Development of large RF bucket ion sources for large area ion beam milling processes to fabricate micro-structures

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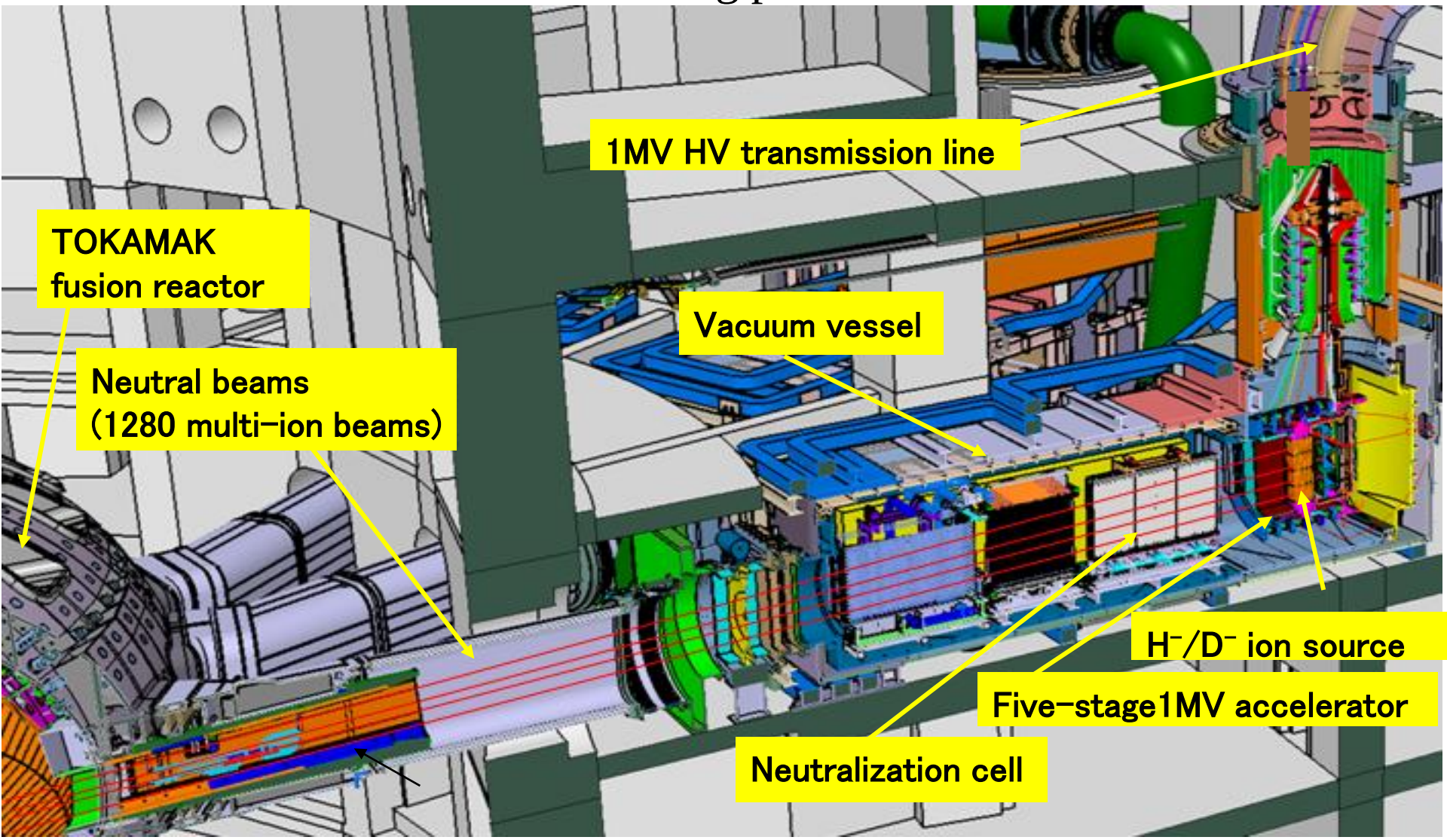
Ion source technology for fusion has been applied to industrial ion beam milling processes



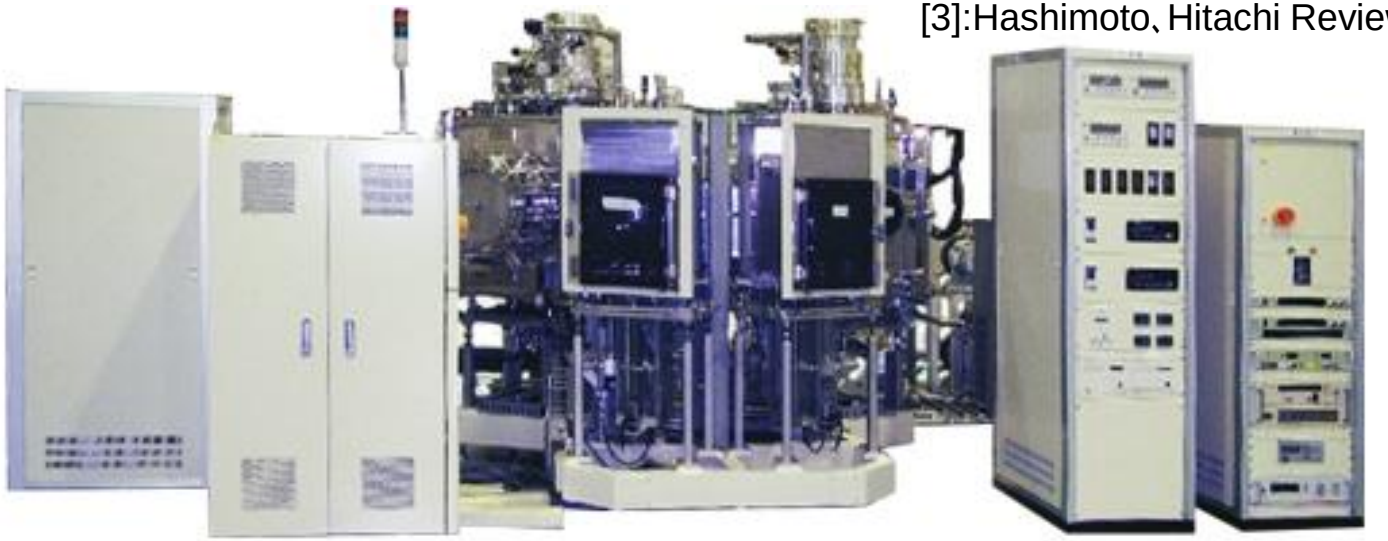
Design of neutral beam injector (NBI) of the fusion experimental reactor ITER

