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High Power UHF CW Klystrons for KEKB and One of the Key Techniques

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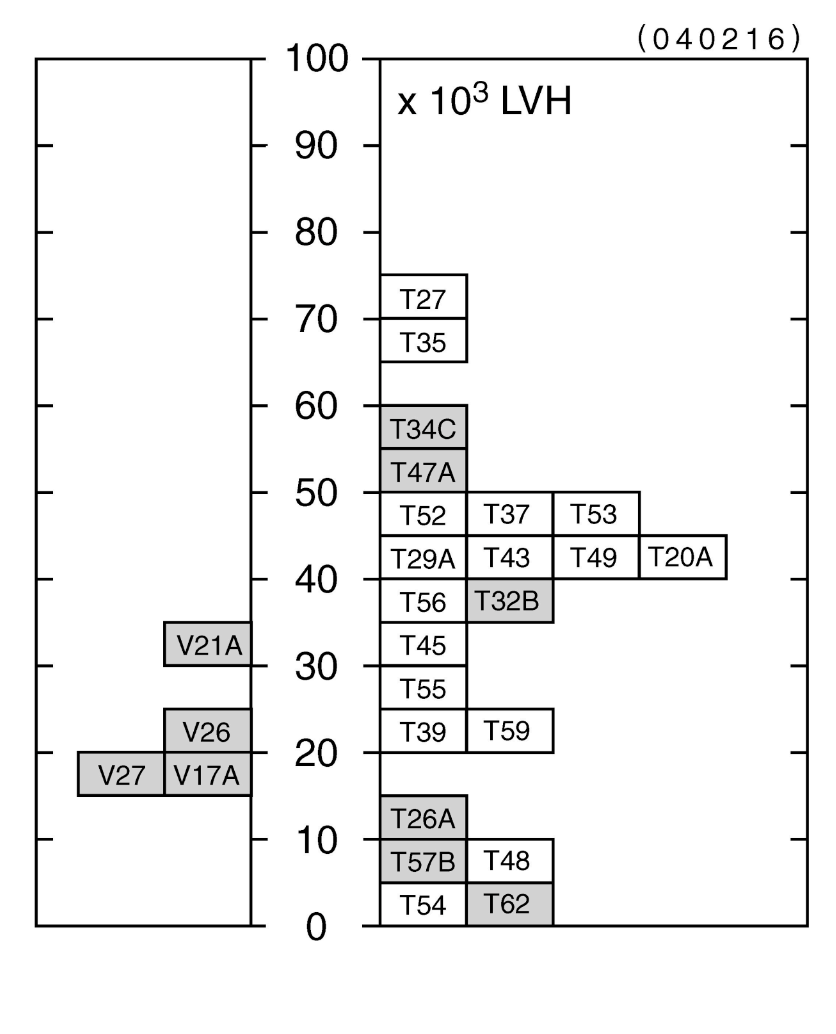
Present Line-up of CW Klystrons for KEKB(24) and PF-AR(2).

Number of klystron in each LV age category.



V : 1MW tubes from Philips (VALVO).

T : 1.2MW tubes from Toshiba.

V tubes now only being used for half of SC cavities.

Both tubes have been developed and improved originally for TRISTAN in close collaboration between KEK and each industry.

Some tubes are very long life, top runner exceeding 72,000 LVH.

Hatched tubes install M-type (cold) cathode for solving Ba related problems.

Klystron MTBF at KEK

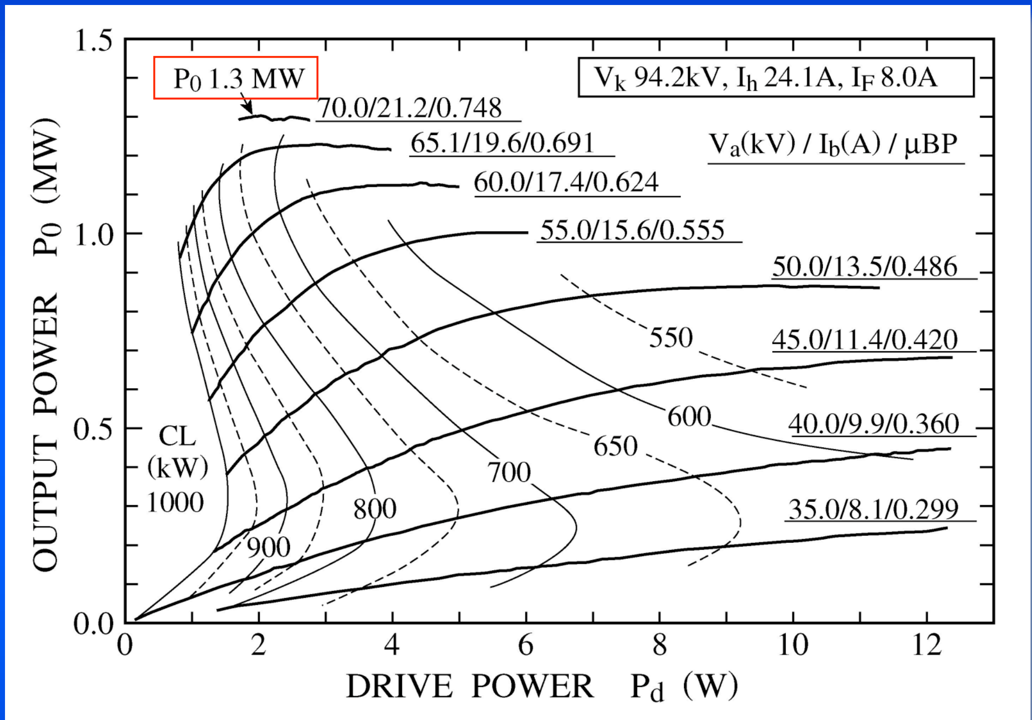
	Power Rating (kW)	Operation Power (kW)	Total LVH (h)	Failures	MTBF (h)
V	800-1,000 CW	150 - 850	543,571.7 (540,143.5)	38 (30)	14,305 (18,005)
T	1,200 CW	350 - 900	1,177,631.8 (1,172,920.4)	34 (25)	34,636 (46,917)

