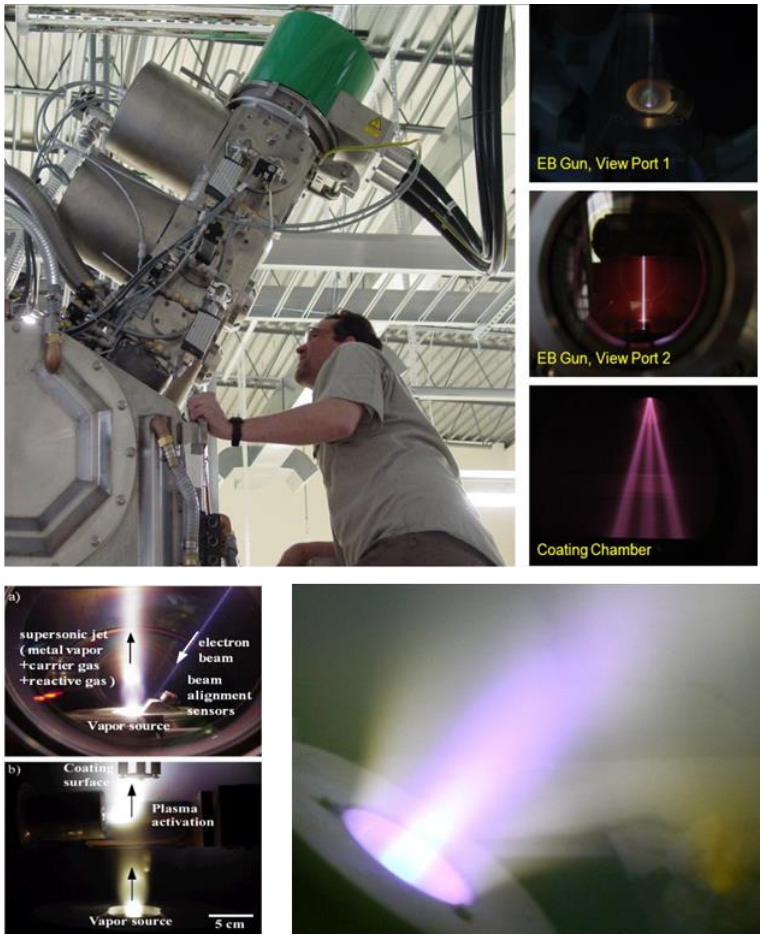

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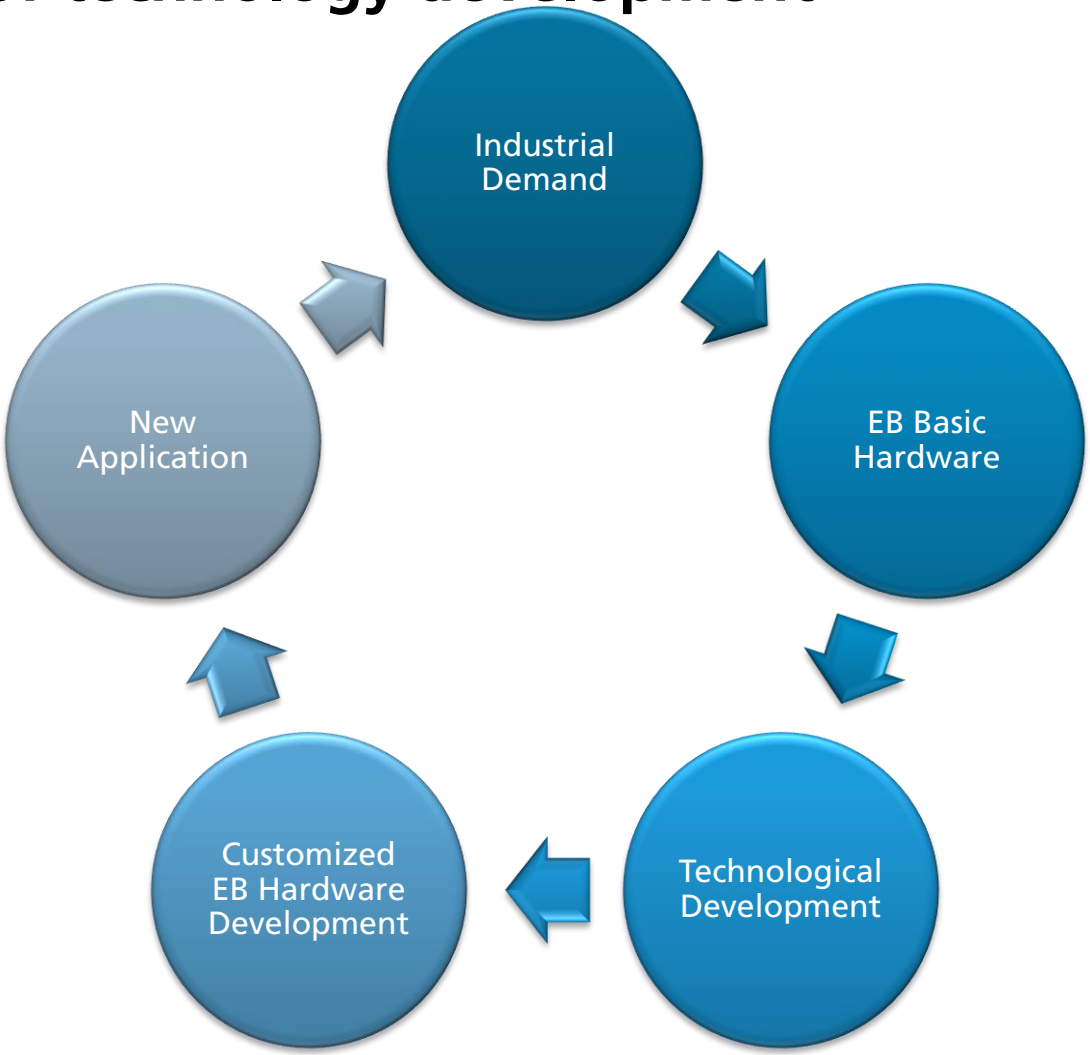
Customized eBeam-Sources
The circle of technology development



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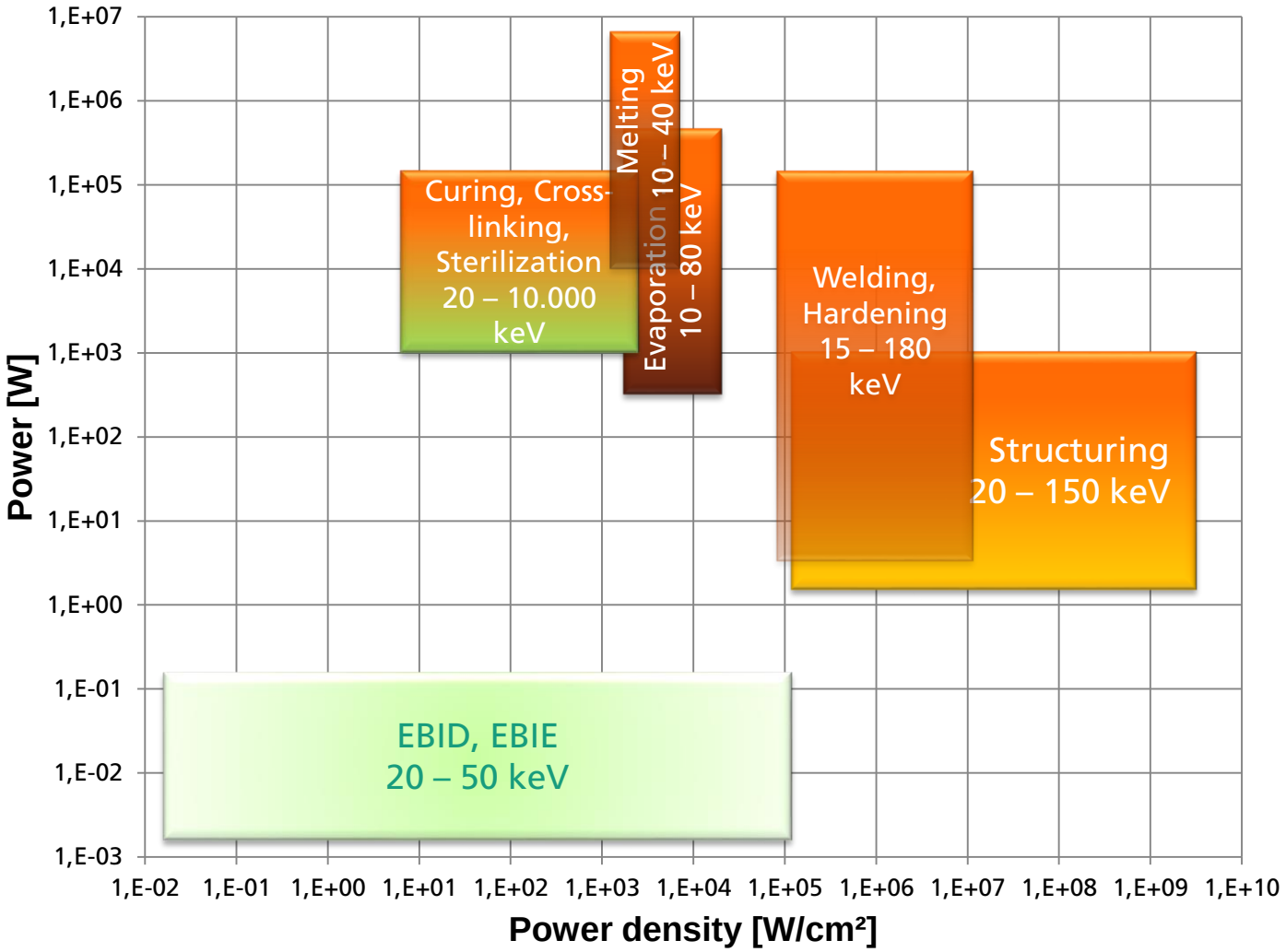
Electron Beam Technology - Applications



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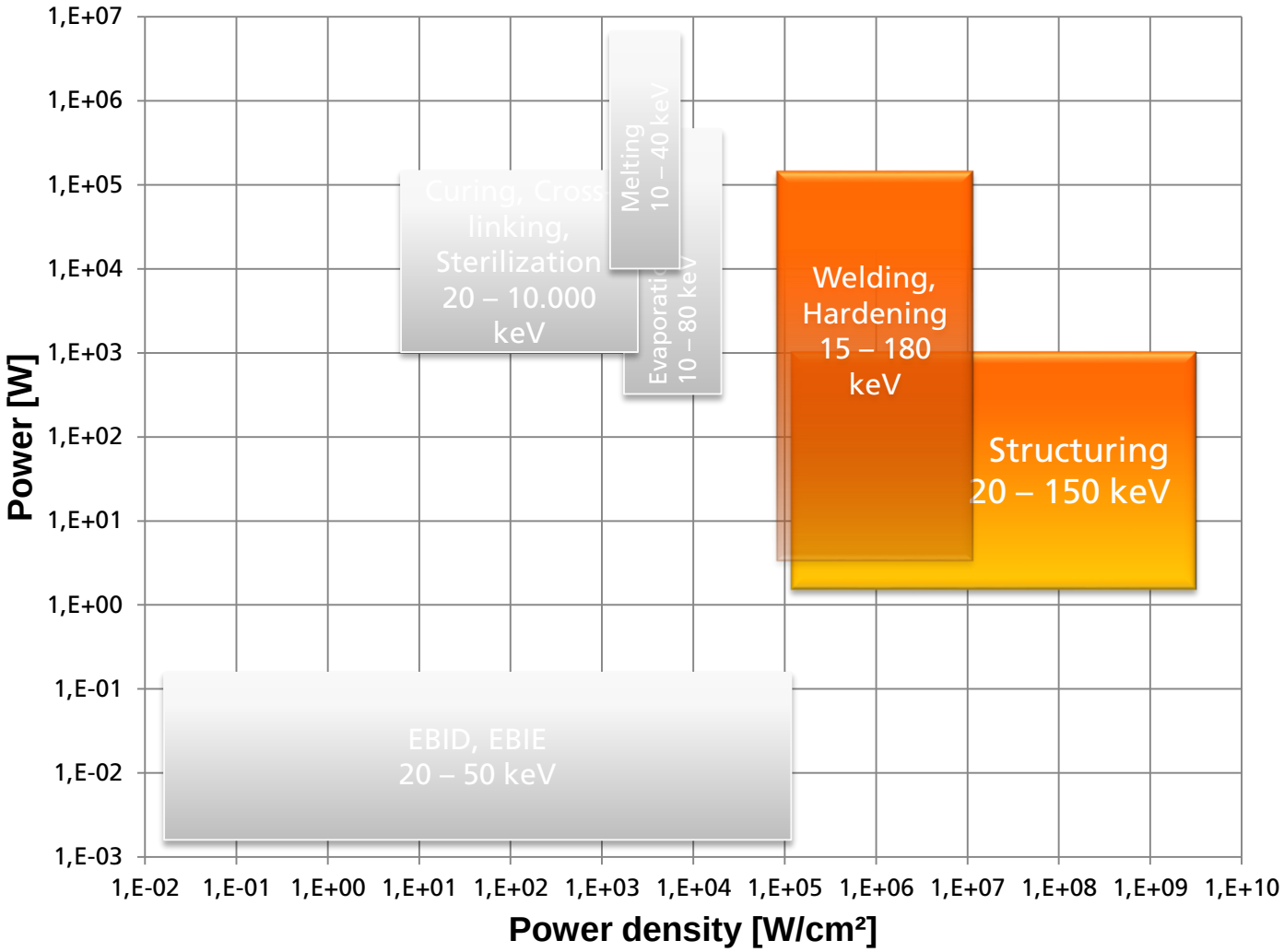
Applications – Welding, Structuring