Reference[1]: Masanobu Tanaka, et al., IEEE transaction on Plasma Science, Vol. 39,1379 (2011)

Background

The bucket type ion source for NBI has been applied to
ion beam milling systems（developed by Hitachi, Ltd. around 1986）
Large area ion beams (max φ580mm) was applied to micro-structure fabrication

Reference[2]:Arimatsu、Hitachi Review、Vol. 68, No.6 (1986) 485
[3]:Hashimoto、Hitachi Review、Vol. 73, No.9 (1991) 897



Reference[4]: Hitachi-high tech solutions HP: http://www.hitachi-hightech.com/hsl/products/industry/advanced_elect

Overview of the ion beam milling system

Research targets

1. Filament lifetime limited long-term operation time of the system
2. Filamentless ion source was required to reduce maintenance time for high throughput processes, and to get chemically active ion species (O, F, etc.).

Contents of this presentaion

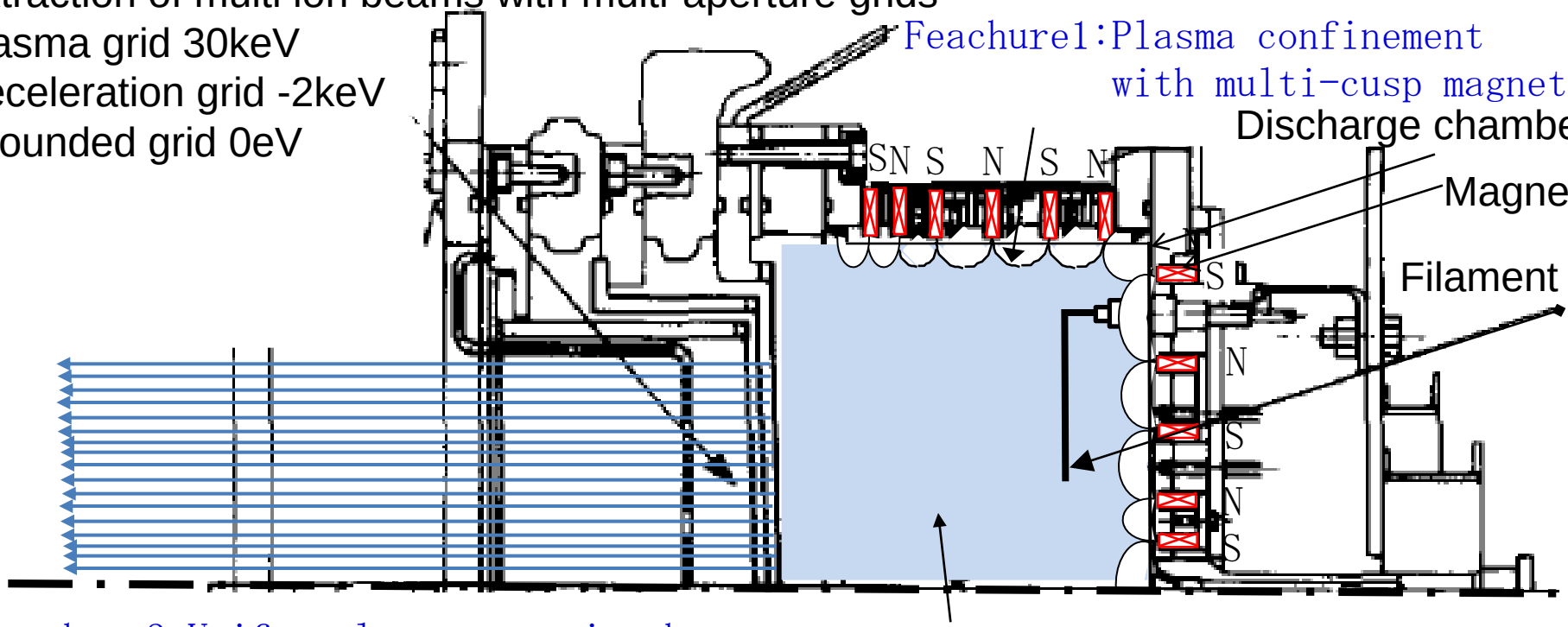
1. Outline of ion beam milling systems with bucket ion source and their applications
2. Development of the RF bucket ion source equipped with multi-cusp magnets