Numbers in parentheses denote the data when initial failures during the period below 1,000 LVH are not included, considering Infant Mortality.

Stable, reliable and long life performances have been assured, which contributed much to KEKB's success.

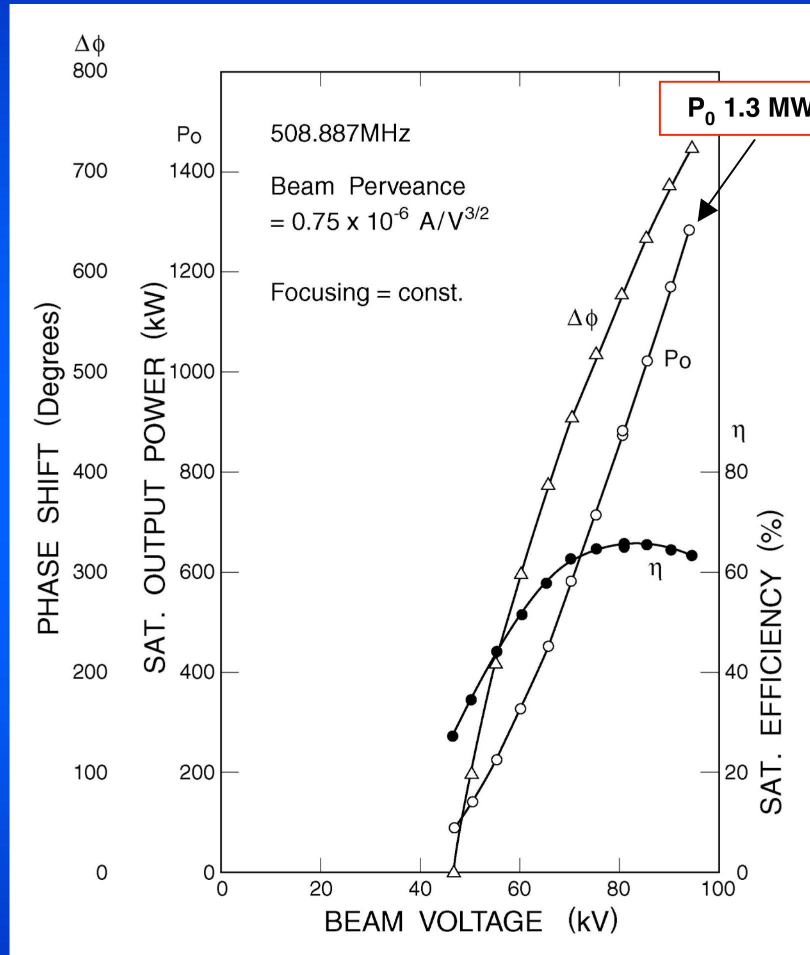
MTBF : Mean Time Between Failures

Operation of a T-tube at the World's Highest Power Level (1.3 MW CW)



Klystron characteristics at KEKB frequency, 508.887 MHz.
Constant collector loss curves (in kW) are shown up to 1000 kW.
The highest rf output is 1.3 MW.