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Customized eBeam-Sources

Thermionic Emitter

Axial gun CTW
80 W – 10 kW

40 – 70 kV

Cold Cathode Emitter

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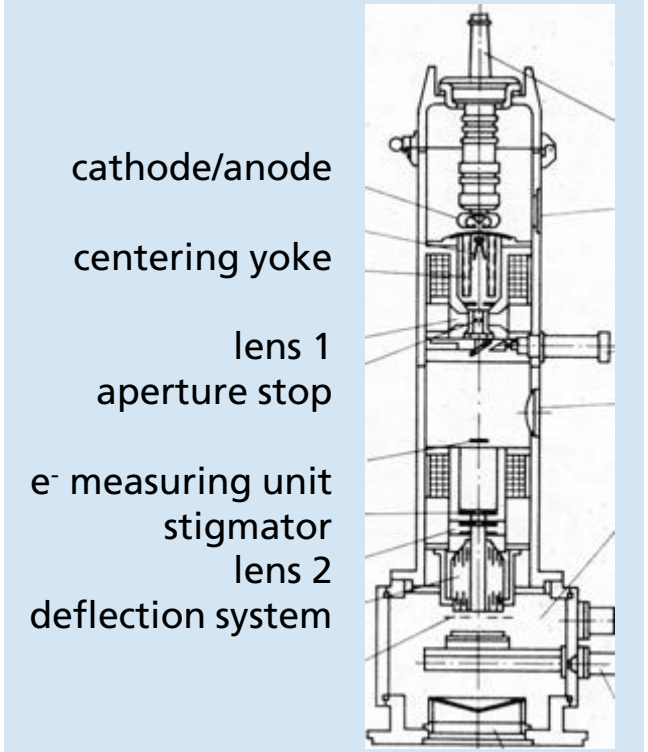
Low power axial gun – Basic ST 10/60

- acceleration voltage
  40 … 60 kV
- maximum beam power
  80 W … 10 kW
- beam diameter
  15 … 500 µm
- deflection field
  30 x 20 … 100 x 100 mm²
- deflection frequency
  200 kHz



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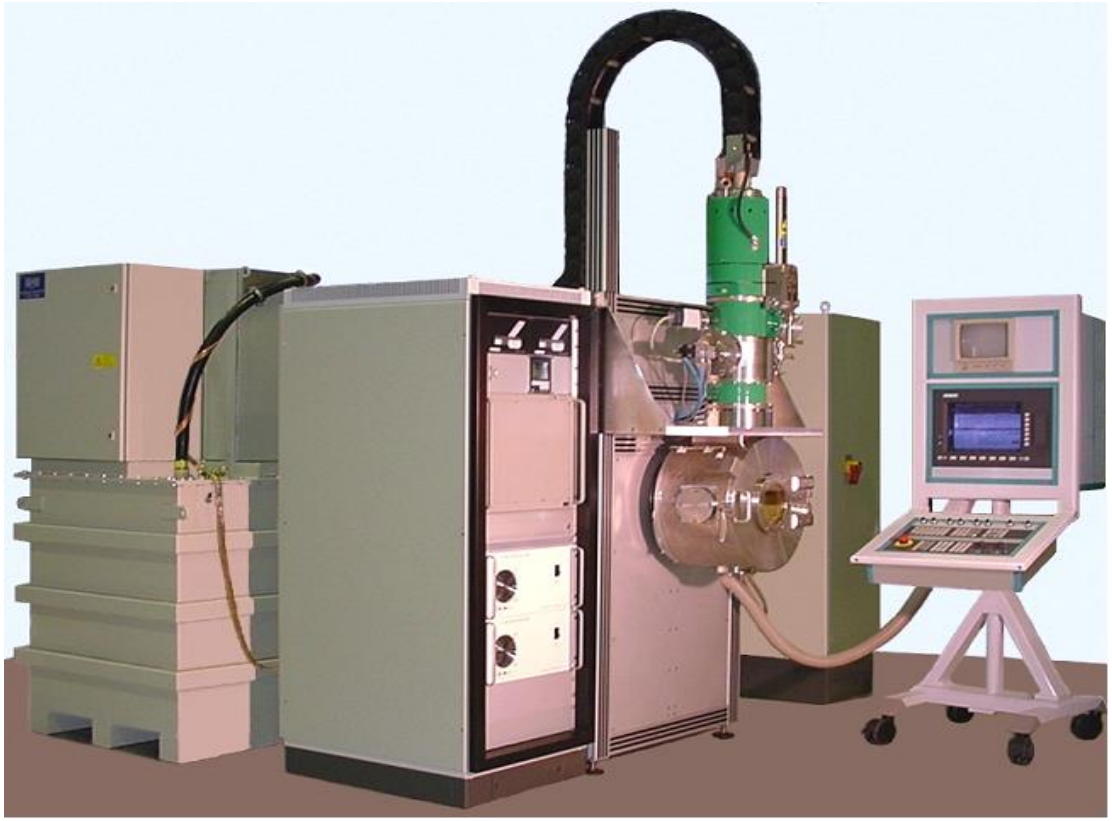
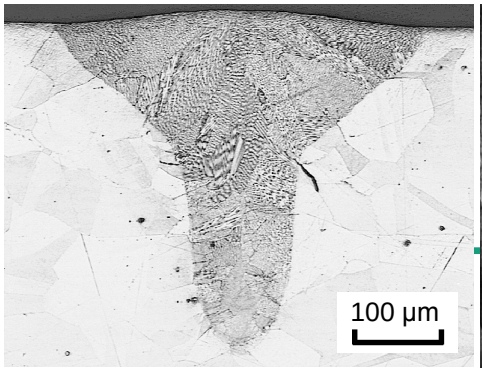
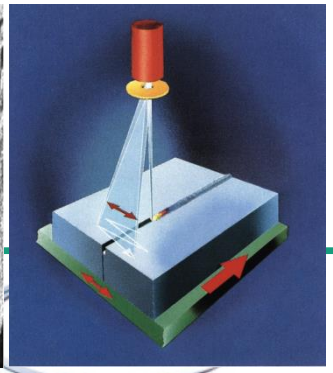
Micro-Welding: Customized eBeam-Source ST 2/70







Operation characteristic:

⇒ production plant

Technologies:

⇒ EB microwelding of mini sensors
welding depth ≈ 750 µm,
seam width ≈ 100 µm

⇒ EB microlabeling
Structural width: ≥ 50 µm

Components:

⇒ EB gun ST **2 kW / 70 kV**

⇒ **HSS beam deflection** unit

⇒ surface imaging and
automatic beam alignment
by backscattered electrons
(RICO system)

⇒ Technology Package

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Customized eBeam-Sources

Thermionic Emitter

Axial gun MEBW 2 kW	60 kV
Axial gun CTW 80 W – 10 kW	10 – 70 kV

Cold Cathode Emitter

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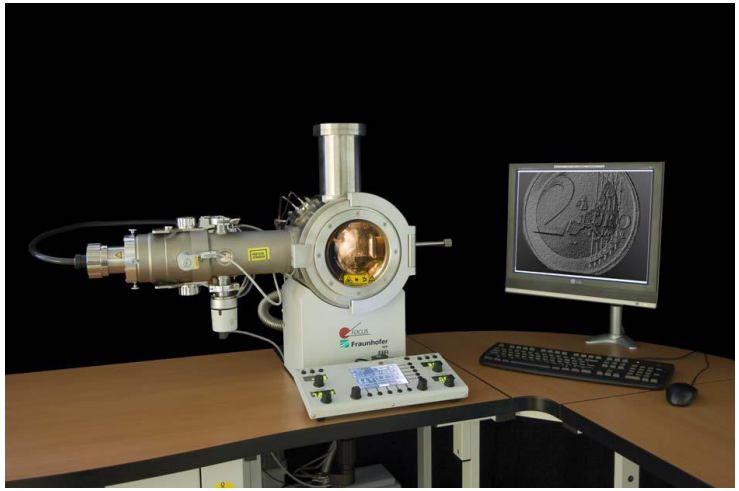
Low power axial gun – Basic MEBW 60

- Supplier: Focus GmbH
- basic research in the field of electron beam micro-welding, engraving, structuring
- development of technologies for customer parts
- investigations regarding new applications of electron beam technology

electron beam gun	2 kW / 60kV
wide angel deflection	± 35°
work pressure	5 x 10^{-4} mbar
substrate size	150 x 150 x 150 mm
1 rotatable axis	0 … 32 min^{-1}
short cycle times	< 2 min



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FOCUS GmbH

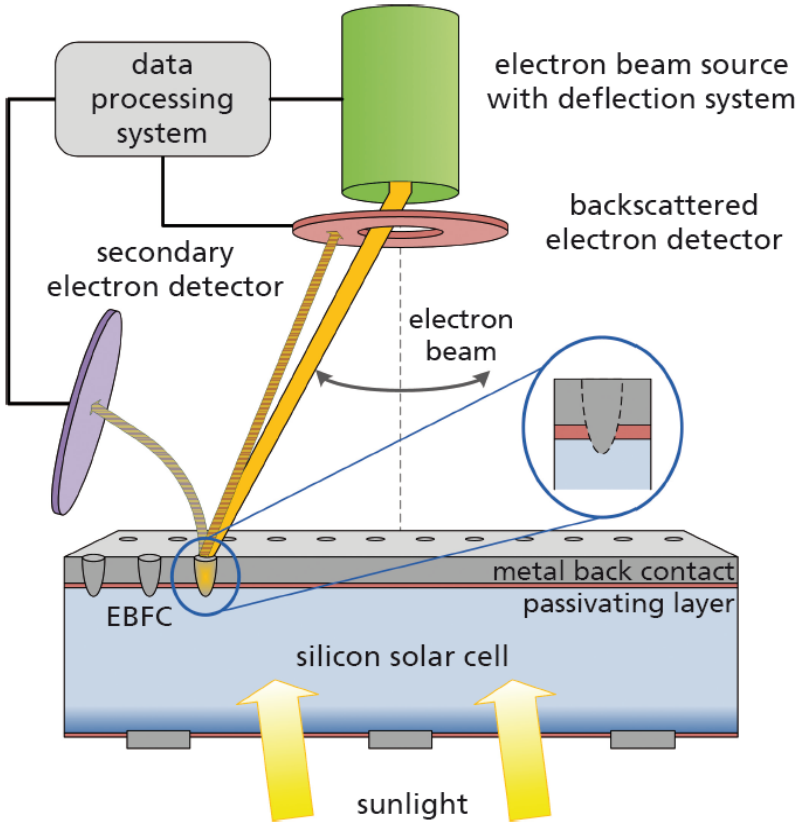
Fraunhofer FEP

EBFC: Customized eBeam-Source MEBW 60 - EmicPro

Surface Passivation and Electron Beam - fired Contacts (EBFC)

For this task, the electron beam has some advantages over the laser:

- Energetic electrons can penetrate thick metal layers with volumetric, adjustable absorption profile and with low energy reflection losses.
- High-power electron beam can economically be generated and operated in cw or pulsed mode
- Inertia-less beam deflection enables very fast processing (goal: 7.200 8"-wafers / hour).
- EB-contact formation is a vacuum-based process. Therefore, it is per se compatible to vacuum deposition modules in a solar cell production line.
- Secondary effects (BSE, SE, X-ray, current probe…) can be used for process monitoring / quality control.