1. Outline of ion milling sysytems equipped with bucket ion sources

(1) Feachures of bucket ion sources for fusion devices

Bucket ion source for Heliotron NBI (30kV, 35A) *Reference[5]: Obiki, et al., RSI, 52(1981)1445

Extraction of multi ion beams with multi-aperture grids
Plasma grid 30keV
Deceleration grid -2keV
Grounded grid 0eV



Feachure3 Uniform large area ion beam extraction without magnetic field effect (φ22cm 、1765 multi-beams)

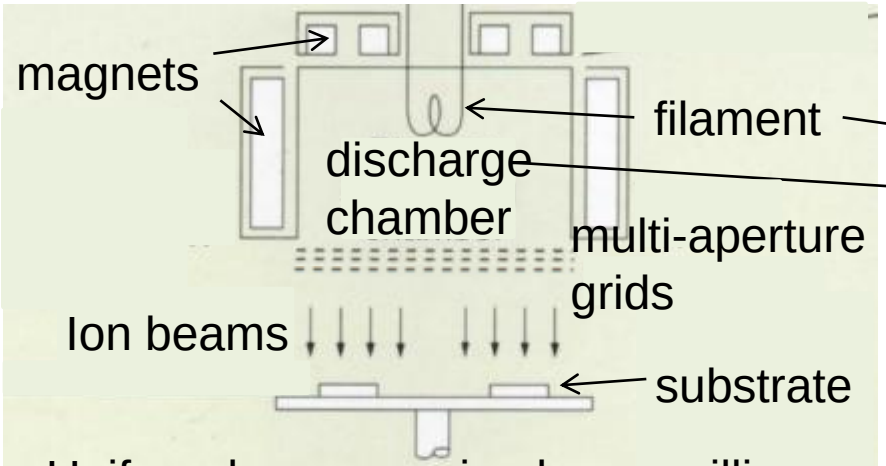
feature2 Largearea uniform plasma in a field-free region (φ34cm、depth15cm)

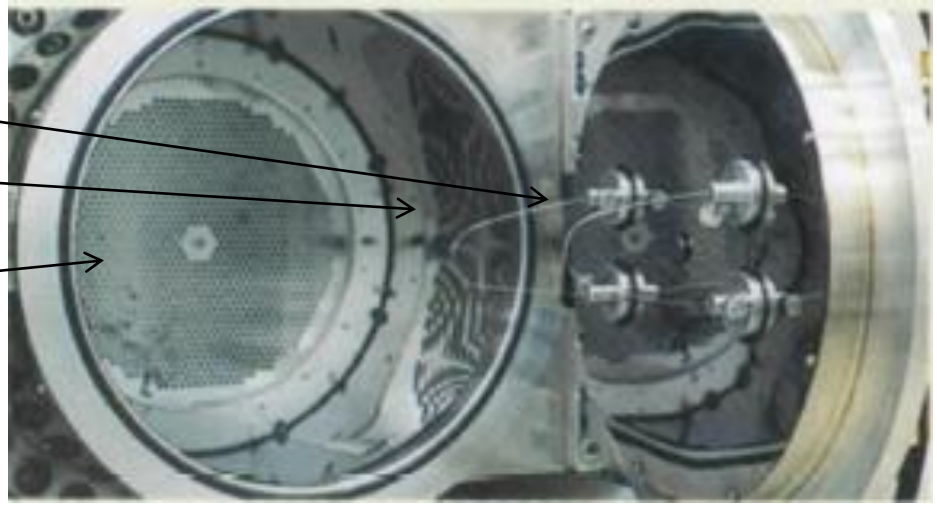
applied to large-area, high-throughput ion milling processes.

Hitachi Ltd. developed ion beam milling systems equipped with the bucket ion source .

Reference[6]: Y. Ono, et al., J. Vac. Sci. Technol. A4, 788–790 (1986).

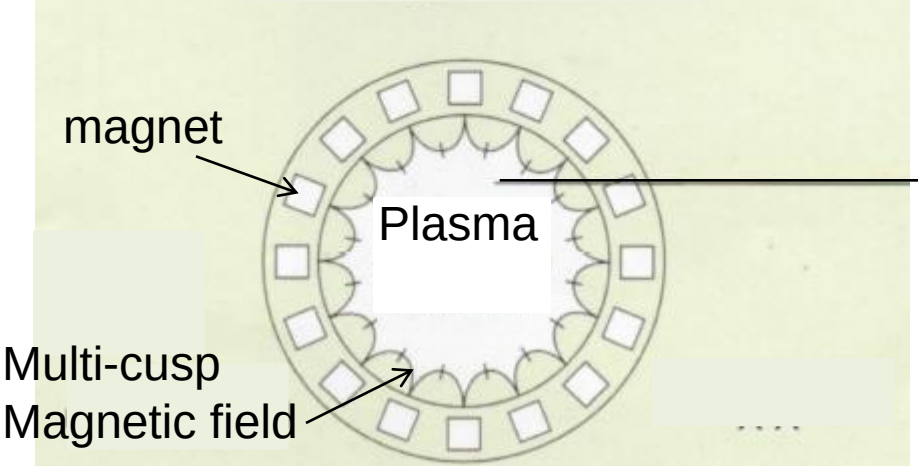
(2) Application of the bucket ion sources to ion beam milling systems