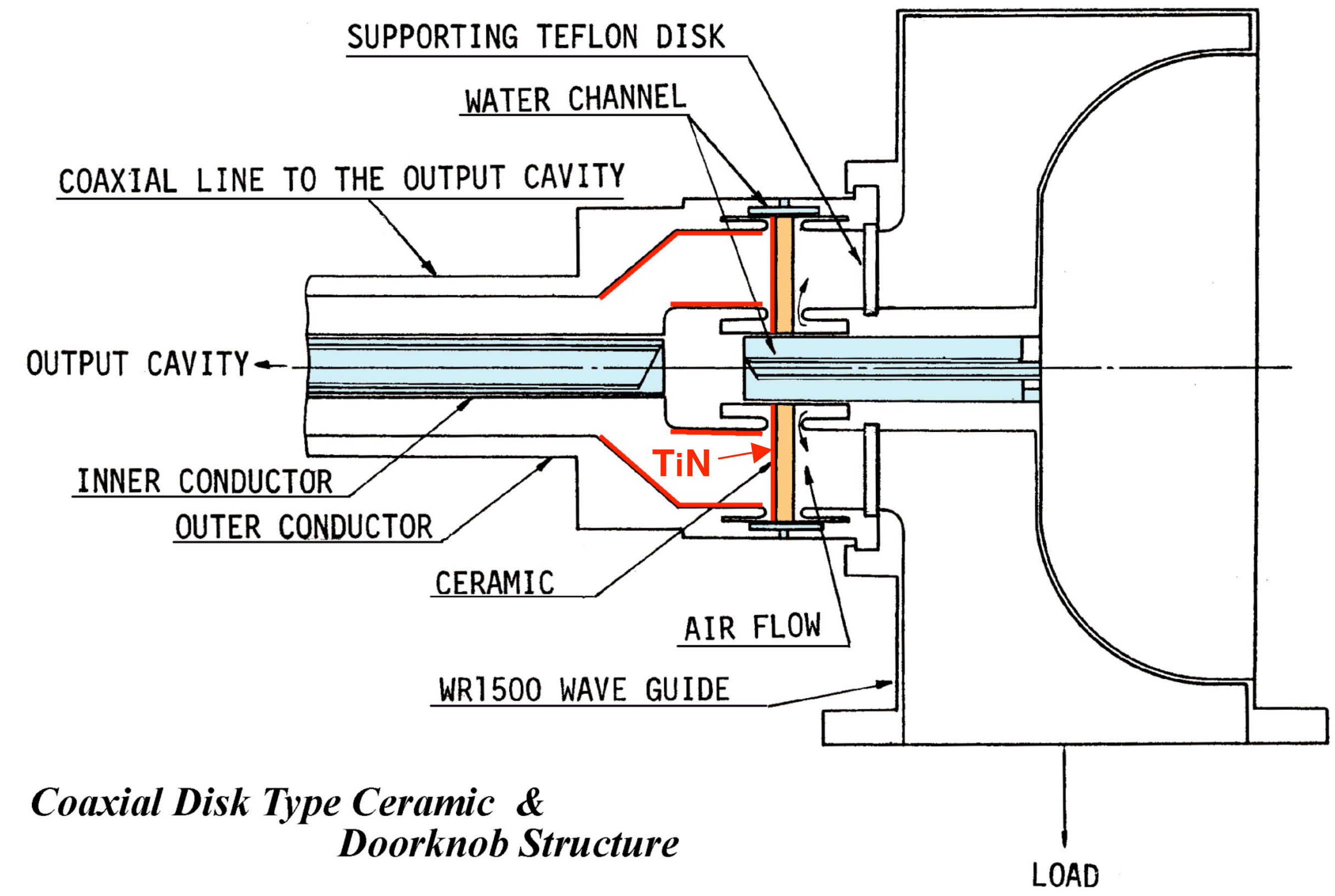
P_0 1.3MW, V_k 94.1kV, I_b 21.2A
η 64.8%, VSWR of the load 1.07.
Max η 65.5% at V_k 85.2kV for I_b 18.3A.



Performance of T41 as a function of beam voltage.

Klystron Output Coupler

The output coupler of our klystron is completely all right at the power level over 1.3 MW CW.