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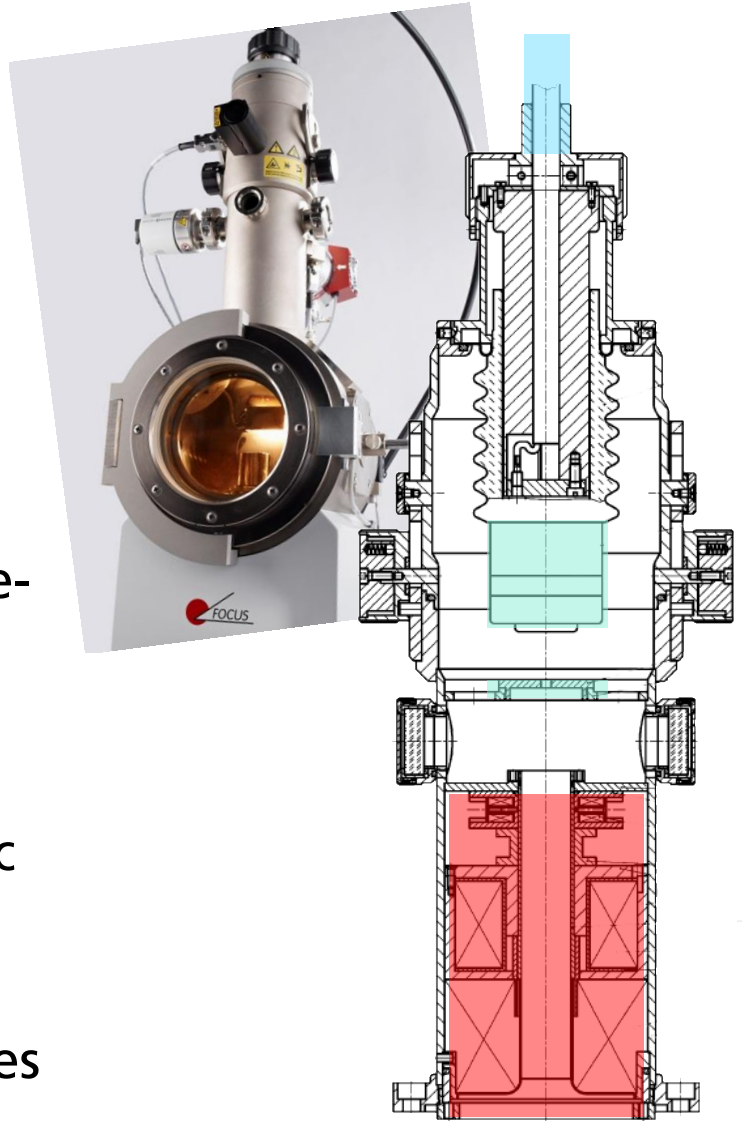
Gefördert aus Mitteln der Europäischen Union
Europa fördert Sachsen. EFRE Europäischer Fonds für regionale Entwicklung
Fraunhofer FEP

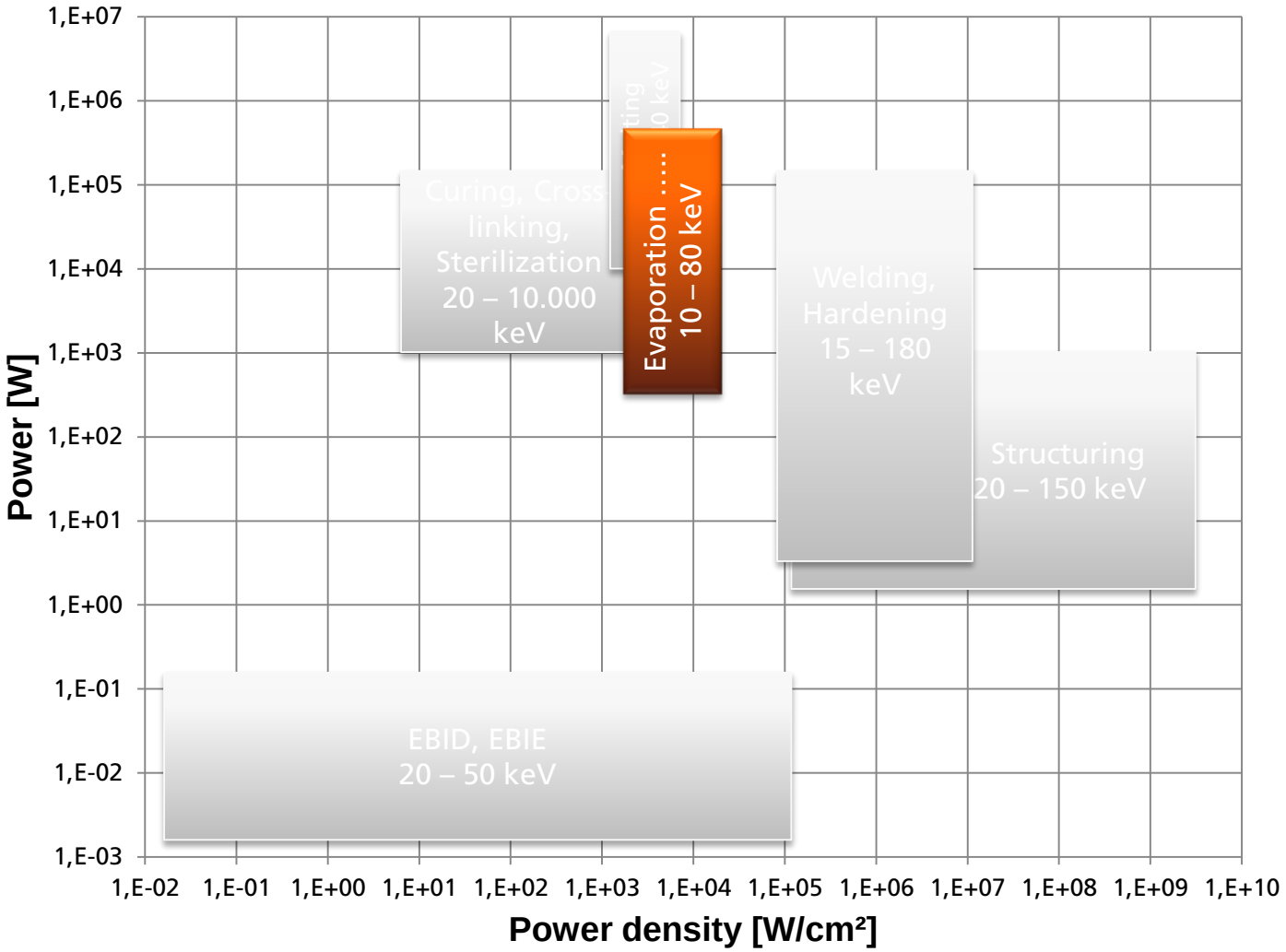
EBFC: Customized eBeam-Source MEBW 60 - EmicPro

Development of next generation

- Pulsed high-voltage supply for fast modulation of beam power
- Optimized new developed cathode and anode for better beam quality and longer cathode-lifetime
- Development of electron-optics for micro-machining of large areas (deflection system, dynamic lenses, alignment, stigmator)
- Synchronization of all „beam-axes“ together with handling axes



Applications – Evaporation



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Customized eBeam-Sources

Thermionic Emitter

Axial gun MEBW 2 kW	60 kV
Axial gun CTW 80 W – 10 kW	10 – 70 kV
Axial gun ERIC 60 – 300 kW	40 – 80 kV

Cold Cathode Emitter

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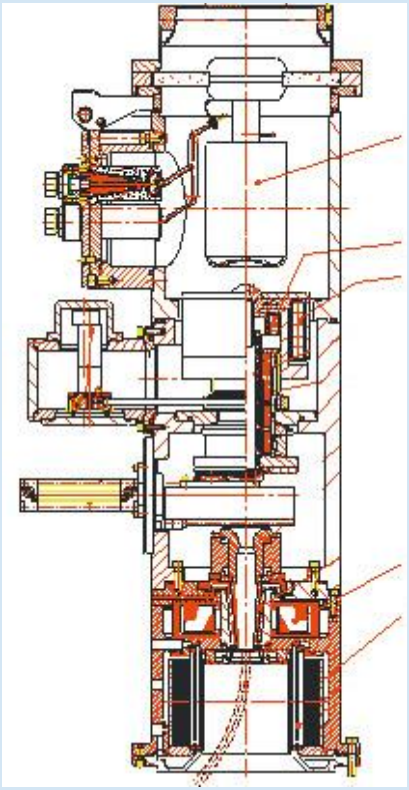
High power axial gun – Basic ERIC 160/40

- acceleration voltage
  40 kV
- maximum beam power
  160 kW
- beam diameter
  app. 10 mm
- deflection angle
  30°
- deflection frequency
  3.5 kHz



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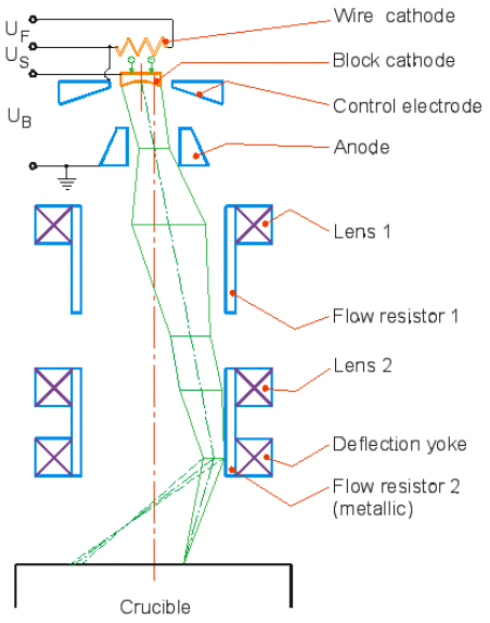
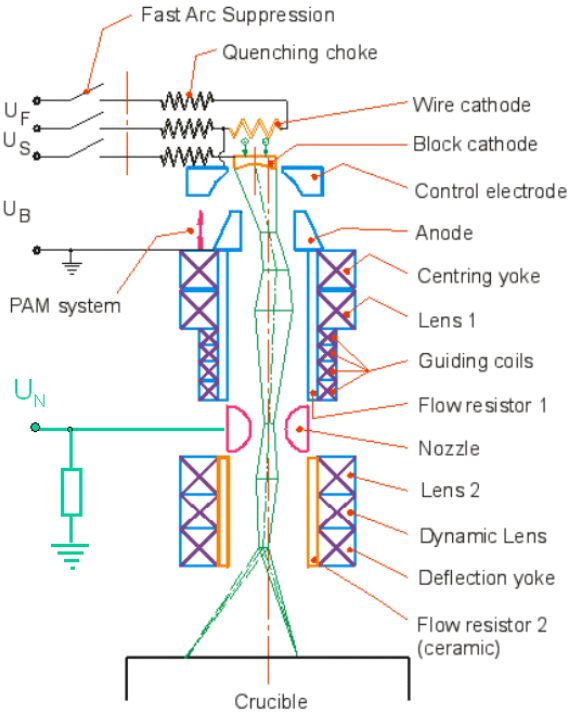
ERIC eBeam System

EB system for **R**eactive **I**on-aided **C**oating of large-area substrates at high rates

Conventional high-power EB gun



ERIC gun



Development Goals:

- Coating Chamber Pressure ≤ 5 Pa
- Arc recovery time < 5 ms
- Acceleration voltage ≤ 60 kV
- Beam Power ≤ 300 kW
- Power Control
  - in space charge limited mode
  - in thermal saturation mode
- Automatic Centering / Focusing
- Scan frequency x/y ≤ 10 kHz @ 45°
- Dynamic Focusing ≤ 10 kHz @ 10%
- Extended cathode service life