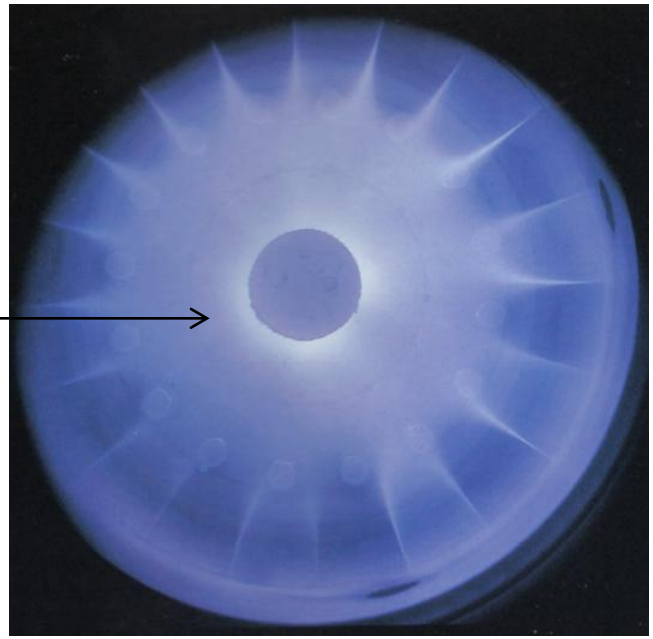




Uniform large-area ion beam milling
(~1 kV, ~1 mA/cm^2、Φ120-580mm)

Outkine of the ion beam milling systems



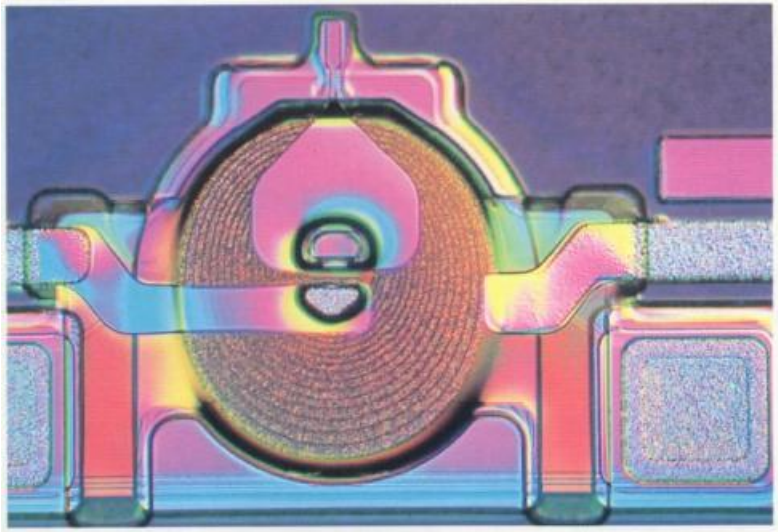


Cross section of the bucket plasma source

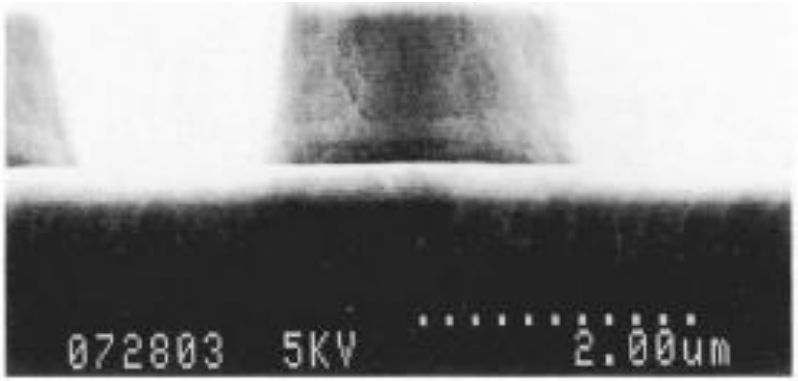
Plasma with multi-cusp field

* Reference[7]: Hitachi, Ion beam milling system, pamphlet (H)DS-E019 0996

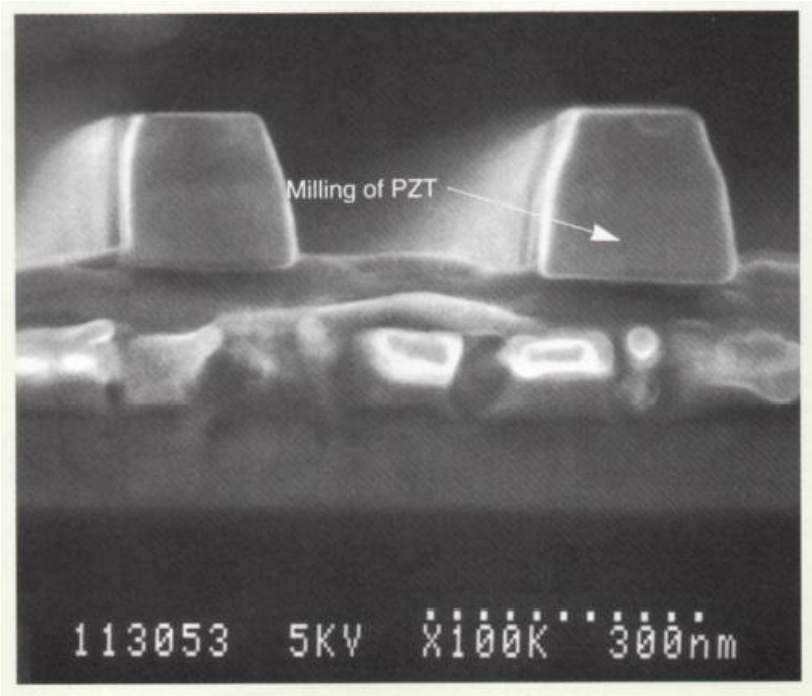
(3) Micro-structure fabrications with ion beam milling systems