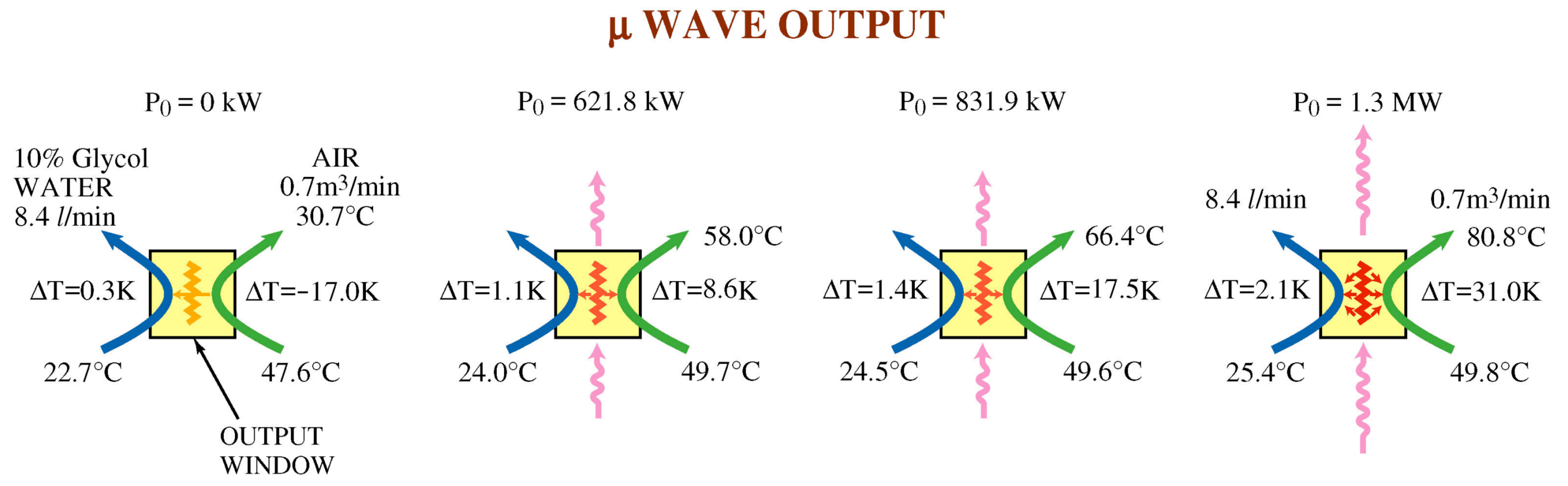


Coaxial Disk Type Ceramic & Doorknob Structure

Key Techniques :

