



CEPC Vacuum chamber NEG coating & heating spraying production line

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Outline

- - Preview of CEPC vacuum system
- -Production line of vacuum chambers
- -Prototype of cathode for NEG coating
- -Spraying for heating film R&D
- -Conclusion
- -Acknowledgement

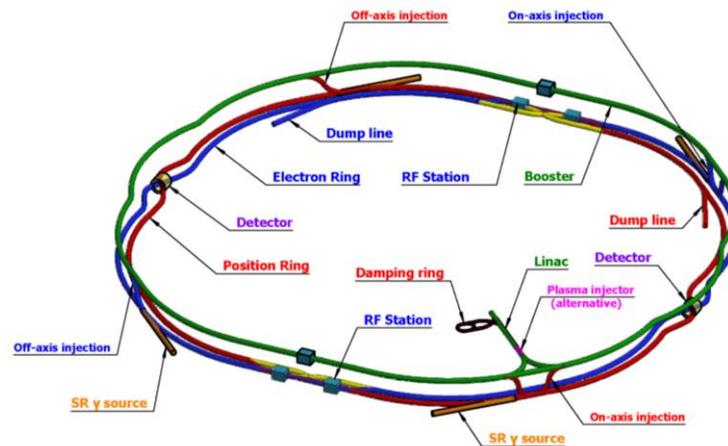
Preview of CEPC vacuum system



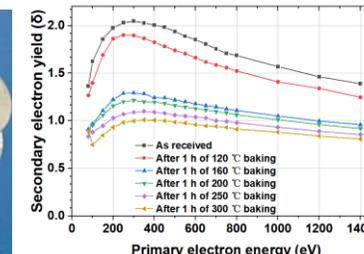
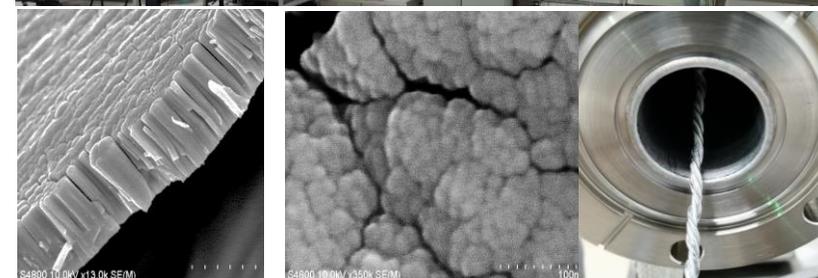
Machine and Vacuum Parameters

	E	I	ρ
	Gev	A	m
Higgs	120	0.0167	10700
W	80	0.084	10700
Z	45.5	0.803	10700
tt	180	0.0033	10700

Accelerator	length/m
LINAC	1,601+335
Damping ring	147
Booster	100,000
Collider	200,000
Transport line	4,680
Total length/m	306,763



◆ Technical developments in TDR



Vacuum requirements and configuration



	Energy	Material	Cross Section/mm	Length/m	Dynamic pressure /Torr
LINAC	30 GeV	Stainless steel, copper	Φ20~30	1,601+ 335 (BTL)	Acc $<2 \times 10^{-7}$ E-gun $<2 \times 10^{-8}$
Damping ring	1.1 GeV	Extruded aluminum 6061	Φ30/Al 6061	147	$<2 \times 10^{-8}$
Booster	30 to 180 GeV	Extruded aluminum 6061	Φ56/thickness of 2mm	100,000	$<3 \times 10^{-8}$ tt $<4 \times 10^{-8}$
Collider	45.5~180 GeV	Extruded copper, NEG film SEY <1.2	Φ56/thickness of 2mm	100,000 × 2	Z $<8 \times 10^{-10}$ tt $<1 \times 10^{-8}$
MDI	45.5~180 GeV	Copper/tungsten alloy, NEG film	Φ20	12	$<3 \times 10^{-9}$
LTB	30 GeV	Stainless steel	Φ56	3,000	$<1 \times 10^{-7}$
BTC(CTB)	6 GeV	Stainless steel	Φ56	240 × 6	$<1 \times 10^{-7}$
DL	1.1 GeV	Stainless steel	Φ30	240	$<1 \times 10^{-7}$

EDR goal, scope and plan

- **1. Vacuum chambers massive NEG coating and heating spraying production line development**
 - The conventional NEG coating method is not suitable for the CEPC project, as there is a need to coat a total length of 190km of vacuum chambers within a 5-year timeframe. Implementing a production line can enhance stability, ensure timely production, and reduce labor costs. Therefore, a production line incorporating NEG coating and heating spraying will be developed to explore a new method for constructing vacuum chambers for the CEPC.
 - The construction of the vacuum chambers for the collider rings will be completed in 5 years with the use of 2 production lines, each equipped with 1 welding oven, 7 and 2 NEG coating and spraying setups.
 - 2024: The whole production line design and bidding. key components and processing like flanges sealing automatically, heating spraying will be developed.
 - 2025: the production line construction and debugging. **Composition of 2025 CEPC proposal.**
- **2. Optimization of NEG coating:**
 - NEG coating is used to sustain the vacuum of beam pipe and suppress the e-clouds of positron ring. Because the resistance of NEG coating increases with the thickness increases, but the life of the NEG coating decreases significantly when the thickness is less than 200nm, it is necessary to optimize the thickness and impedance of NEG coating.
 - 2024: Optimization the thickness of NEG coating distribution along the vacuum chamber.
 - 2024~2025: The new composition and construction development to increase the pumping properties of NEG coating, especially increase its reactivation times (life-times).
 - 2026~2027: Optimization the resistance of NEG coating.