Thin film magnetic head of a hard disk drive*



Gold wiring*



PZT device (piezoelectric device)*

<u>Feachure of the ion beam milling</u>

1. High-throughput micro-structure fabrication
with uniform, low divergence large-area beam

2. Physical etching with Ar ion momentum
Process is possible for any materials
Materials difficult in chemical etching and metals can be processed.

* Reference[7]: Hitachi, Ion beam milling system, pamphlet (H)DS-E019 0996
•Reference[8]:Watanabe, et al.J. Plasma Fusion Res.
•Vol.81 (2005) *792*

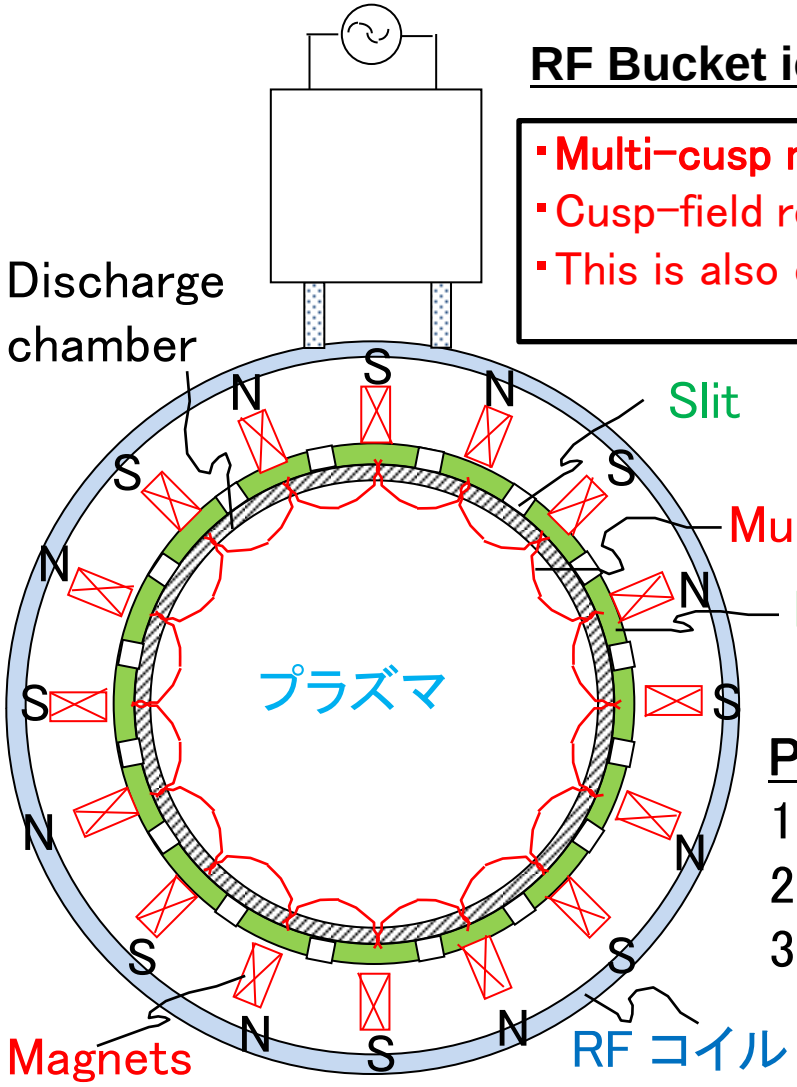
Other applications：MEMS, high-frequency filter, compound semiconductor, printer
Subjects to be solved:filament lifetime,filament chemical damage for active ions (O, F)

2. Development of RF bucket ion sources

Issues of conventional RF ion sources: Plasma loss on discharge chamber,
Sputtering of the chamber,
Plasma non-uniformity

RF Bucket ion source was developed to solve the issues.

- **Multi-cusp magnets were set inside the RF coil for ICP**
- Cusp-field reduced plasma loss, sputtering, heat load
- This is also effective for improvement of plasma uniformity



Potential issues checked for design

1. RF field effect on magnets (eddy current)
2. Magnetic field effect on RF discharge
3. Ion acceleration by RF field and ion sputtering