① Hybrid Cooling System ② Titanium Nitride Coating of Window Ceramics

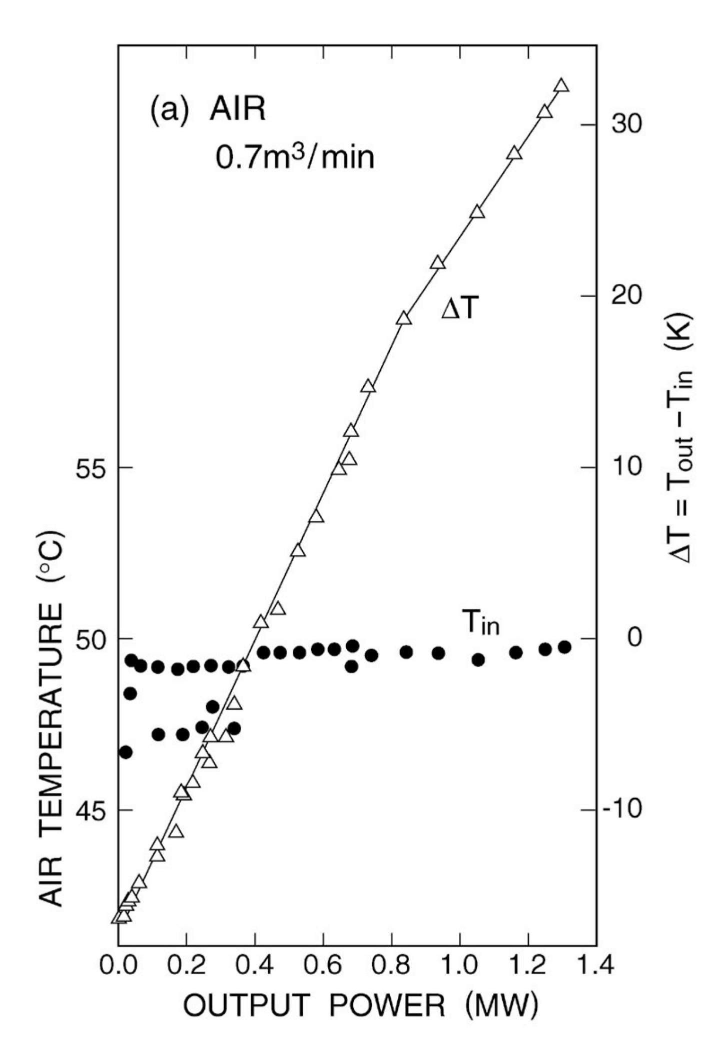
Hybrid (Air & Water) Cooling System

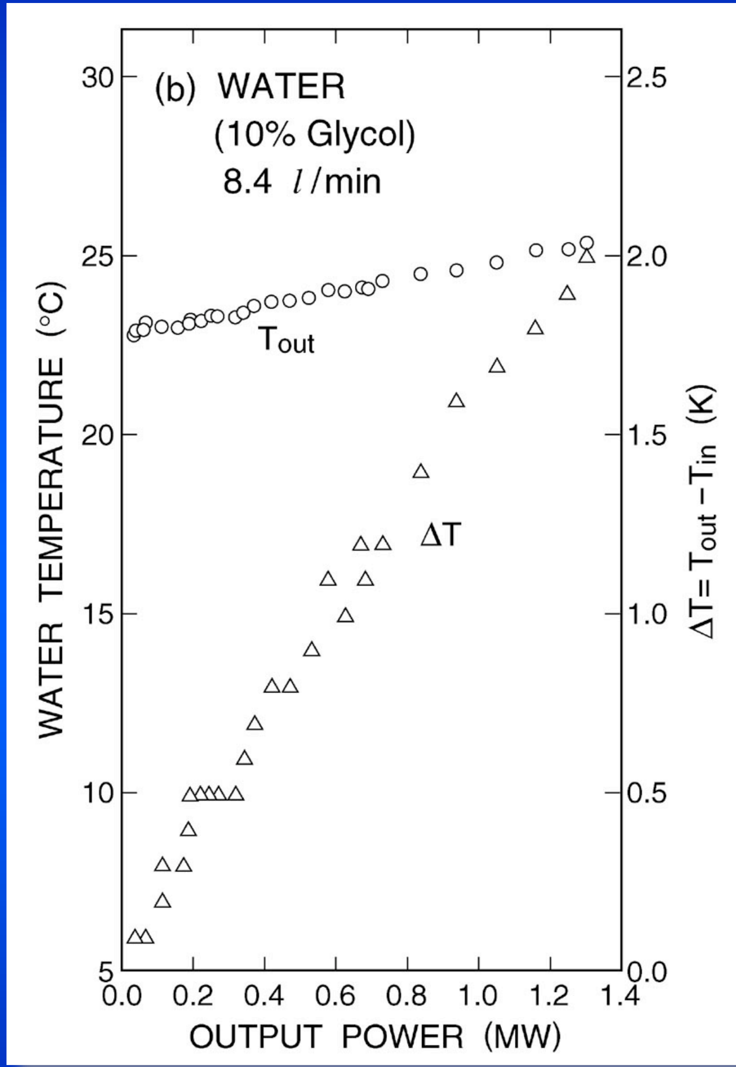


WATER :	P_W=0.17 kW	P_W=0.63 kW (84%)	P_W=0.80 kW (77%)	P_W=1.21 kW (74%)
AIR :	P_A =-0.23 kW	P_A =0.12 kW (16%)	P_A =0.24 kW (23%)	P_A =0.42 kW (26%)
TOTAL :	$P_W + P_A$ = -0.06 kW	0.75 kW	1.04 kW	1.63 kW
KLYSTRON BODY LOSS :		ΔT_B 1.2 K, 8.6 kW	ΔT_B 1.2 K, 8.6 kW	ΔT_B 2.7 K, 19.4 kW

Figure summarizes power balance of the system.
At P_0 1.3 MW total power from window 1.63 kW, while body loss 19.4 kW.
About 26% of heat from window removed by air and 74% by water.
Ratio by air increases with rf power P_0 .

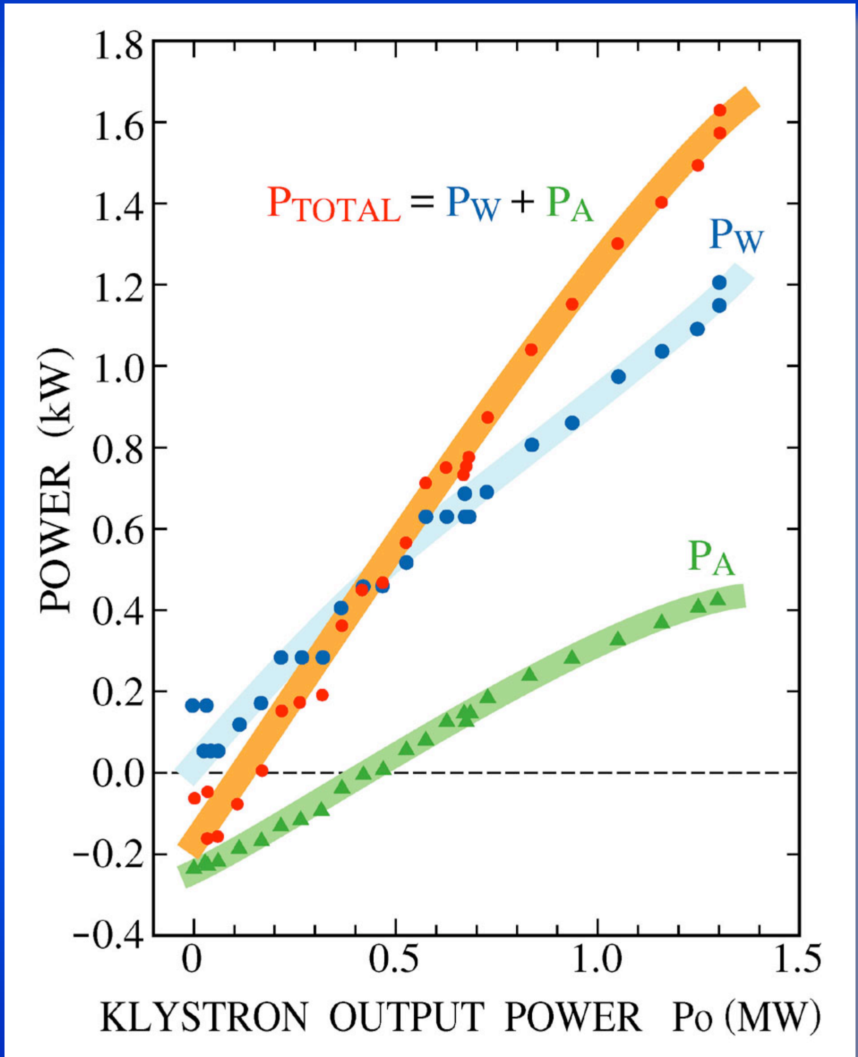
Linear Heating (1)