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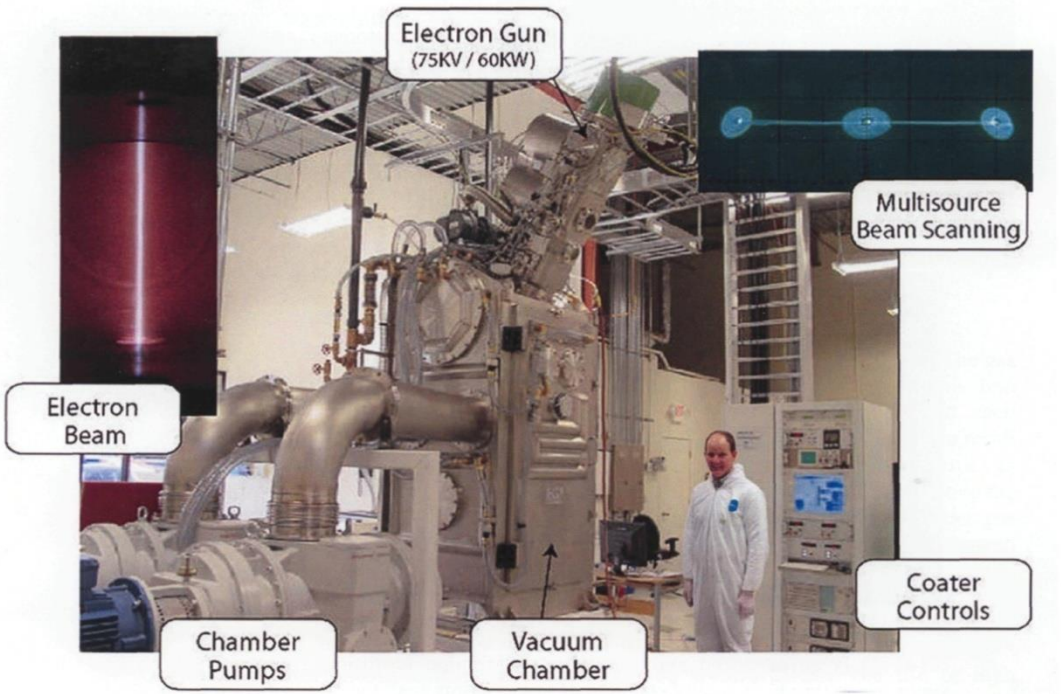
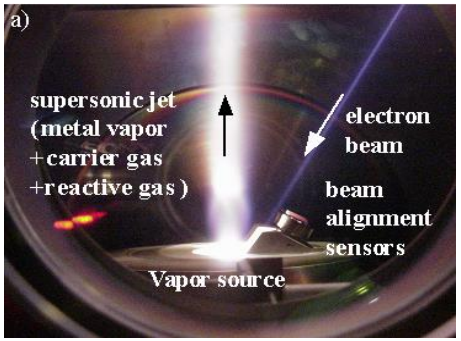
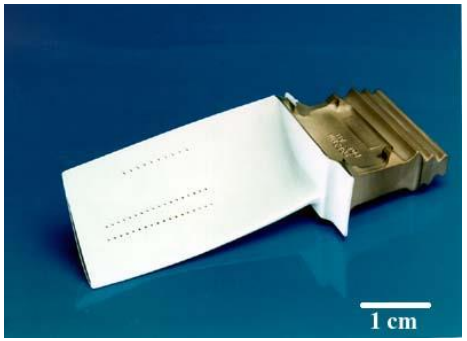
DVD-Process: Customized eBeam-Source ERIC-LVO 60/75







Customer's Technology:

⇒ Directed Vapor Deposition (R&D / Pilot Scale)

⇒ Application examples:
- Thermal barrier & bond coatings
- Hot corrosion resistant coatings

FEP Components:

⇒ EB gun ERIC-LVO 60 kW / 75 kV
- operation pressure ≤ 30 Pa
- deflection angle ± 30 °
- deflection frequency ≤ 3 kHz
- arc recovery time ≈ 5 ms
- MF high-voltage power supply
- three-stage vacuum system

⇒ Control system & Supply cabinet

Customized eBeam-Sources

Thermionic Emitter

Axial gun MEBW 2 kW	60 kV
Axial gun CTW 80 W – 10 kW	10 – 70 kV
Axial gun ERIC 60 – 300 kW	40 – 80 kV

Cold Cathode Emitter

20 - 45 kV	Axial gun EasyBeam 30 - 400 kW

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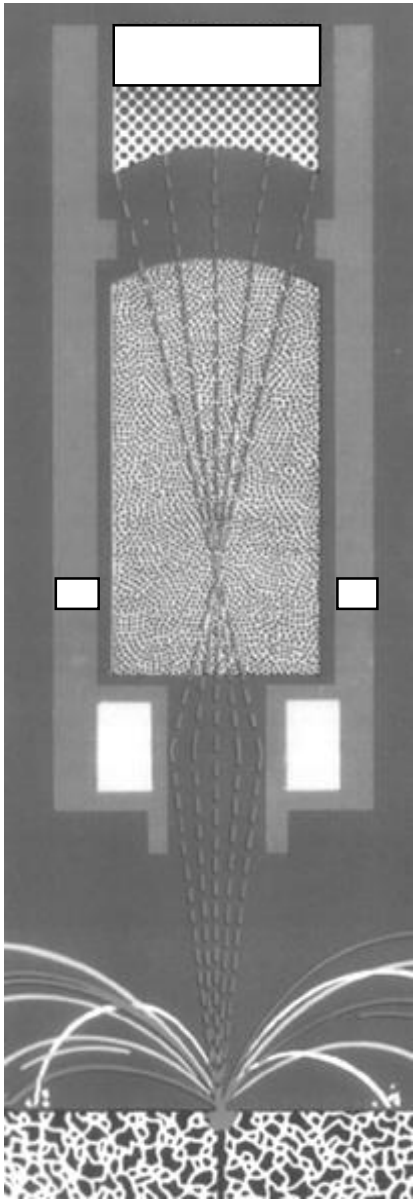
Cold-Cathode EB Guns

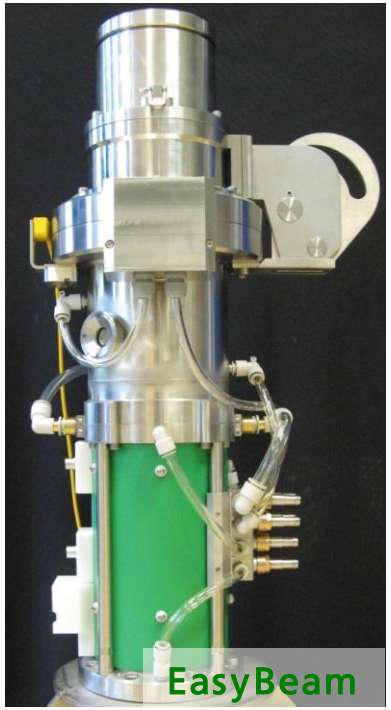
Cold-Cathode Glow-Discharge Electron Beam sources for PVD -

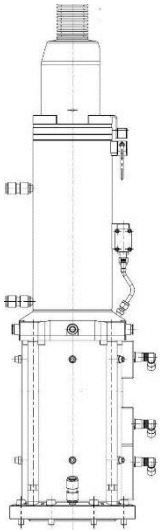
Some Work Principles

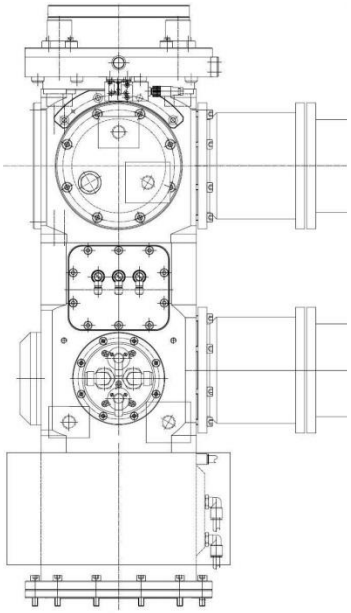
- Inside the beam source, a high-voltage glow-discharge is sustained. The potential drop between cathode and anode occurs mainly across the cathode sheath. (U = 10…40 kV)
- Bombardment of the cathode by ions from the plasma generates secondary electrons (Emission current density up to 100 mA/cm²)
- Secondary electrons are accelerated through the cathode sheath ("transparent anode") - appropriate cathode contour promotes shaping of an Electron Beam with cross-over
- Then: Conventional electron optics applicable

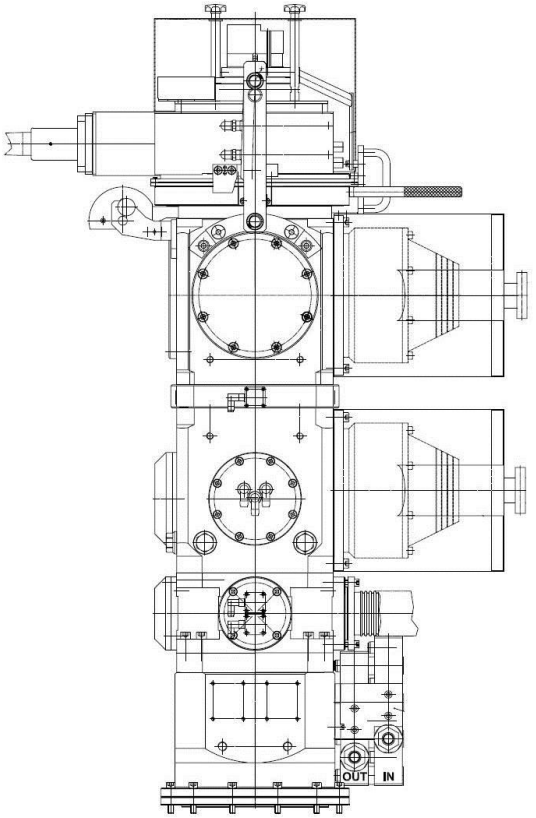


Fraunhofer FEP: High-Power Gun Series









Type	EasyBeam	ERIC	ERIC-LVO
Acceleration Voltage **Beam Power**	30 … 40 kV 30 … 150 kW	40 … 60 kV 60 … 300 kW	75 … 80 kV 60 … 300 kW
Coating Chamber Pressure **Flange Size**	≤ 1.0 Pa NW 100 … 160	≤ 5.0 Pa NW 250	≤ 50 Pa NW 250
Turbo Pumps **Roots Blower**	No No	2 No	2 1
Gun mounting angle **Beam Scan angle / frequency**	0° ... 135° ± 30° / 1 kHz	0° ... 135° ± 35° / 1 ... 10 kHz	0° ... 135° ± 35° / 1 ... 10 kHz

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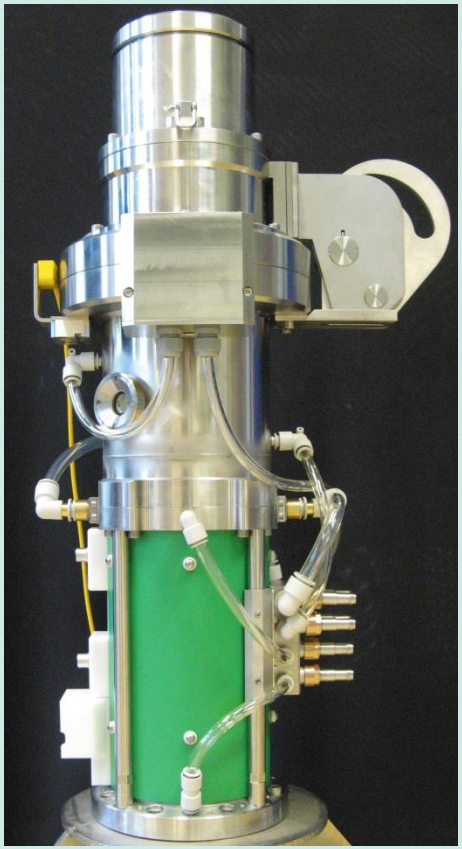
High-rate PVD:
Customized eBeam-Source EasyBeam 120/40

“EasyBeam“ 60 kW / 30 kV

Beam Scanning: ±15°, f <100 Hz

“EasyBeam“ 120 kW / 40 kV

Beam Scanning: ± 30°, f < 1 kHz



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Melt-refining + High-rate PVD: Customized eBeam-Source EasyBeam-Hybrid

The next generation - HYBRID CATHODE approach

“Merge the best of both worlds!”