Cross section of the plasma source

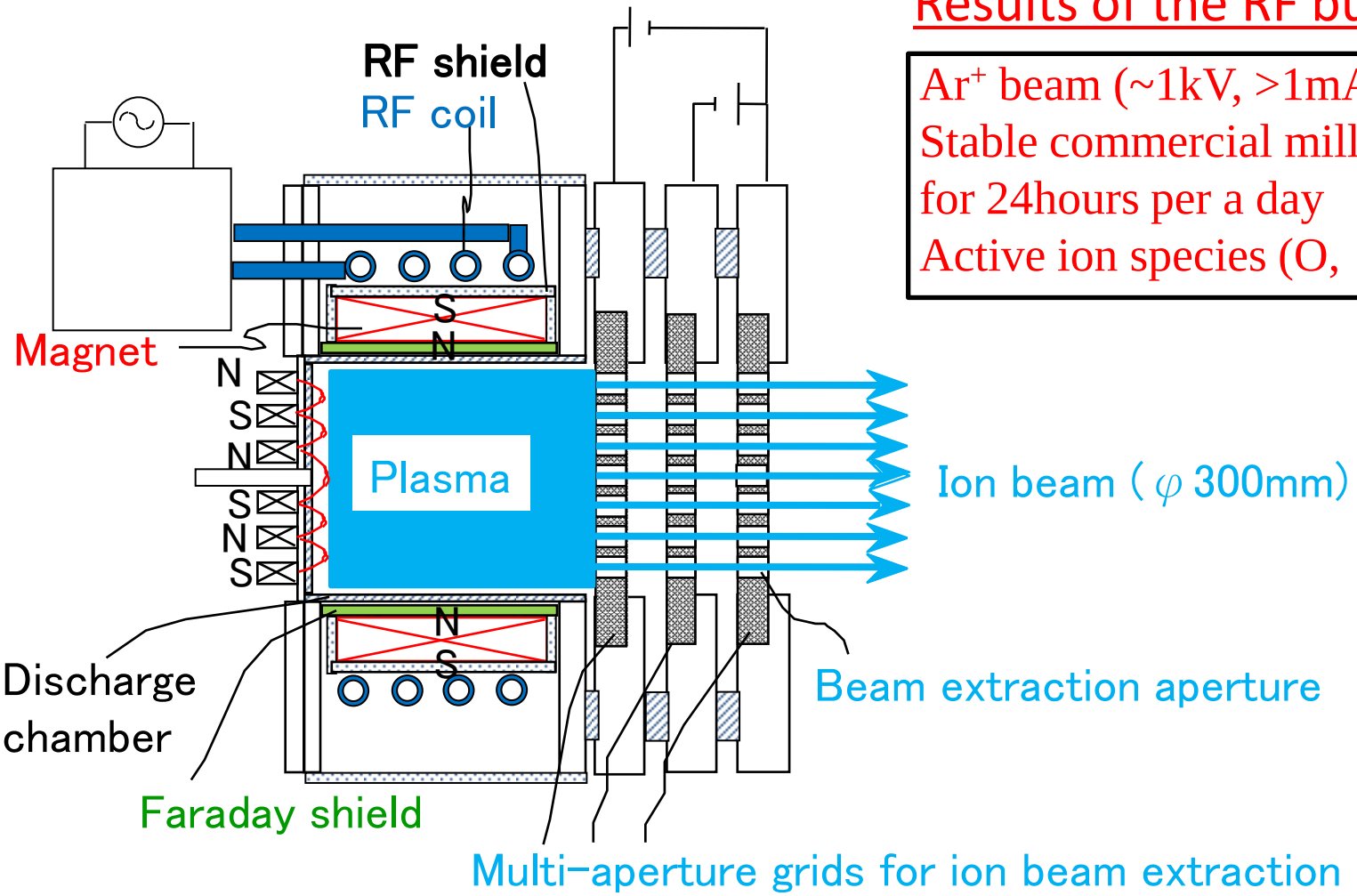
Ref[9]:Masanobu Tanaka, Japan Patent, JPA 2006-315619 (22 November 2006).

Methods to solve the potential issues

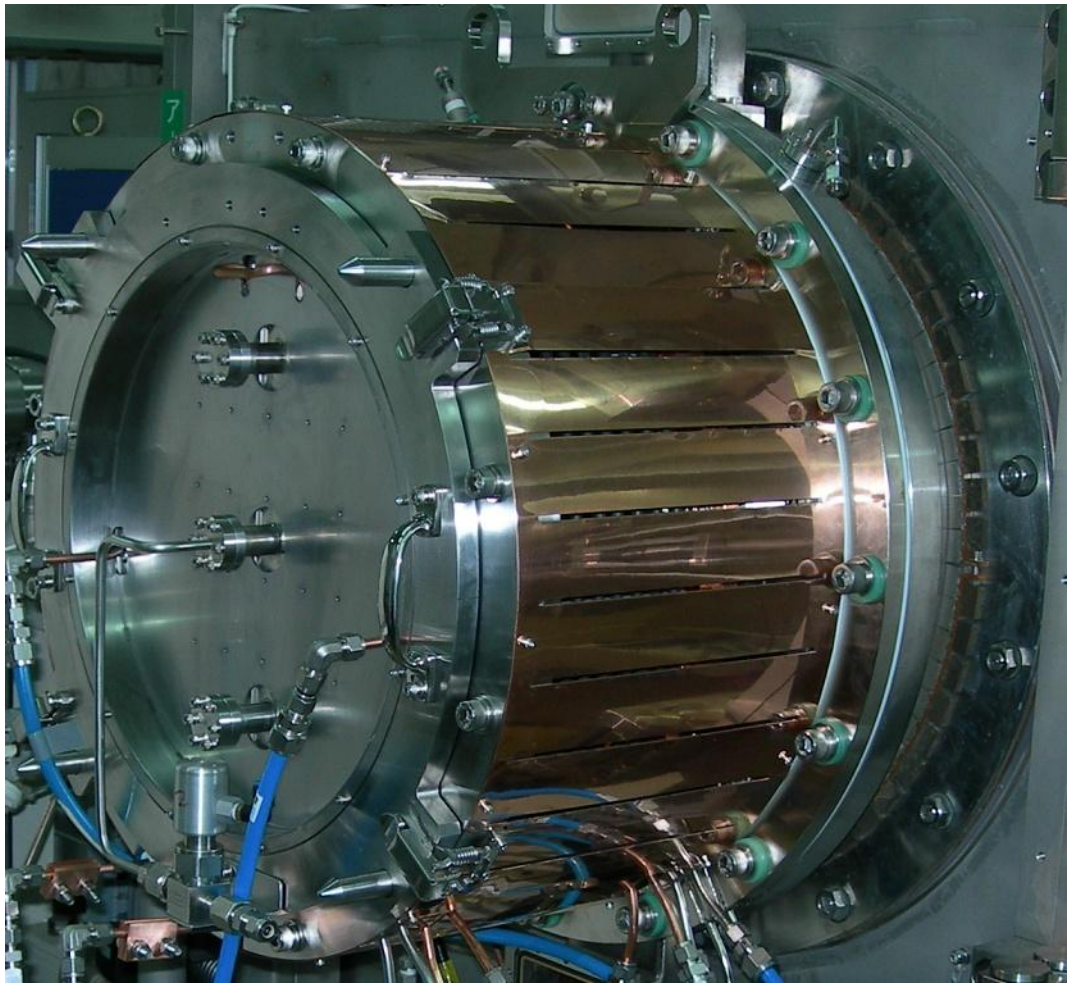
1. RF shield for magnets
2. Magnetic field are localized close to the chamber and most regions are free of field effect
3. RF field is screened by Faraday shield and magnets were set between the slits on the shield.