Production line composition

Classification	Sub-devices	Parameters	Note
Electron-beam welder	<ul style="list-style-type: none"> • Electron-beam gun • Power supply • Vacuum chamber 	<ul style="list-style-type: none"> • Meets the Length of 11.4m vacuum chamber • 6 working position 	Design and manufacturing
Brazing	<ul style="list-style-type: none"> • Mechanical holder • Power supply 	<ul style="list-style-type: none"> • 350°C • 11.4m long 	Low temperature brazing in air by conductivity heating, expecting steady by double hole copper tube
Heating film spraying facility	<ul style="list-style-type: none"> • Electron-beam gun • Power supply • Controller • Mechanical Structure 	<ul style="list-style-type: none"> • Meets the Length of 11.4m vacuum chamber • Multilayer Spray • Ceramic and conductivity layer 	R&D
NEG coating tower	<ul style="list-style-type: none"> • Pumping system • Vacuum measurement • Power supply • Vacuum chambers • Discharge Gas • Cathode、controller 	<ul style="list-style-type: none"> • Meets the Length of 11.4m vacuum chamber • 6 working position • Background vacuum <5e-7Pa • Baking temperature 200°C 	Developing to be more fitted the production line
Measurement and testing	<ul style="list-style-type: none"> • Dimension measurement • Leakage testing 	<ul style="list-style-type: none"> • Dimension measurement 11.5m/0.1mm • Leakage testing 1e-10 mbar·L/s 	Design and manufacturing
Cleaning	<ul style="list-style-type: none"> • rinsing 	<ul style="list-style-type: none"> • deionized water rinsing 	Design and manufacturing
Production line auxiliary equipment	<ul style="list-style-type: none"> • Moving band • robot arm system • controller 	<ul style="list-style-type: none"> • Meets the Length of 11.4m vacuum chamber 	Design and manufacturing

Procedure of NEG coating, spraying

■ Spraying

- Sandblasting
- Spraying_Isolation_layer
- Spraying_Conductivity-layer
- Spraying_Isolation-layer
- Spraying_Contactor-layer

■ Cleaning

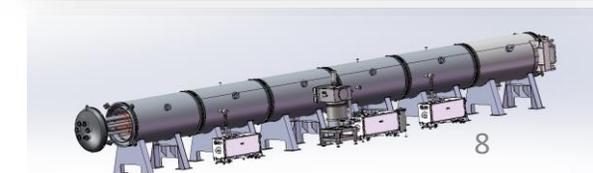
- Outside
- Inside

■ NEG coating

- vacuum chambers, cathodes assembling by mechanical arms (flanges sealing).
- Leakage testing.
- Deliver the assembles to vacuum oven/ baking/ NEG coating;
- Disassembly the vacuum chambers

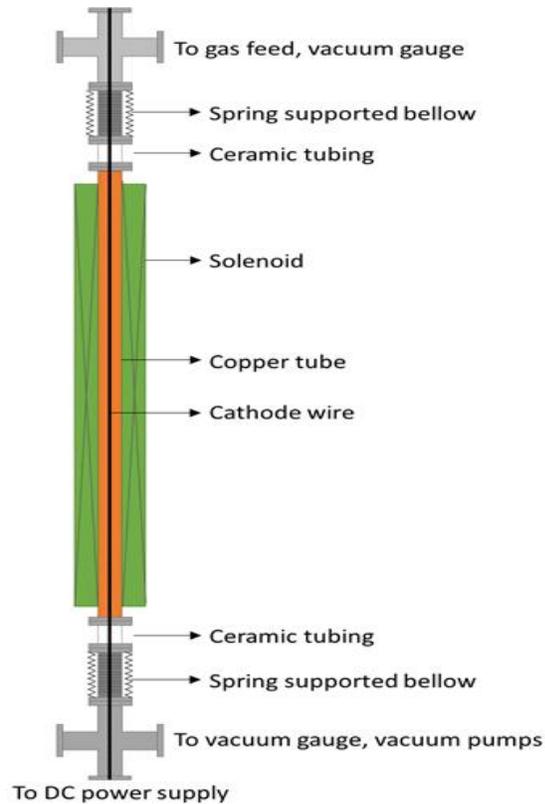


Function	Materials	Thichness/um
Transition-layer	MCrAlY alloy	50~100
Isolation-layer	Al2O3 cermic	~150
Conductivity-layer	NiCr alloy	~100~200
Isolation-layer	Al2O3 cermic	~150
Contactor-layer	Copper	~50



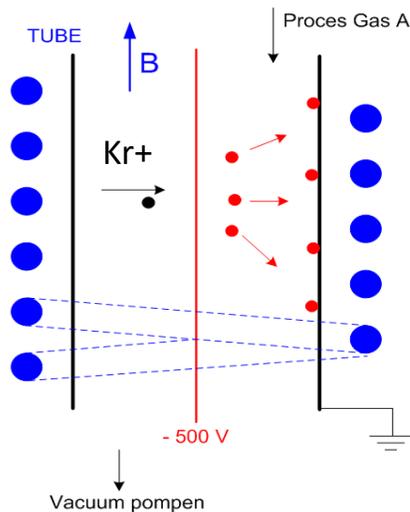
NEG coating mechanism & method

- HEPS, LHC, MAX IV, SIRIUS, APS_U etc.

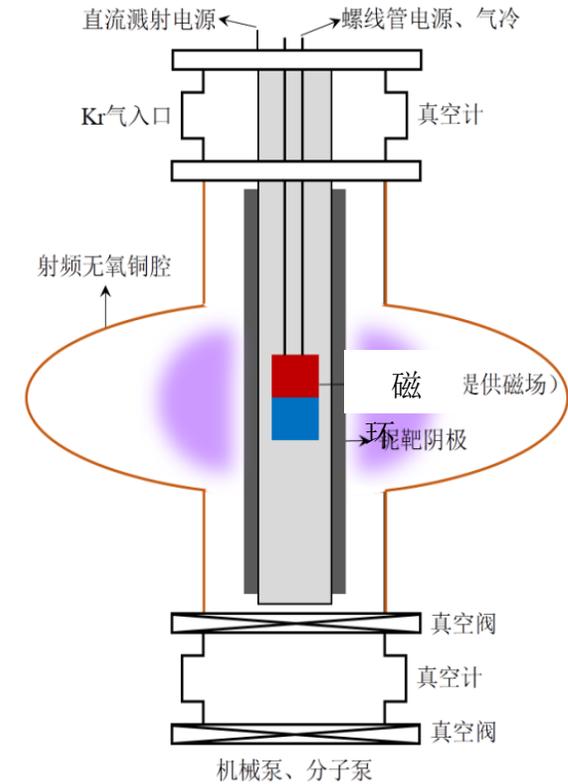


Outside magnet (solenoid)

Cathode wire



- CSNS, BEPCII vacuum chambers;
- Nb coating;