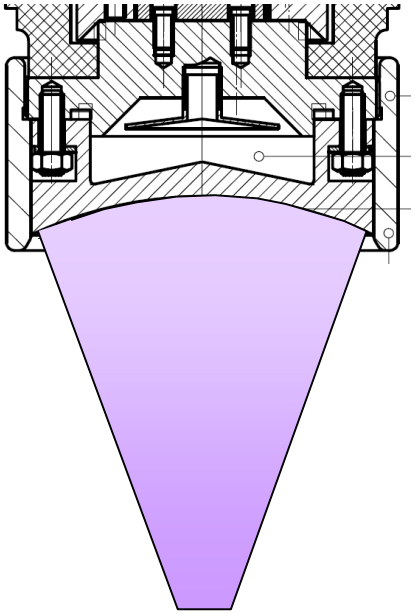
Simplified design and supply, easy to control and to adjust

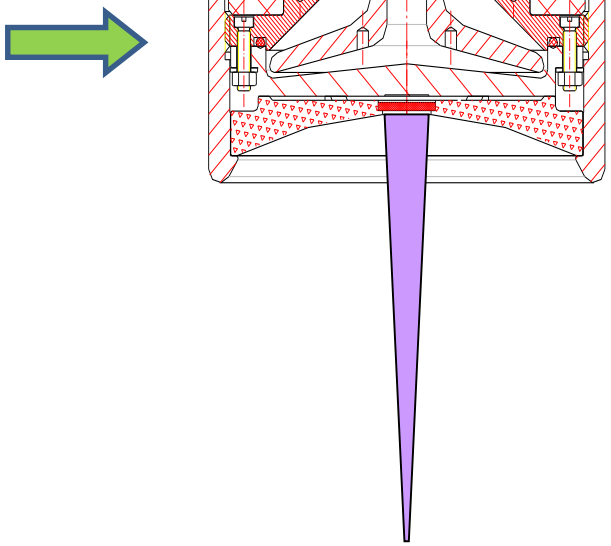
High acceleration voltage and power density, no cooling fluid

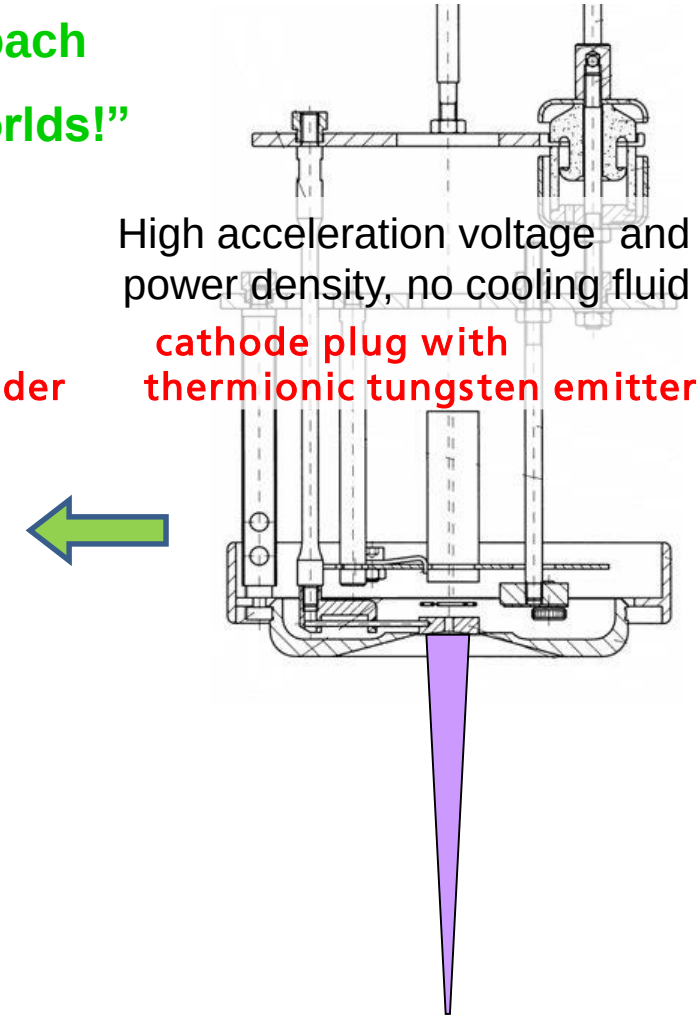
cold cathode plug with aluminum cathode

hybrid cathode plug with LaB_6 emitter in graphite holder

cathode plug with thermionic tungsten emitter







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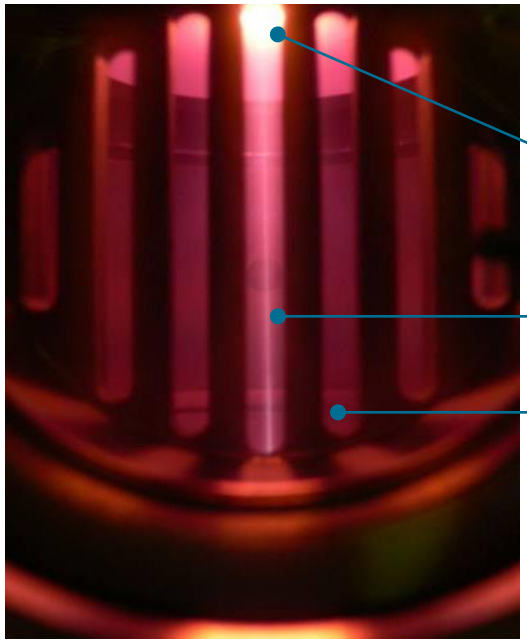
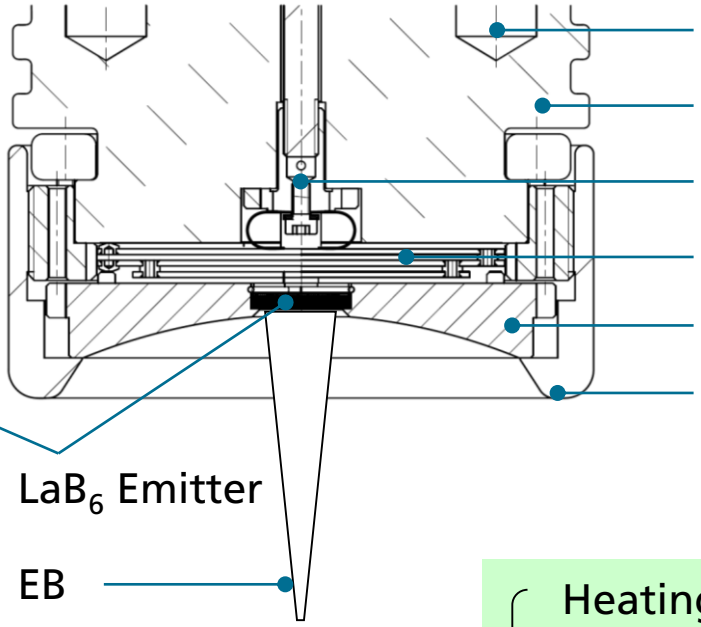
High-Voltage Glow-Discharge EB sources with Hybrid Cathodes





(isolated against HV)
Cooling water channels
Ceramic isolator
High-voltage feed-through
Thermal isolation shield
Graphite holder („Pierce“)
Clamping fixture screw

LaB_6 Emitter

EB

Glow-discharge Plasma
(He or H_2 / NO oxygen!)

- Heating of the thermionic cathode
- Space charge compensation
- Purge gas for cathode chamber

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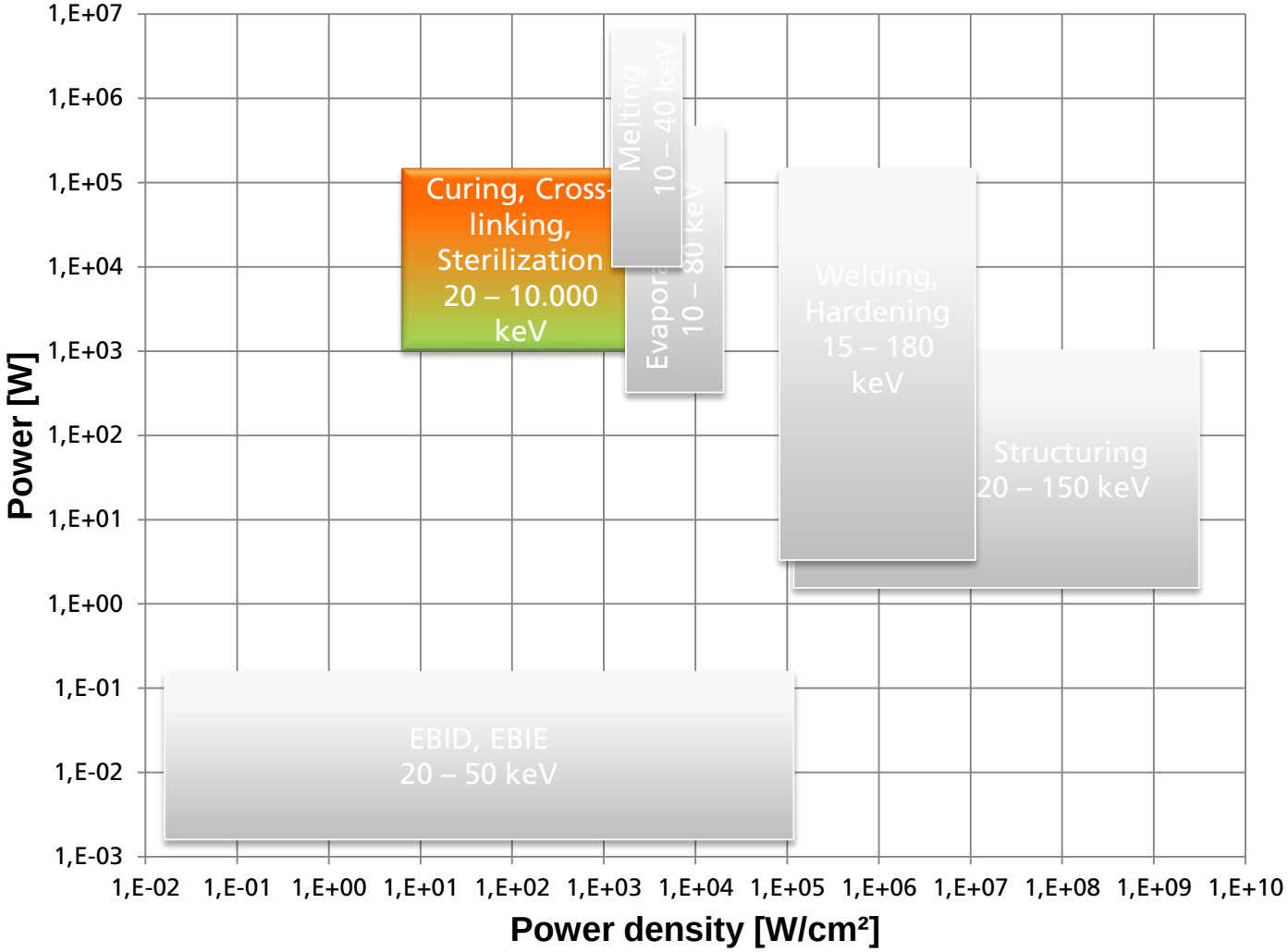
Applications – Curing, Crosslinking, Sterilization



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Customized eBeam-Sources

Thermionic Emitter

Axial gun MEBW 2 kW	60 kV
Axial gun CTW 80 W – 10 kW	10 – 70 kV
Axial gun ERIC 60 – 300 kW	40 – 80 kV
Broadbeam FEPtron 30 kW	150 kV