Results of the RF bucket source

Ar^+ beam (~1kV, >1mA/cm^2)
Stable commercial milling process for 24hours per a day
Active ion species (O, F and others)



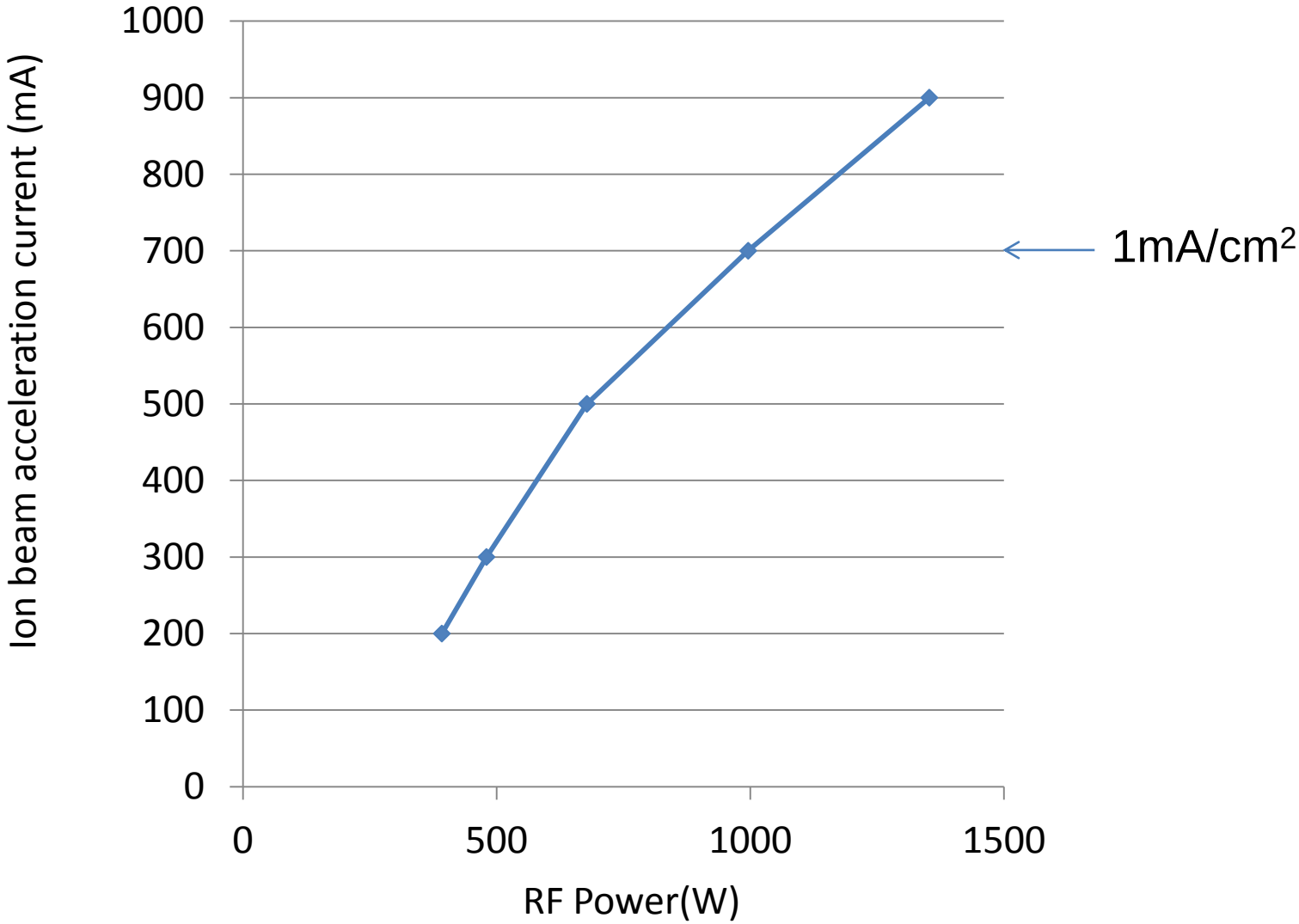
Cross section of the RF ion source



Picture of the RF bucket ion source

3. Experimental result of the RF bucket ion source performance

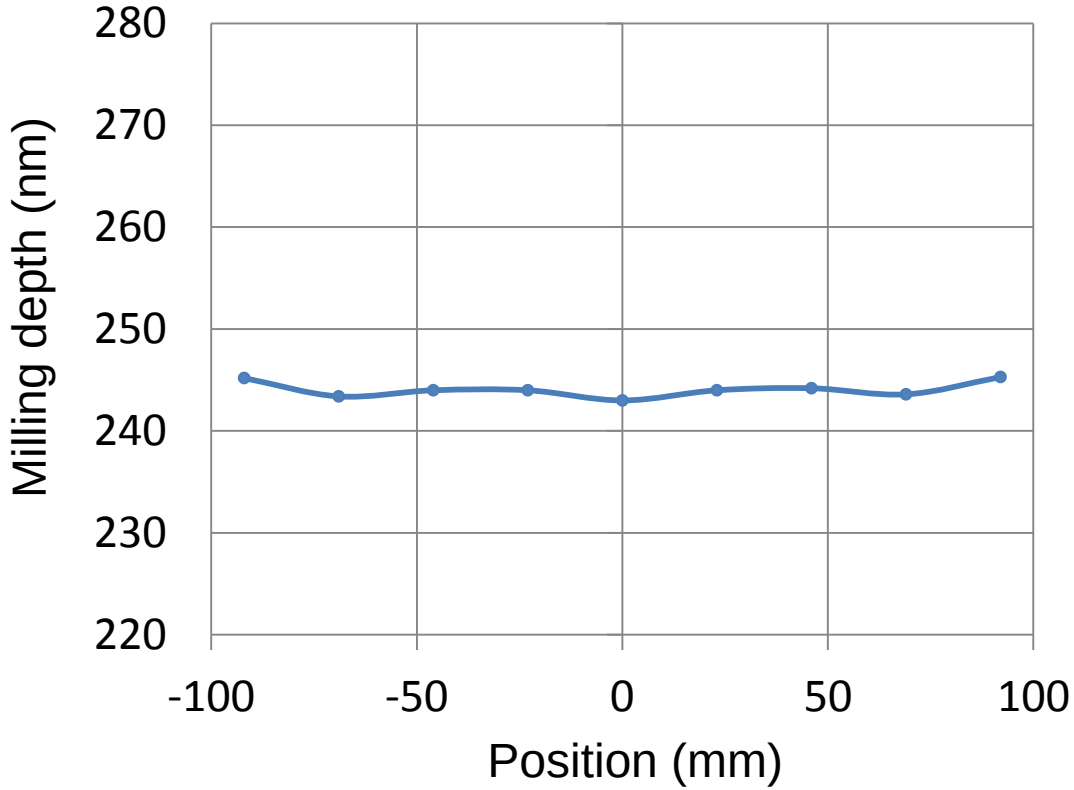
The beam current increased according to increase in the RF power in the range of 400-1400W, and reached 0.9 A at around 1400 W.
The average current density in beam extraction area of 300 mm diameter is above 1mA/cm^2.



Relations between Ion beam acceleration current and RF power

4. Experimental result of ion milling rate distribution

The RF bucket ion source was applied to the ion beam milling system for measurement of milling performance and uniformity. Ar ion beams produced by the ion source were irradiated to a SiO_2 thin film on a Si substrate of 200 mm diameter for 5 minutes. Measured distribution of the milling depth was shown below.
The average milling depth is around 244.1 nm and milling rate is 48.8 nm/minutes. Deviation of the maximum and minimum depth is 2.3 nm. It corresponds to ±0.47 % of the average depth, which is far lower than the target deviation.



Milling distribution of φ200mm SiO2 film

Summary