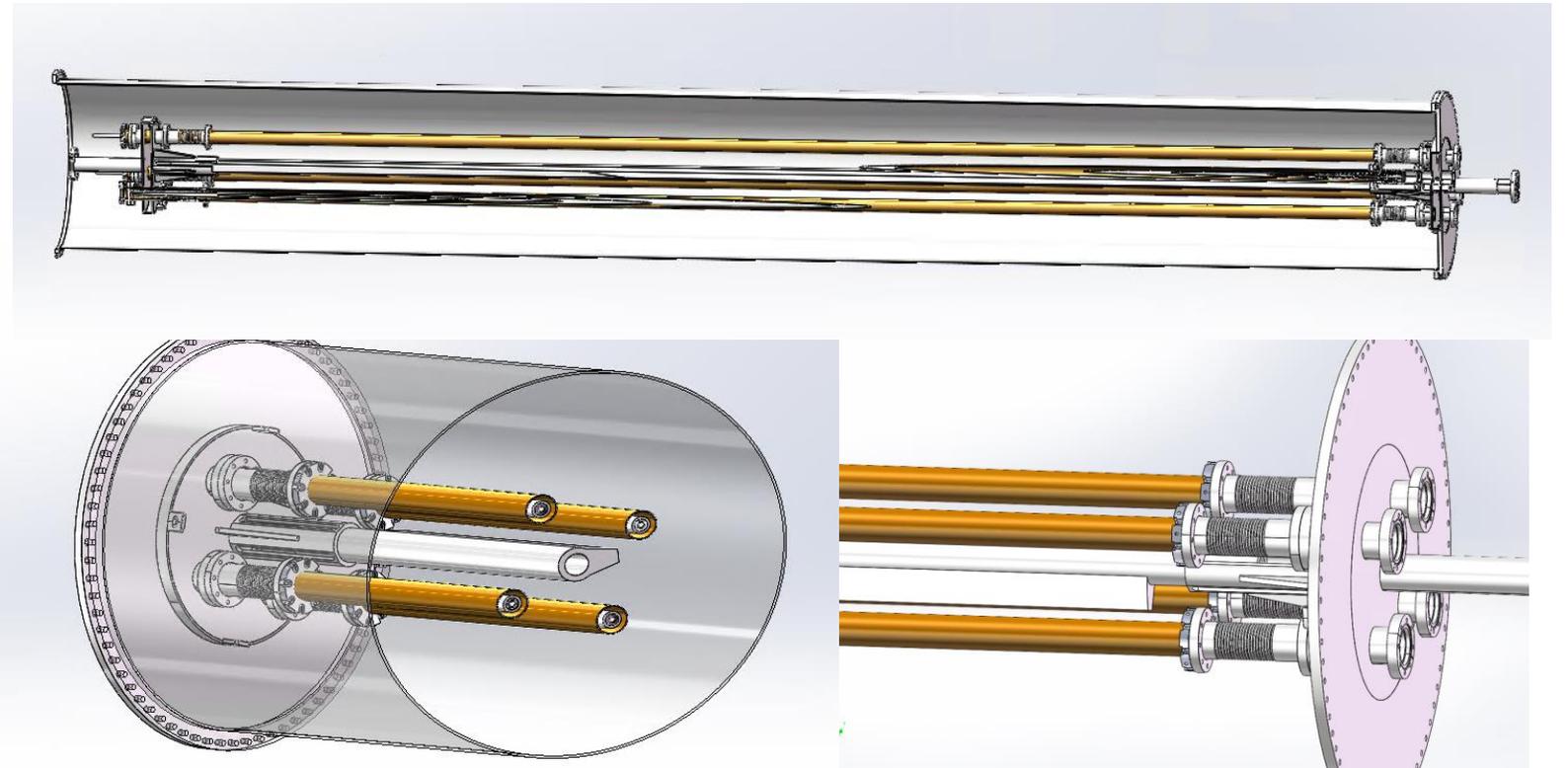
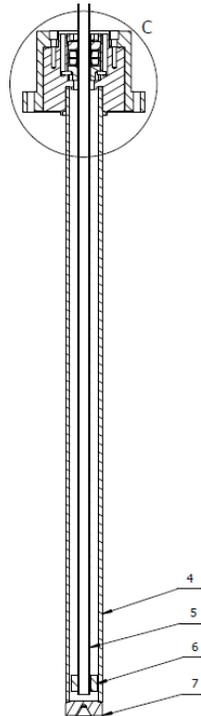