Cold Cathode Emitter

20 kV	PED gun 1 J per pulse
20 - 45 kV	Axial gun EasyBeam 30 - 400 kW

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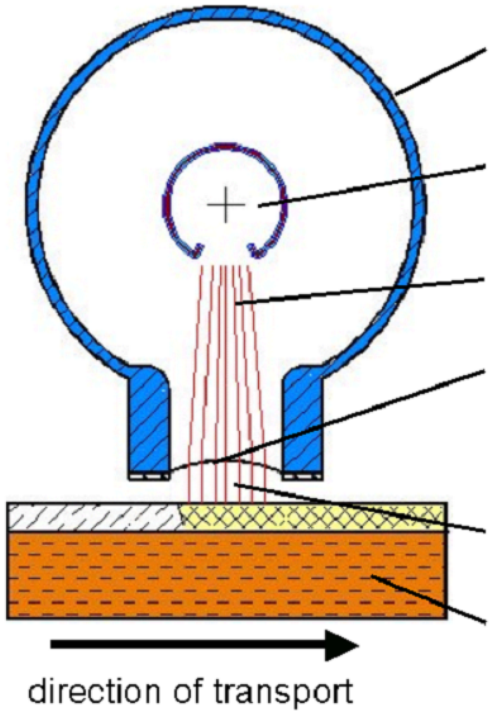
High power linear gun – Basic FEPtron 5/120



Linear type EB gun,
high-vacuum inside

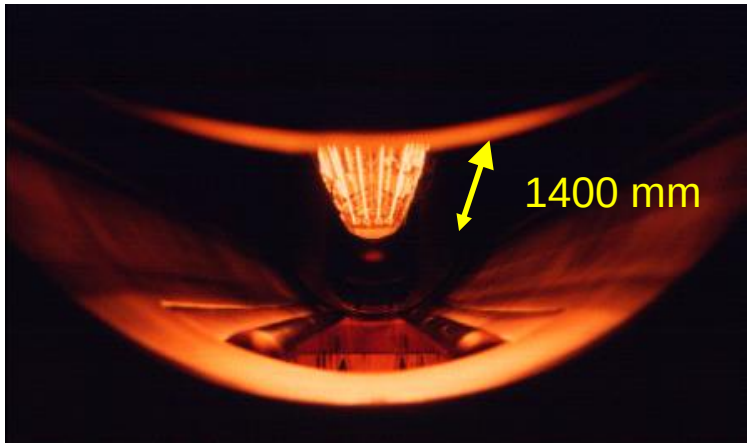
Cathode system

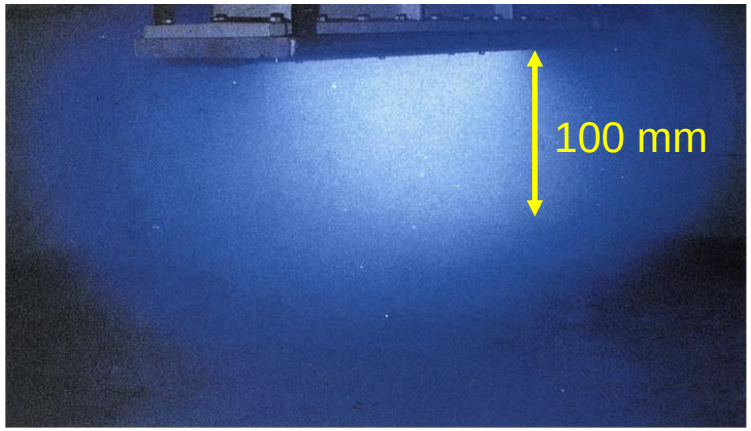
Electrons with energy $E_{kin} = e \cdot U_B$

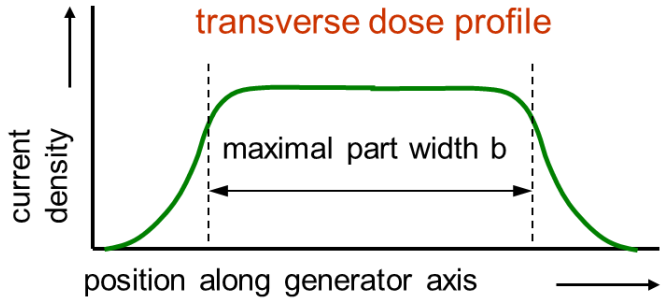
Electron exit window:
A metal membrane between
atmosphere and high vacuum

Electron curtain directed onto product

Product with treated border layer
and untreated coating







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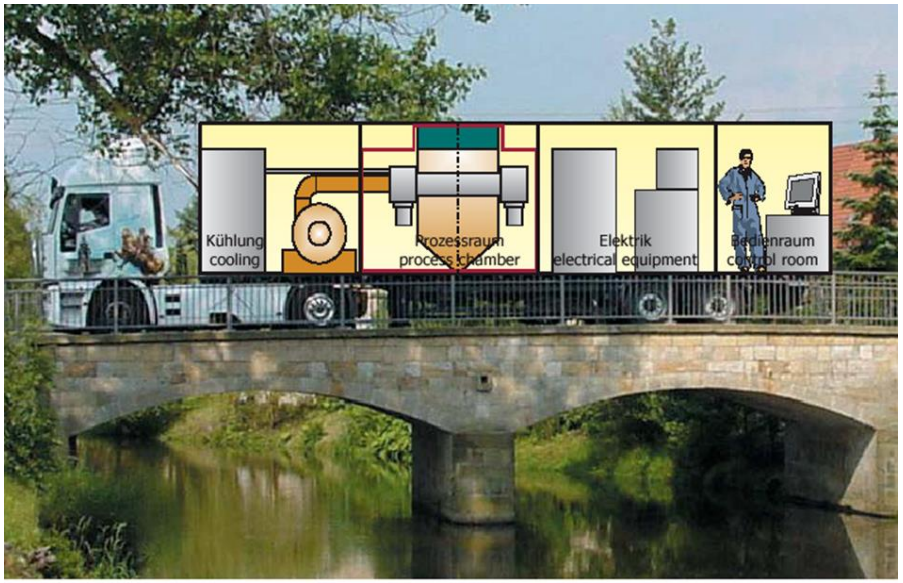
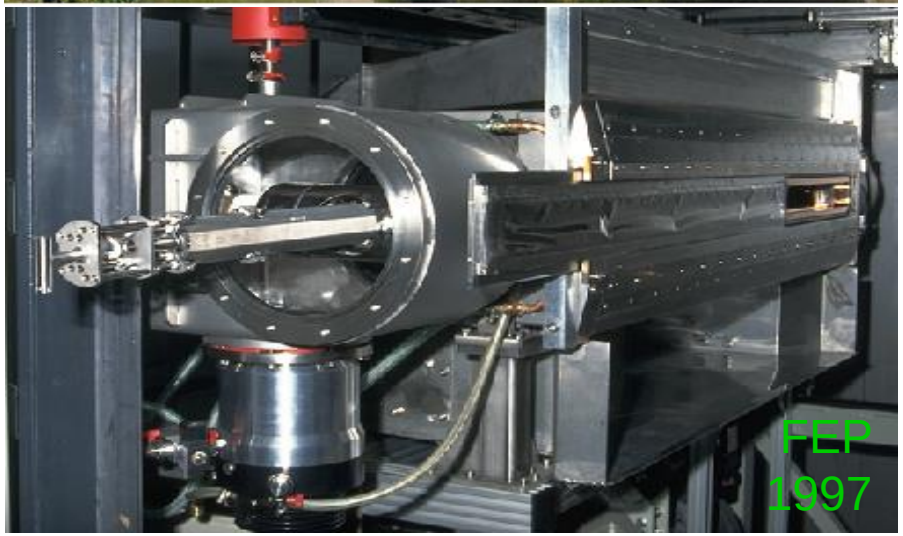
Seed Treatment: Customized eBeam-Source FEPtron 30/150





Pilot Plant WESENITZ 2
- troughput 30 t/h
- chemical free seed treatment

FEP's Low-Energy Technology
allows to adapt acceleration voltage

⇒ improved dose homogeneity across layer

⇒ reduced loads of the carrier material

⇒ optimized investment costs

2D EB Systems available at FEP

2D EB System type	Lab	Production I
Acceleration voltage (kV)	80 – 120	80 – 150
Layer thickness (µm)	10 – 60	10 – 120
Dynamic dose rate (kGy·m/min)	4 000	4 000 – 6 000
Transportation speed (m/min)	1 – 600	f (D)
Homogeneity of dose (%)	< ±15	< ±10
Working width (mm)	300	1 400

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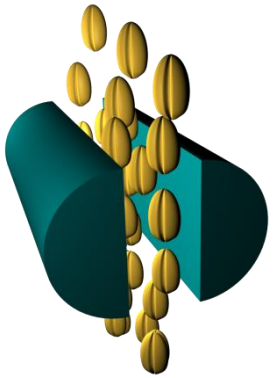
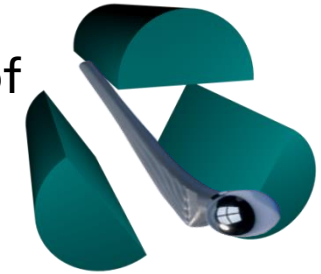
Electron treatment of surfaces

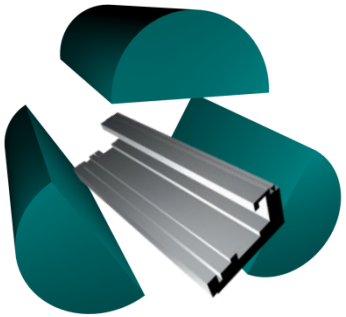
Treatment of seed or bulk goods



Surface sterilization of medical products



Lacquer curing on 3D-products



It would be nice to have a toroidal source for homogenious dose application onto 3D-surfaces

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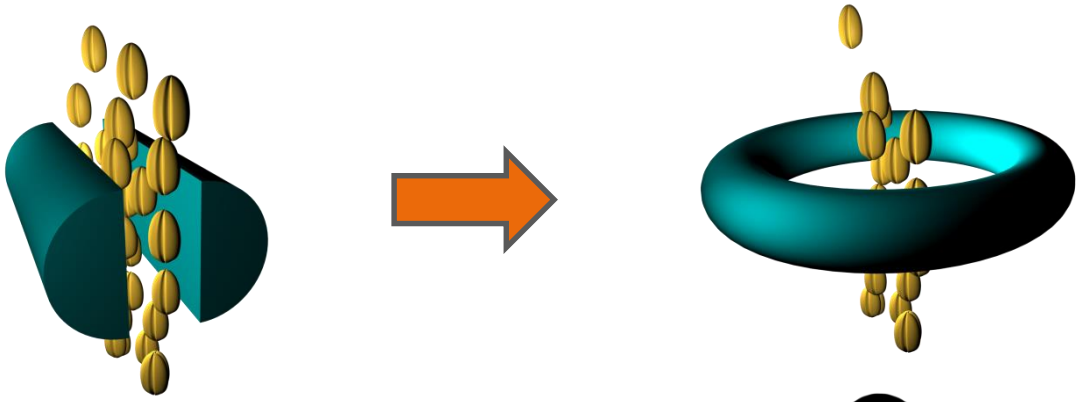
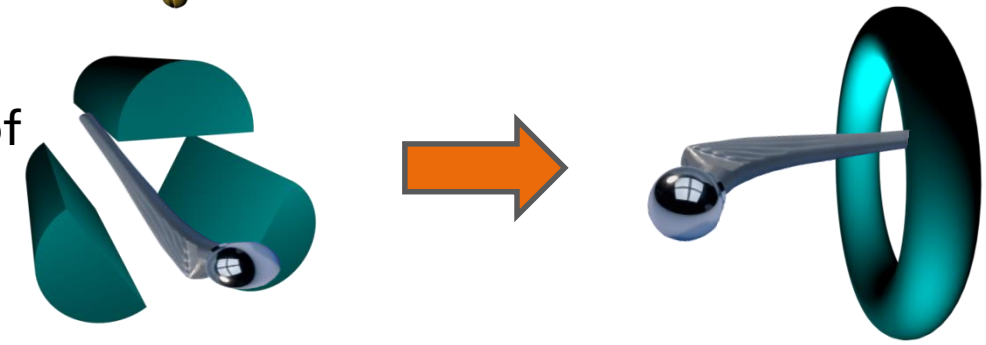
Electron treatment of surfaces