Temperature rise of (a) cooling air and (b) chiller cooling water containing 10% ethylene glycol as a function of klystron output power up to 1.3 MW.

Linear Heating (2)



Temperature rise is (Dissipated power) linear.

No abnormal increase

→ Heating mainly caused by ceramic dielectric loss.

→ Multipactoring effectively suppressed by TiN coating.

Suppression of Multipactoring : Most Important Key Factor to Get Higher RF Power.

◎ Structure & quality of film depend on

coating method,
equipment used
and
coating conditions.

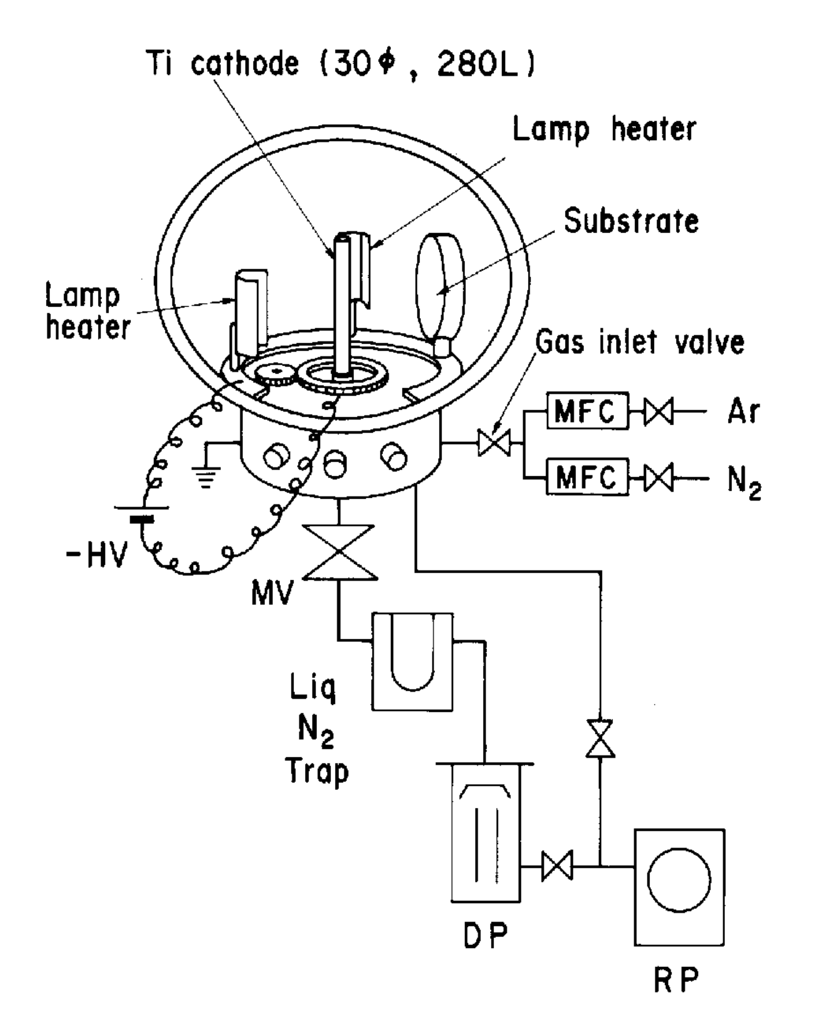
◎ In our case, DC Reactive Sputtering used.

O_2 background high
Deposition rate low (1~3 Å / min)

⟶ TiNxOy rather than TiNx formed with island and columnar structure.

⟶ Many weak links and High Resistivity.