Inside magnet

Magnetron sputtering cathode

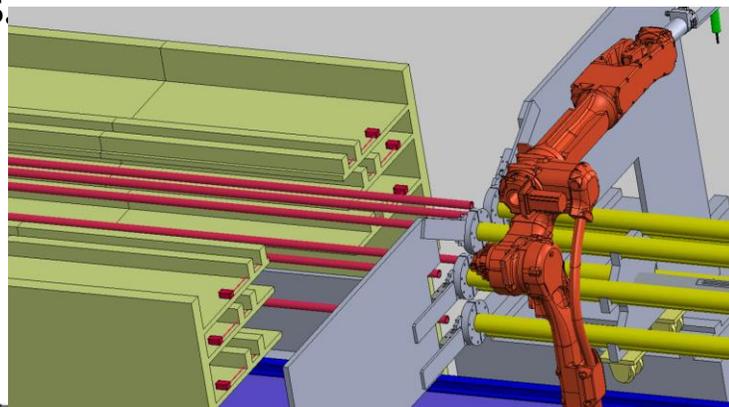
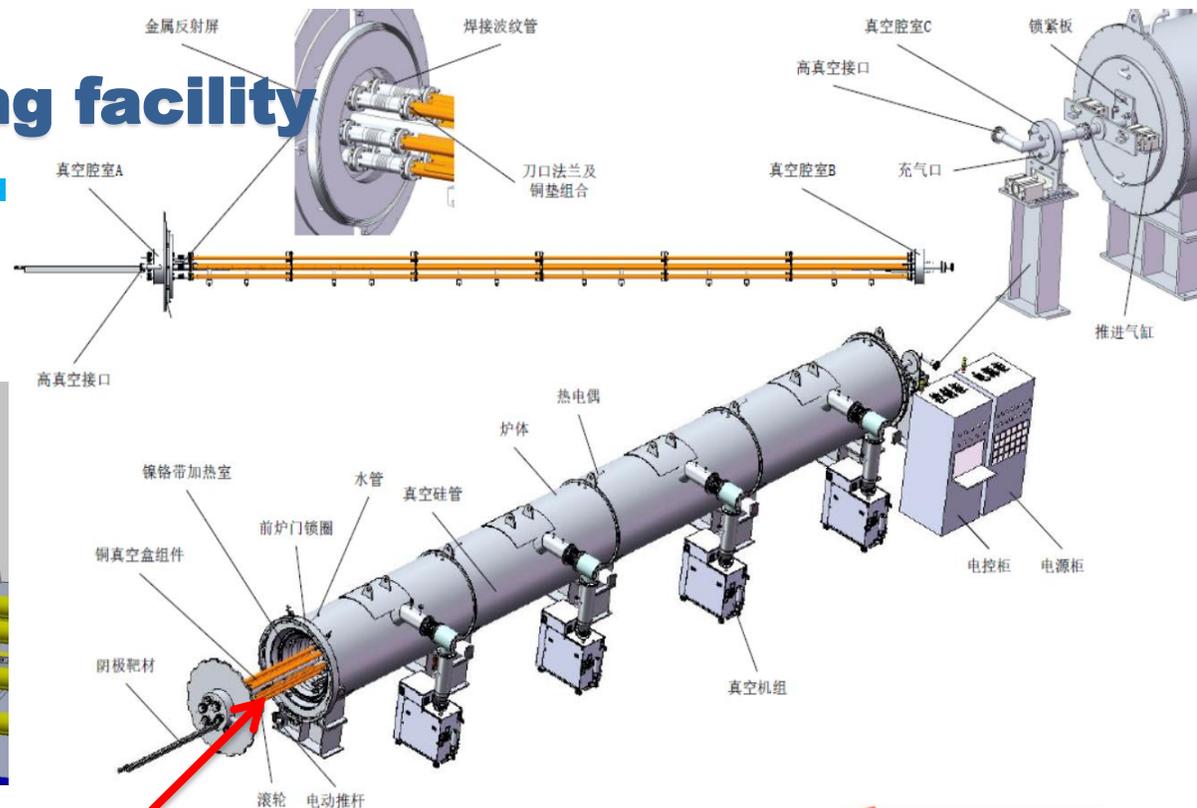
Massive production of NEG coating for CEPC—Upgrade plan

- Due to the diameter of CEPC is D56, we plan to replace the cathode wire with a magnetron sputtering cathode
- Permanent magnet instead of the solenoid which supplies magnetic field for DCMS;
- By combining the low vacuum chamber outside of the vacuum chambers to be coated with NEG, the high vacuum process is simplified;

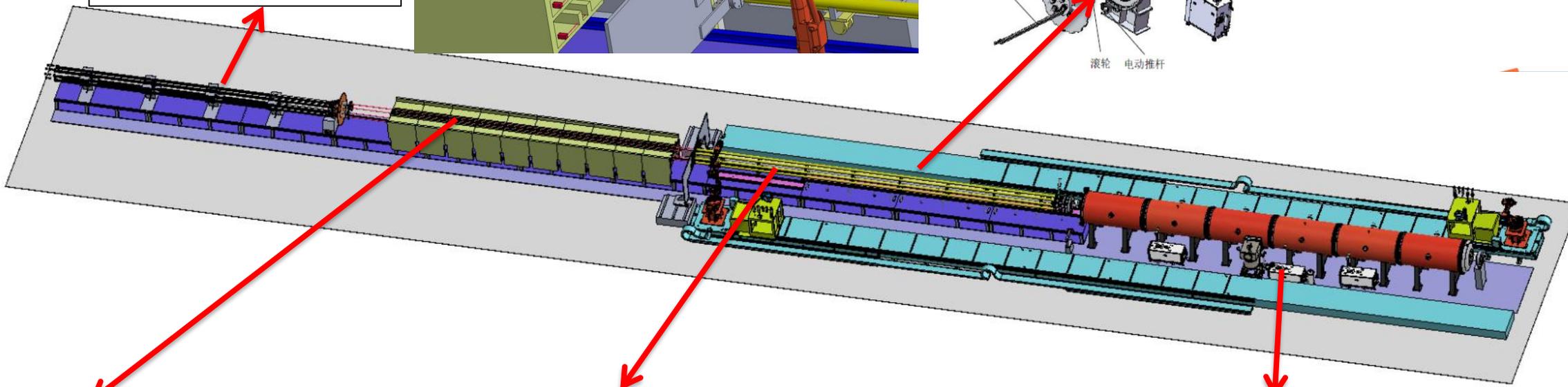


layout & composition of NEG coating facility

- NEG coating, VC assembly and disassembly with automatic robot arms.