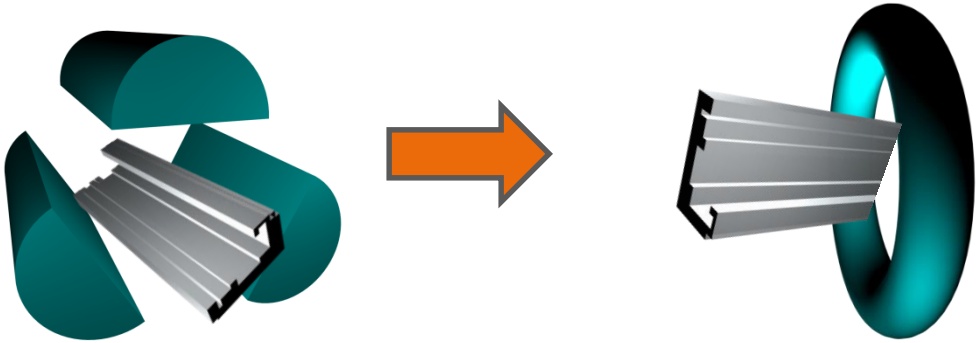
Treatment of seed or bulk goods



Surface sterilization of medical products



Lacquer curing on 3D-products



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Customized eBeam-Sources

Thermionic Emitter

Axial gun MEBW 2 kW	60 kV
Axial gun CTW 80 W – 10 kW	10 – 70 kV
Axial gun ERIC 60 – 300 kW	40 – 80 kV
Axial gun Scanner 2 kW	150 kV
Broadbeam FEPtron 30 kW	150 kV

Cold Cathode Emitter

20 kV	PED gun 1 J per pulse
20 - 45 kV	Axial gun EasyBeam 30 - 400 kW
150 kV	Toroidal gun TORES 5 - ? kW

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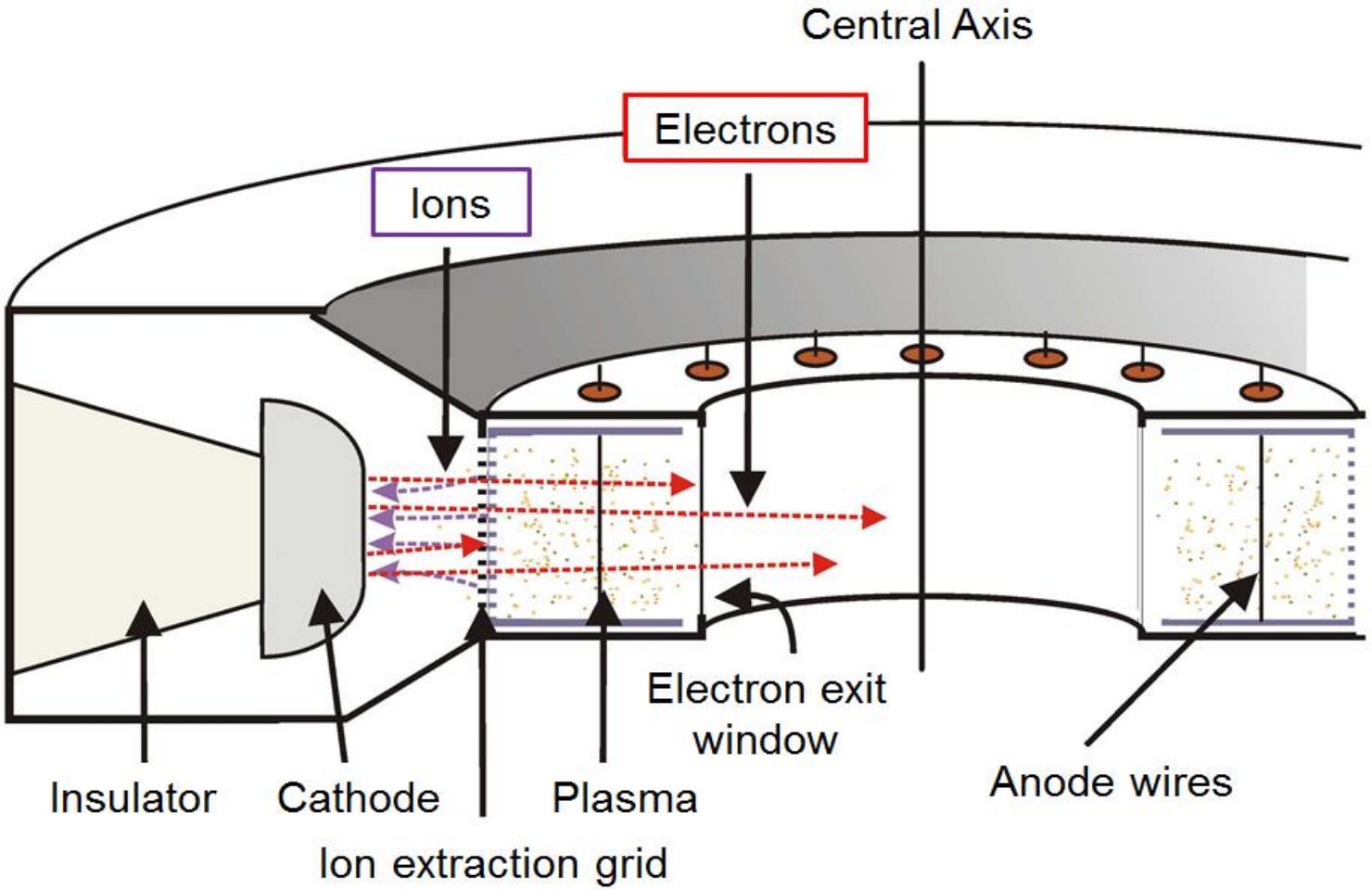
High power toroidal gun – Basic TORES 5/120



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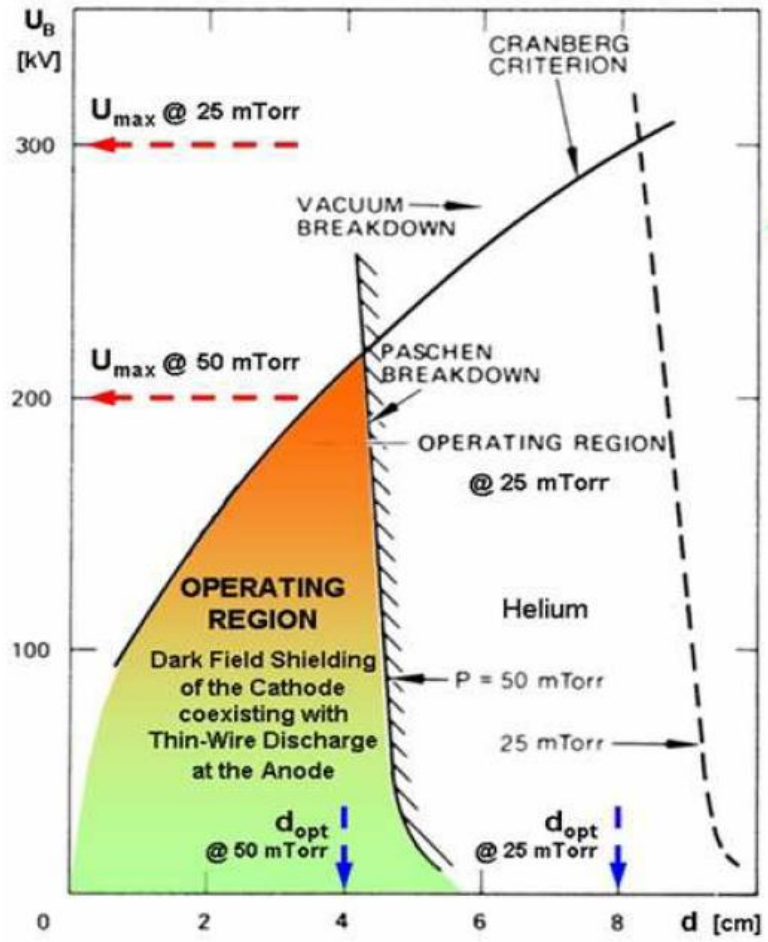
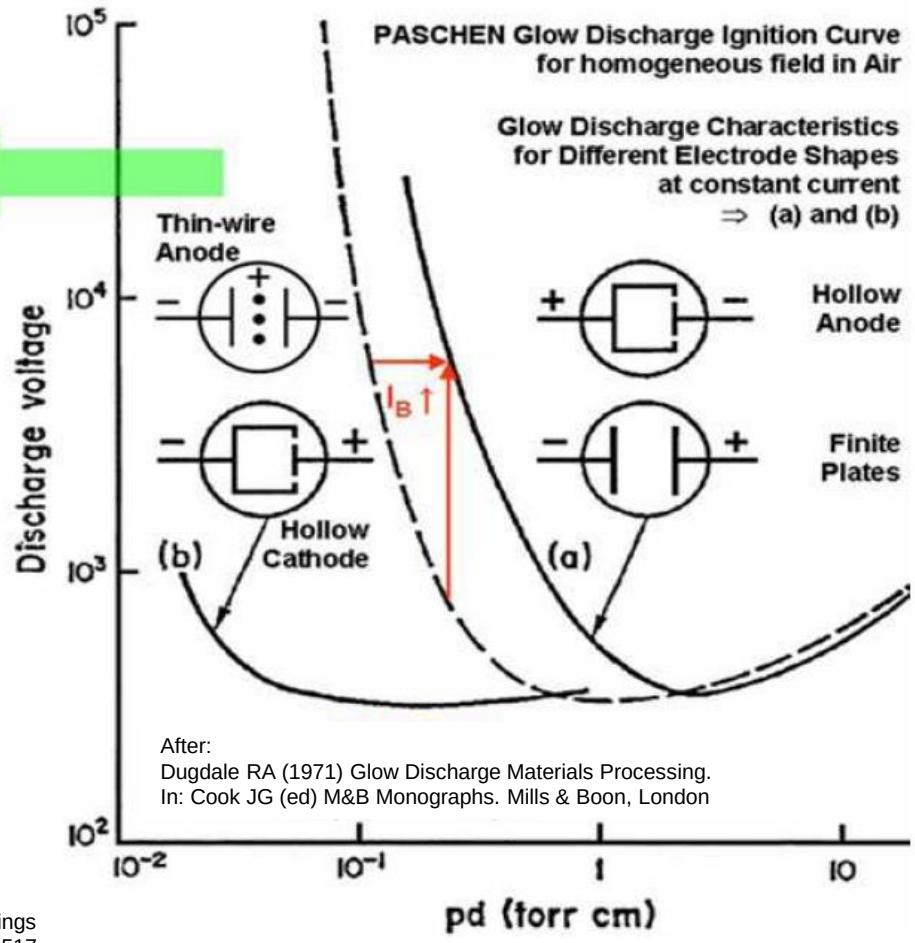
High-Voltage Glow-Discharge EB sources with Plasma Anode -

Issues: Dark-field Shielding

Solution:
Create an auxiliary low-pressure plasma for ion production
(Hollow Cathode or Wire Anode)





After: Amboss K (1974) Design of large area electron beam guns. In: Bakish R (ed) Proceedings of the 6th International conference on electron and ion beam science and technology, pp 497-517.