DC Reactive Sputtering Method



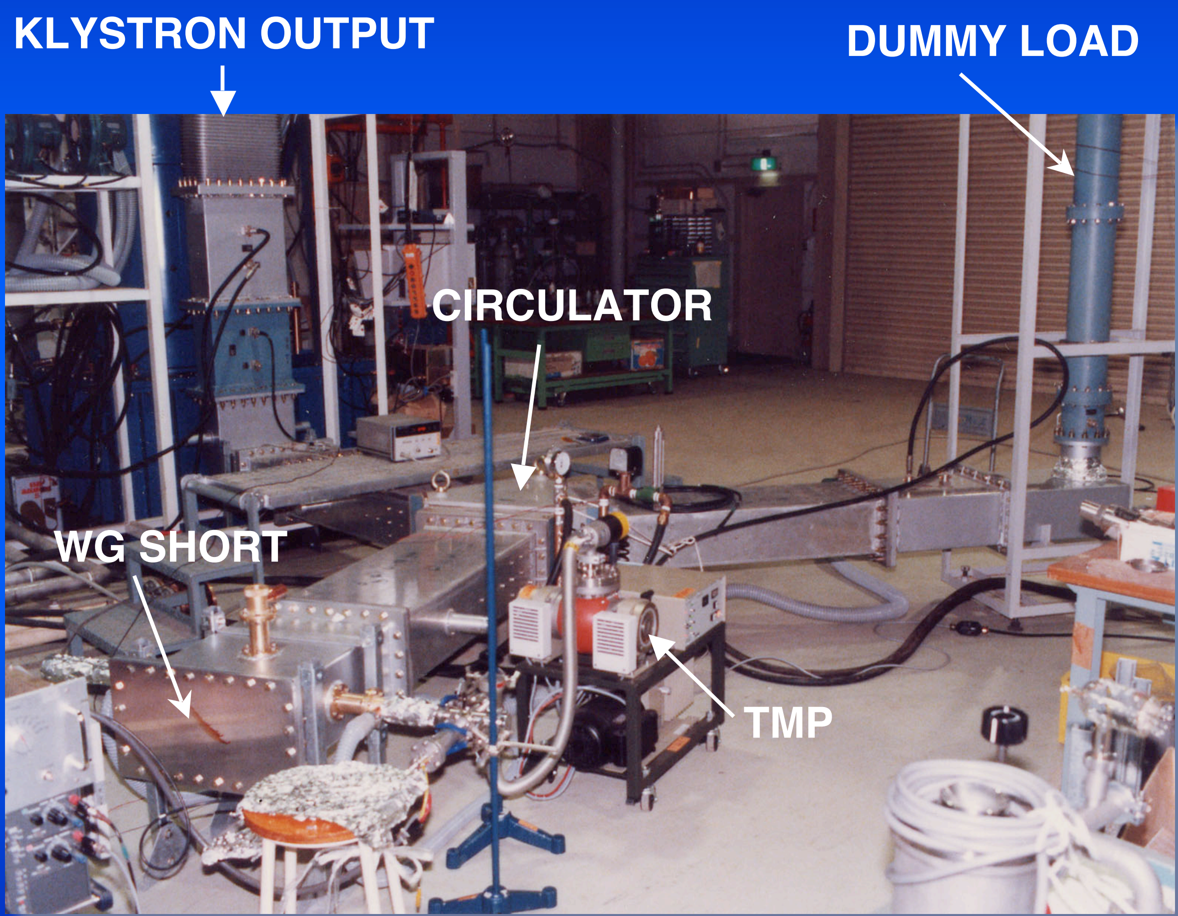
Conditions of DC Reactive Sputtering of TiN_x

Samples		SSA-S (99.5% Al_2O_3)
		1/4 CYLINDER, Lot #1 & #2
		(ID 20mm, OD 25mm, L 200mm)
Preheating Time		30 min
Sample Temperature		About 150°C
Ultimate Pressure		2.5 x 10^{-5} Torr
Residual Gas Pressure after Preheating		2.2 x 10^{-5} Torr
Gas Flow Rate	Ar	31.3 SCCM
	N_2	11.1 SCCM
Total Working Pressure		6.2 x 10^{-2} Torr
DC Output Power		3 kV
		60 mA
Distance between Ti and Substrates		56.2 mm
Deposition Rate		200 Å/h
Target Thickness		Various

Chamber updated.
DP replaced by CP afterwards.

No quality changes, however, observed.
—— We checked and confirmed it.

To Optimize Coating Conditions —— Test Bench Developed at KEK Before.