Cathodes driven

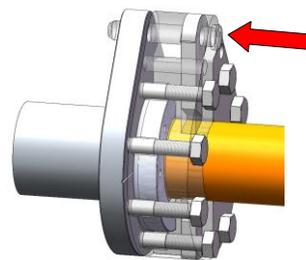
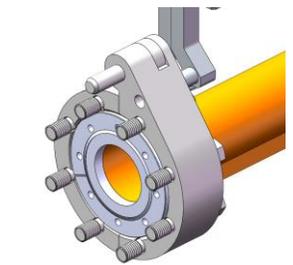
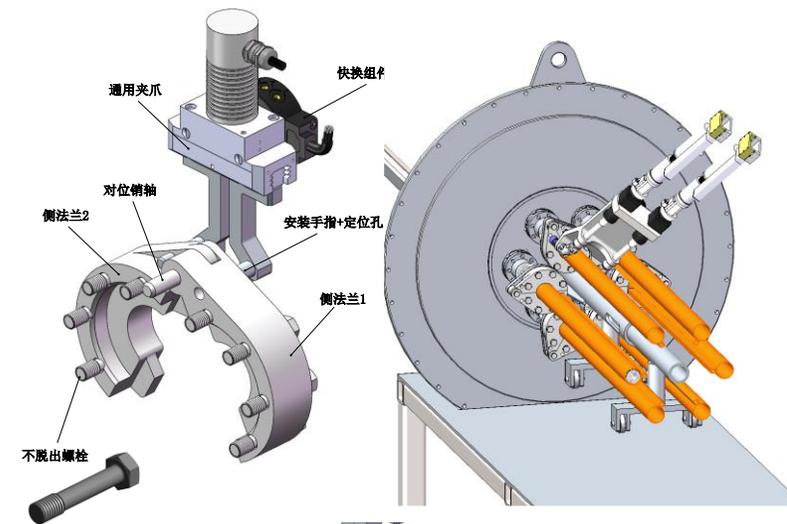
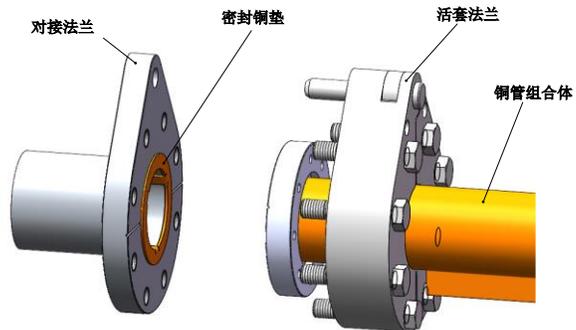
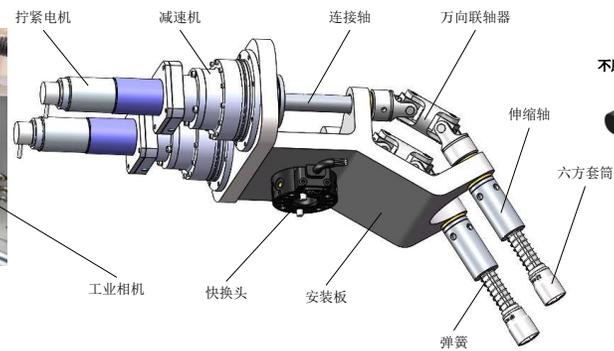
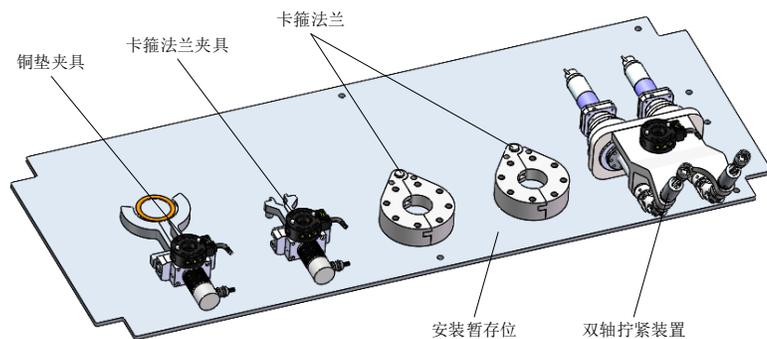
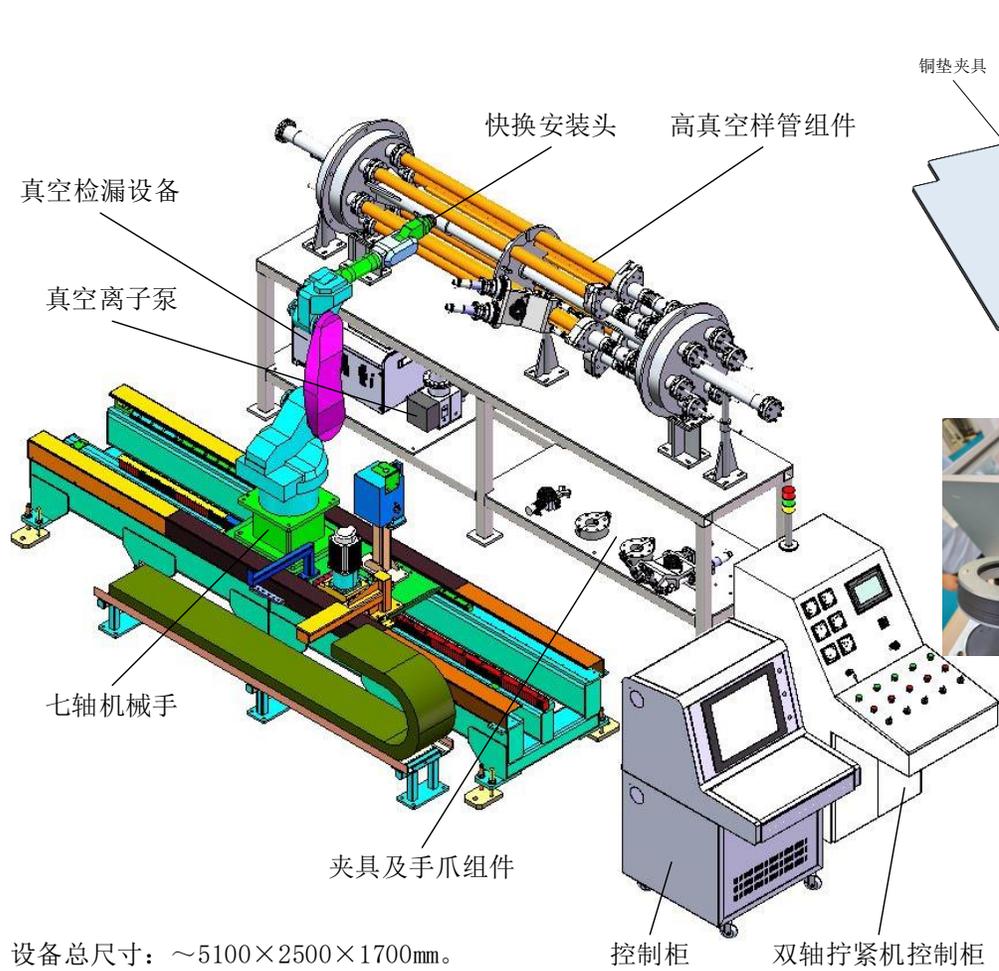