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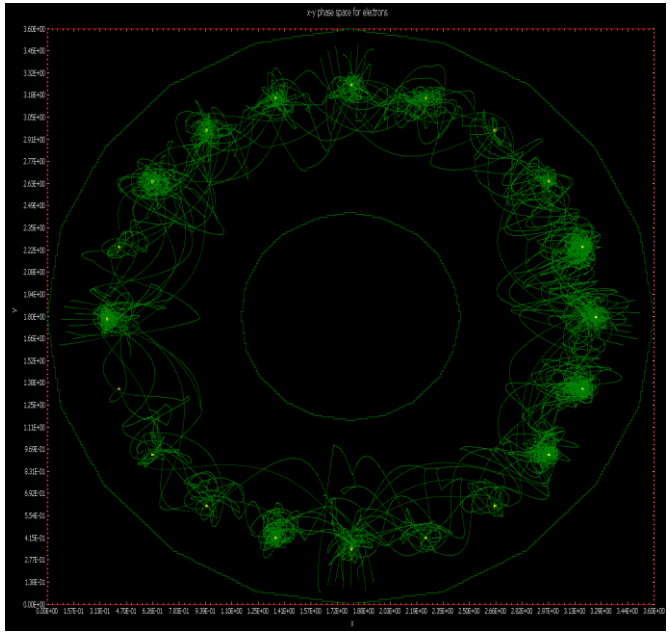
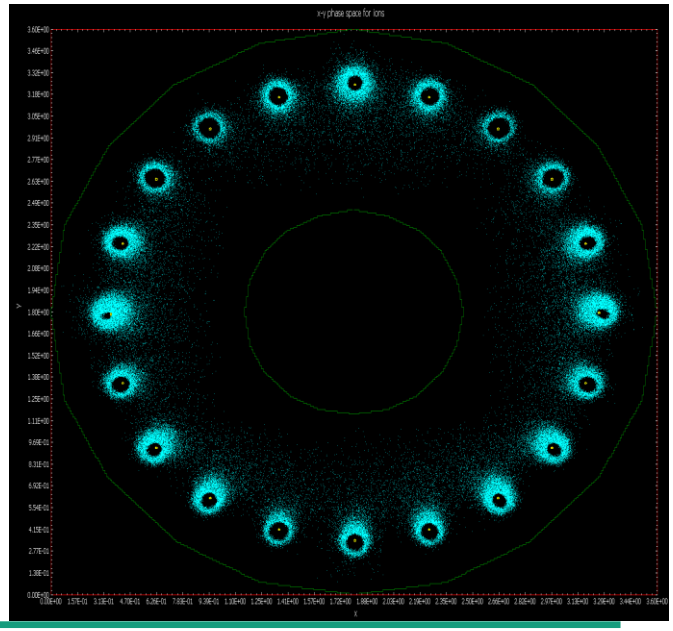
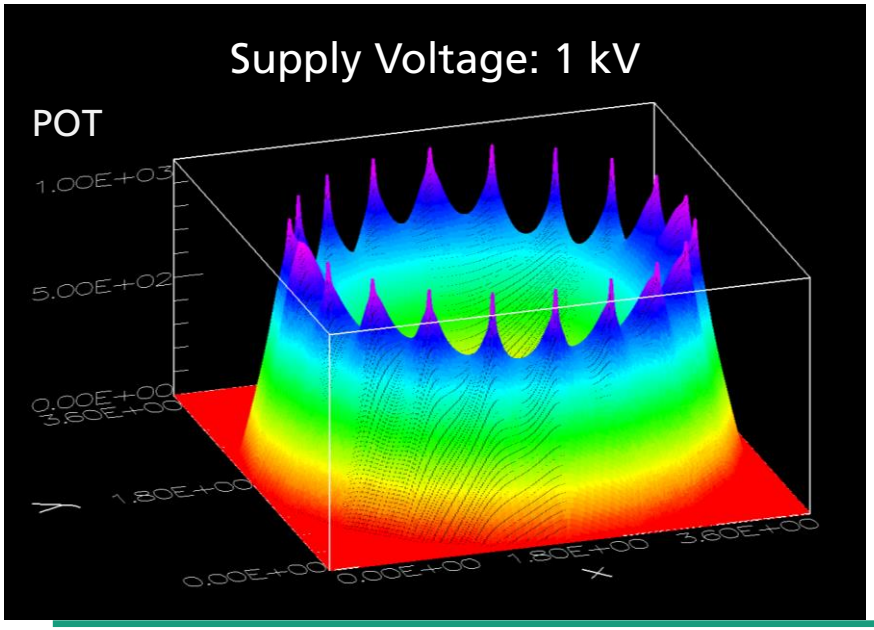
Toroidal EB source with Wire Anode Discharge Plasma

Numerical Simulation – Overview of Results

- Electron trajectories ⇒ Trapping
- Ion density distribution ⇒ Localization
- Distribution of electric potential
  ⇒ Repelling ions off the wires







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Customized eBeam-Sources

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Axial gun ERIC 60 – 300 kW	40 – 80 kV
Axial gun Scanner 2 kW	150 kV
Broadbeam FEPtron 30 kW	150 kV
X-Ray gun 10 kW	150 kV

Cold Cathode Emitter

20 kV	PED gun 1 J per pulse
20 - 45 kV	Axial gun EasyBeam 30 - 400 kW
150 kV	Toroidal gun TORES 5 - ? kW

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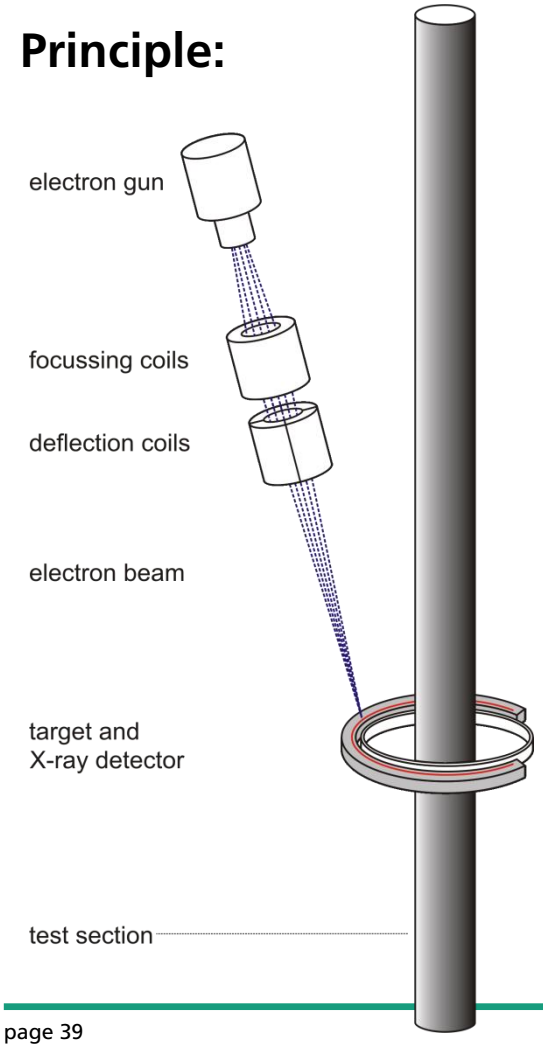
Fast 3D X-Ray: Customized eBeam-Source ROFEX 10/150 (based on ROBOTGUN)

ROFEX – ROssendorf Fast Electron beam X-ray tomograph

Principle:



HZDR

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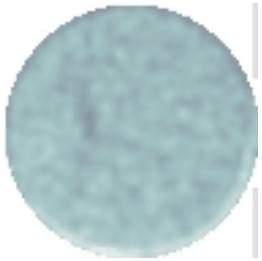
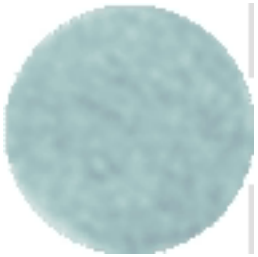
Ultra-fast X-ray computed tomography

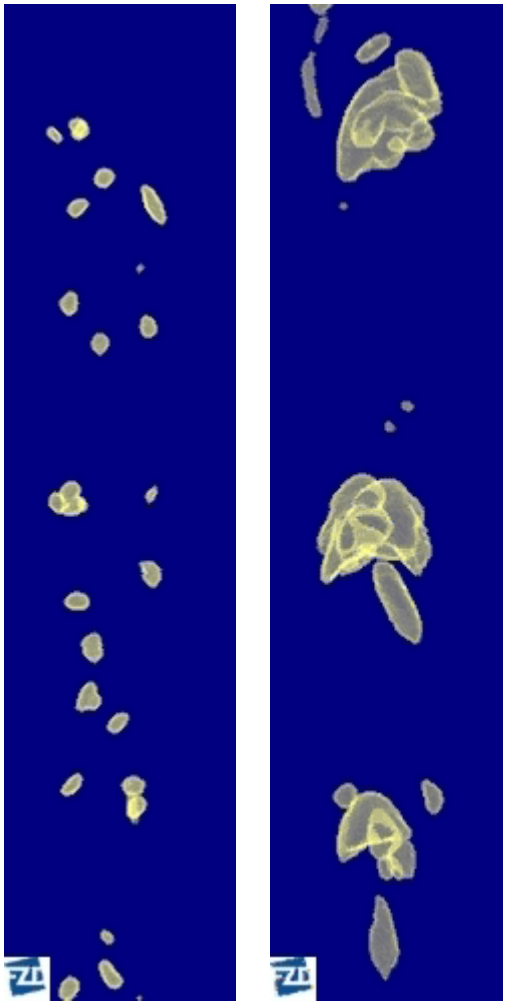
- Basics:
  Fast deflected electron beam sources with sub-mm spot by FEP
- New technical application for investigation of multiphase fluid flow
- Interesting in boiling processes at power plant heating tubes and multi-phase fluids at petrol industry
- Possibility to get moved CT-pictures for fast dynamic investigation
- Cooperation in the field of ultra-fast X-ray detection with
  Institute of Safety Research, Helmholtz-Zentrum Dresden-Rossendorf



low gas flow rate



high gas flow rate



5000 fps

HZDR

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Customized eBeam-Sources

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Axial gun Scanner 2 kW	150 kV		
Broadbeam FEPtron 30 kW	150 kV	150 kV	Toroidal gun TORES 5 - ? kW
X-Ray gun 10 kW	150 kV		

Thermal Processing

Non-thermal Processing

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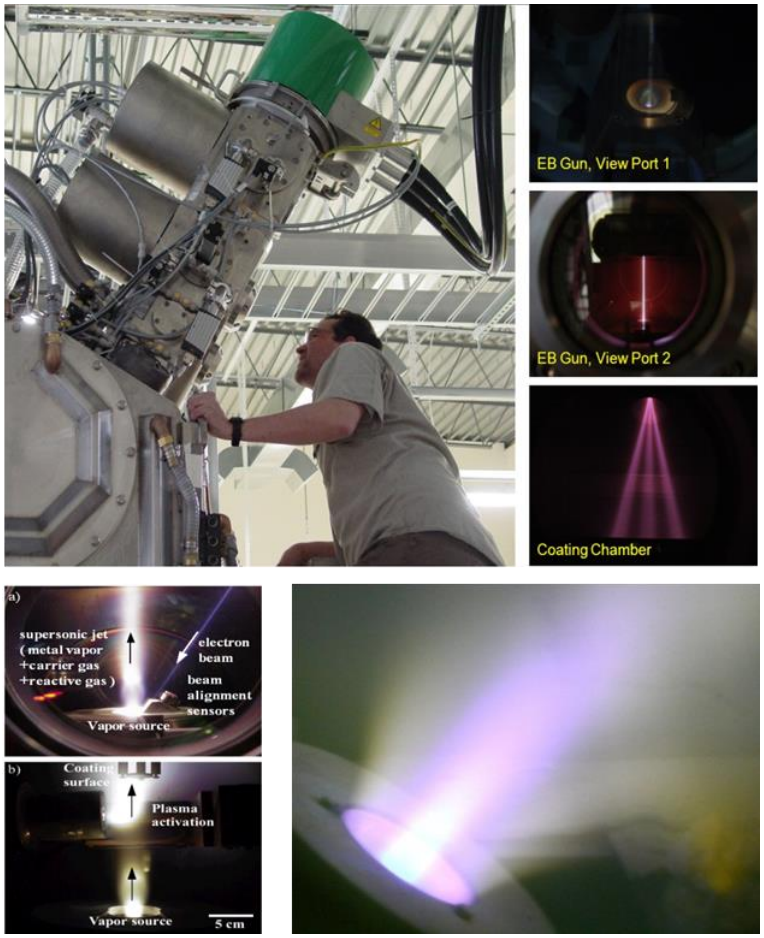
Outline

- Electron Beam Basics
- Customized eBeam-Sources
- Summary



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Summary

- Electron beam technology is an all-round tool for application in different branches
- Processing by electron beam means:
  - energy efficiency
  - very high processing speed
  - environmental friendly
  - long term stability
  - Vacuum or non-vac processing
- We are ready to develop your special electron beam technology
  - New applications require development of customized e-beam sources
  - New e-beam sources create ideas for new applications
  - Actually there are a lot of running development projects

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Electron Beam Technology

Customized Sources – Your Benefit!

Frank-Holm Rögner

Fraunhofer Institute for Organic Electronics,
Electron Beam and Plasma Technology FEP

Winterbergstrasse 28

01277 Dresden, Germany

www.fep.fraunhofer.de

frank-holm.roegner@fep.fraunhofer.de

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