Large area magnetic multi-cusp ion sources, i.e.,bucket ion sources for fusion was applied to ion beam milling systems and ion beam sputter systems, which have been used for industrial application processes as follows.

The bucket RF ion source was developed for long time stable operations of the systems without filaments and is successfully operating for 24h/day in factories.

1. The ion beam milling systems equipped with the bucket ion sources produced large-area uniform Ar ion beams (max Φ580mm) and has been utilized for fabrications of micro-structures for magnetic heads of hard disks, semiconductors, MEMS, PZT (piezo-electric devices), metal wirings and etc.

2. The RF ion source equipped with multi-cusp magnets, i.e., the RF bucket ion source was developed for higher availability of Ar ion beam milling systems and for active ion species like O, F and etc. It enabled long time operation without filament for continuous processes of 24h per a day.

3. The RF bucket ion sources produced large area ion beams with beam extraction area of 300mm diameter. Ar ion beam current density is more than 1mA/cm2 with beam current of 0.9A and acceleration voltage of 0.5-1kV.

4. Measured SiO_2 milling rate was 48.8 nm/minutes with maximum variation of ±0.47 % due to position for a 200 mm substrate.

Acknowledgement

The authors would like to thank Hitachi, ltd. for author's original ion source development done when they are working in Hitachi, ltd.