Cathodes

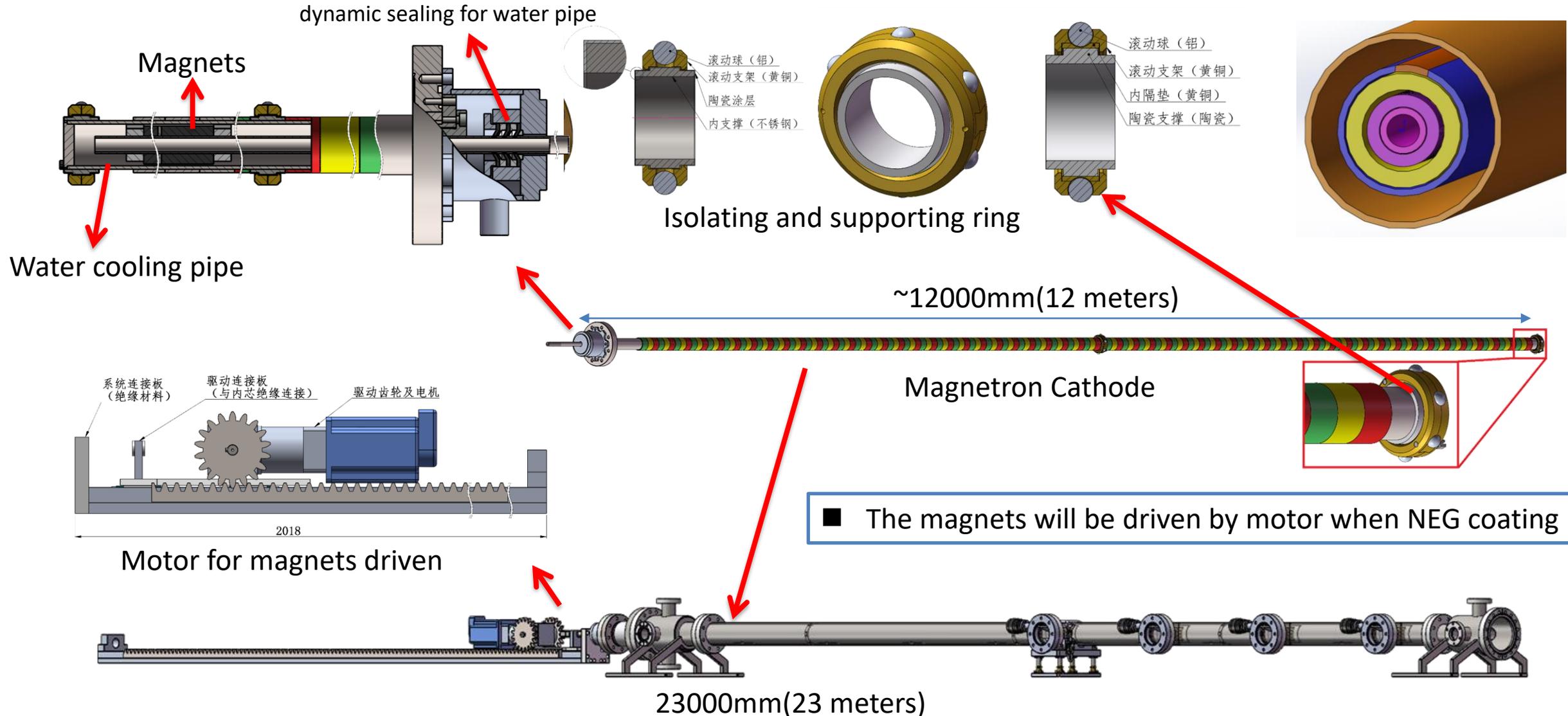
VC assembly

Vacuum oven

Prototype of vacuum chambers assembly



Prototype of cathode for NEG coating



VC baking & Why spray heating film

The baking is the most crucial procedure in achieving ultra-high vacuum

❑ Necessity:

- ✓ In order to meet the ultra-high vacuum requirement of achieving a dynamic vacuum level of 3.0E-10 mbar.
- ✓ NEG coating reactivation

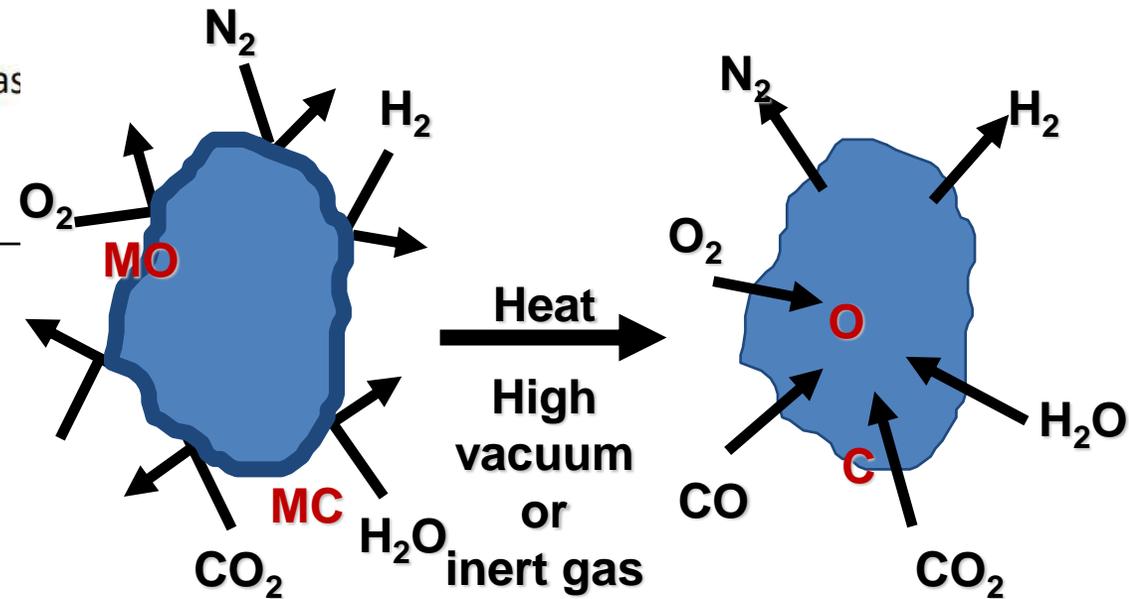
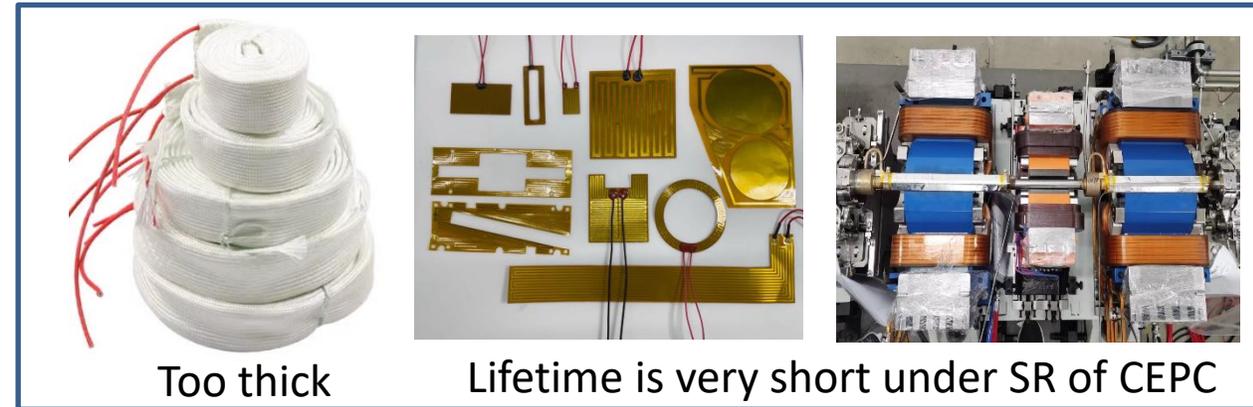
For metals:

- If not baked (not heated) in-situ **water** is the dominant gas specie.
- If baked (heated above ~120°C) in-situ **hydrogen** H₂ is the dominant gas

$$q_{H_2O} \approx \frac{3 \times 10^{-9} \text{ [mbar l]}}{t[h]} \text{ [s cm}^2\text{]}$$

Outgassing rates $q \text{ [} \frac{\text{torr l}}{\text{s cm}^2}\text{]}$ at 20°C:

Austenitic stainless steel not baked, after 10 h pumping	3x10 ⁻¹⁰ (main gas: H ₂ O)
Austenitic stainless steel baked in-situ for 24 h at 150°C	2x10 ⁻¹² (main gas: H ₂)
OFS copper baked in-situ for 24 h at 200°C	~10 ⁻¹⁴ (main gas: H ₂)



Spray for heating film

- ◆ Multilayer heating film will be coated outside of the vacuum chamber which composed by ceramic and conductivity layer
- ◆ The heating temperature could reach 250°C

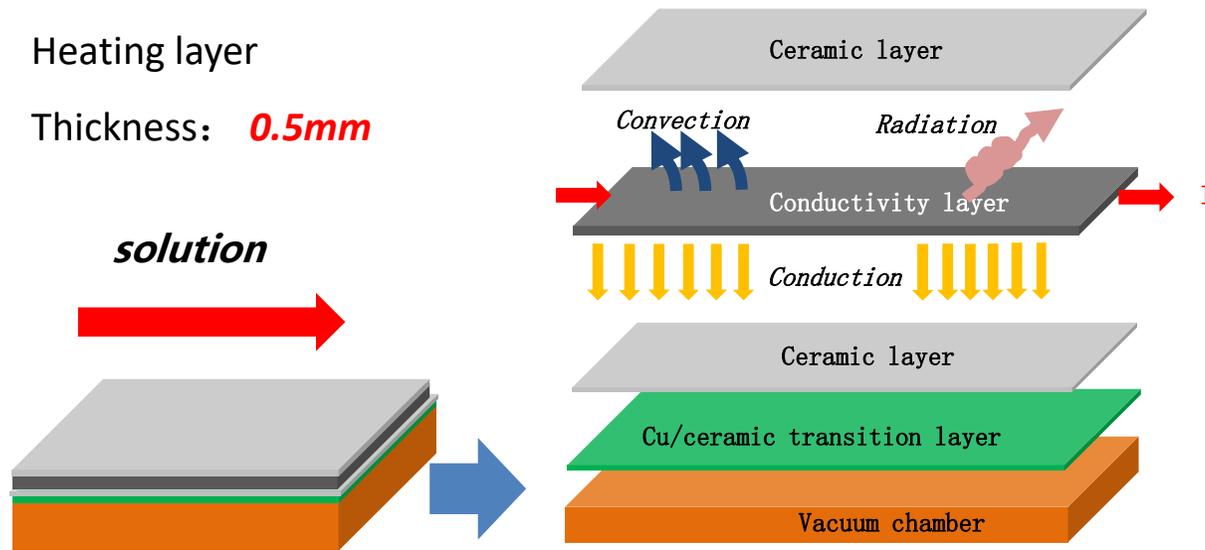
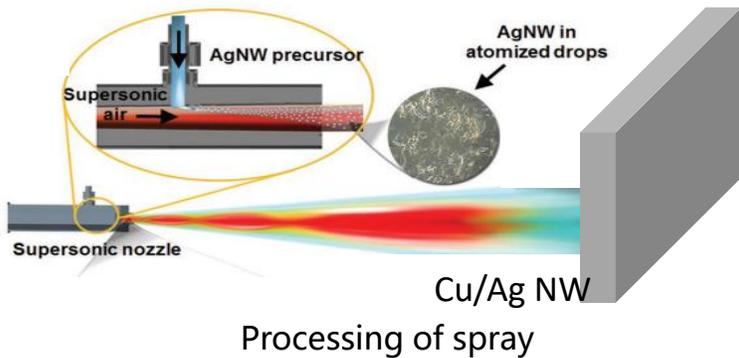
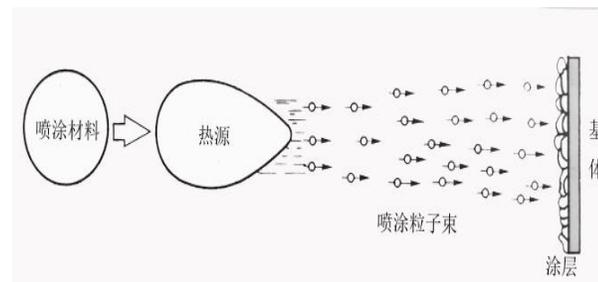


图 2.4 Oerlikon Metco UniCoatPro 大气等离子喷涂设备：(a)控制部分；(b)喷涂部分

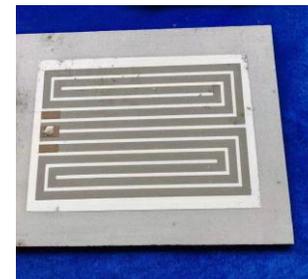
Related commercial products



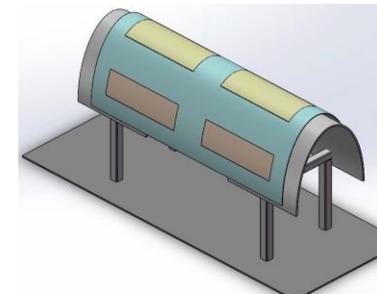
Processing of spray



Plasma spraying



Electric heating circuit

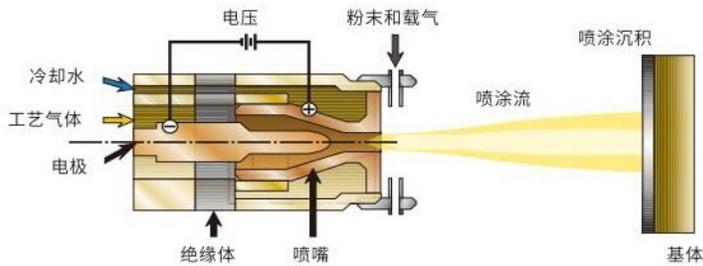


De-icing for airplane



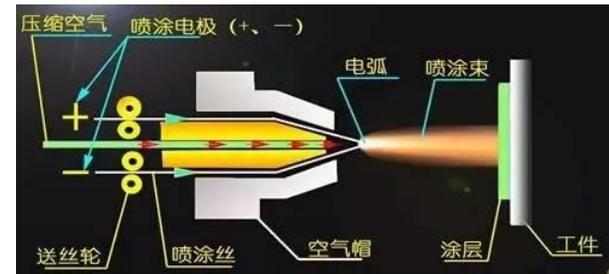
Multiple-layers spraying

■ Plasma spraying



- Gun power: $\leq 55\text{KW}$
- Process gases: Ar/N₂、Ar/H₂、N₂/H₂、Ar/He
- Current: 200A-800A

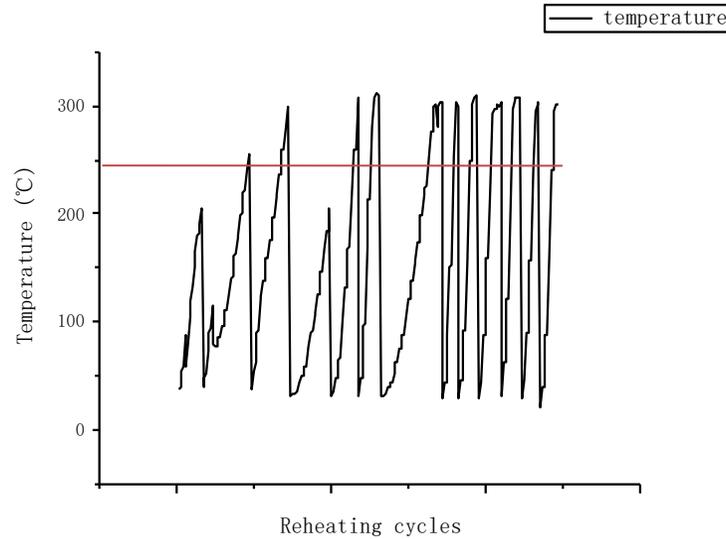
■ Electric arc spraying



- Gun power: 22 KW
- Efficiency: 0.98
- Current: max. 400 A
- Voltage: max. 10 - 70 V

Prototype of Spraying heating film and tests

Reheating test more than 12 times



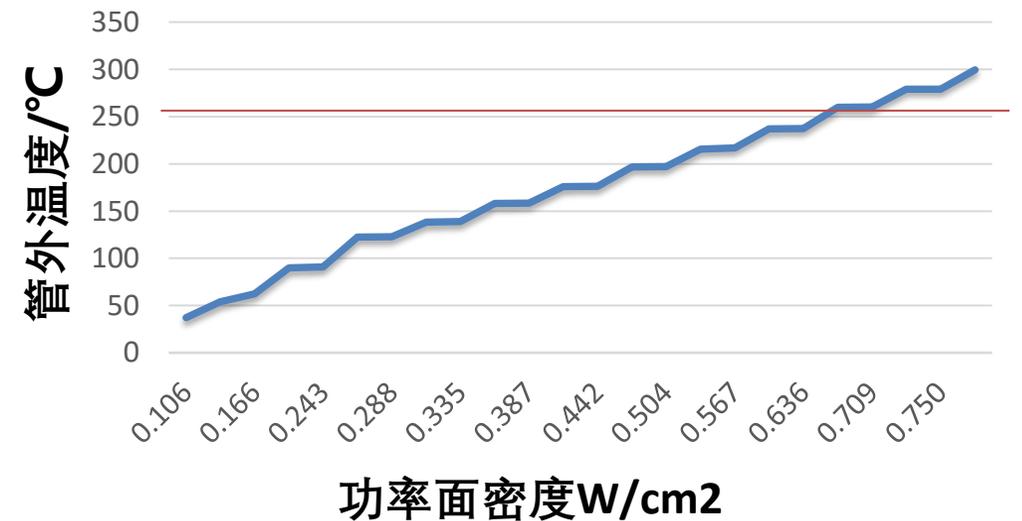
Adhesion test in ultrasonic resining



Dimension: L400*D24 Substrate: copper

Function	Materials	Thickness/um
Transition-layer	MCrAlY alloy	50~100
Isolation-layer	Al2O3 ceramic	~150
Conductivity-layer	NiCr alloy	~100~200
Isolation-layer	Al2O3 ceramic	~150
Contacto-layer	Copper	~50

Temperature vs Heating Power



Conclusion

- Production line of vacuum chambers NEG coating and spraying heating will be R&D in 2 years;
- ✓ NEG coating by magnetron sputtering cathode method R&D will be carried out to adapt the production line;
- ✓ Prototype of Spraying heating film and tests have been carried out, which shows a good results;
- NEG coating optimization for low impedance film, Spraying for heating film plan to be carried out ;

Acknowledgement

- A significant amount of work has been completed in the CDR and TDR, and I would like to thank all those who have contributed to these efforts.
- Thanks for the HEPS, FCC-ee project;

Thanks for your attention