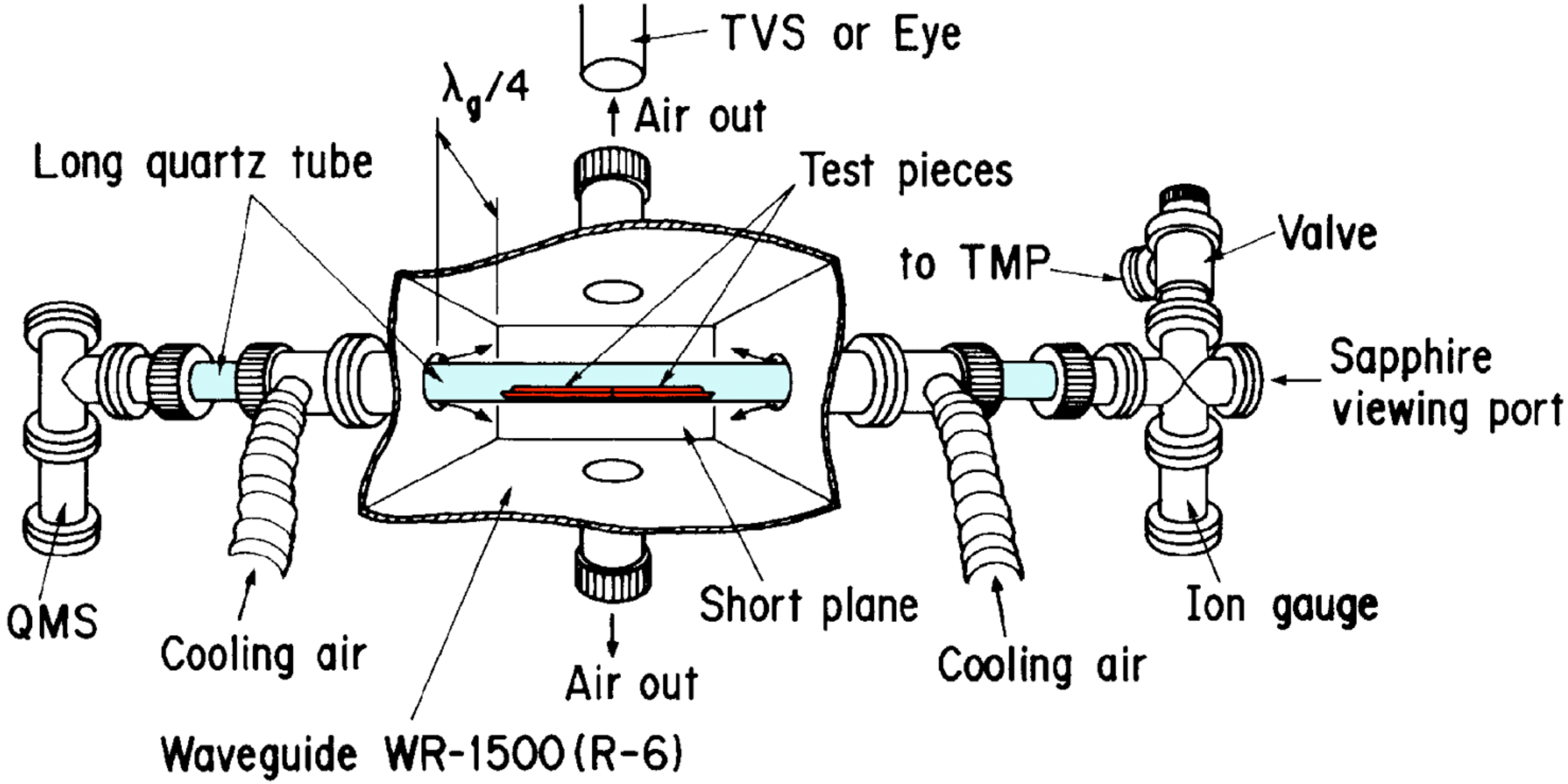


Experiments performed with Yasunao Takeuchi, KEK.

Klystron P_O fed through Y shaped circulator and 100% reflected by WG short.

Ceramic tube or quartz tube placed at antinode position of WR1500 (R6) WG.

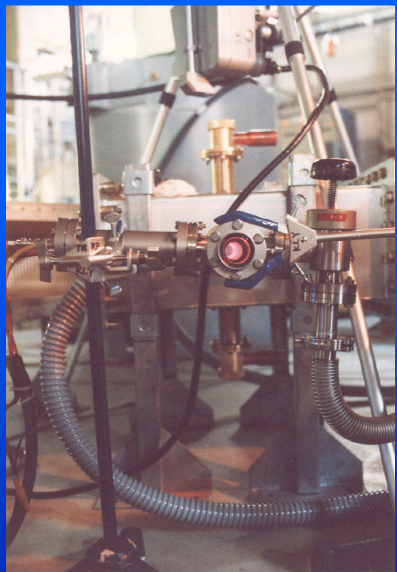
Small ceramic samples exposed to rf field in a quartz vacuum tube.



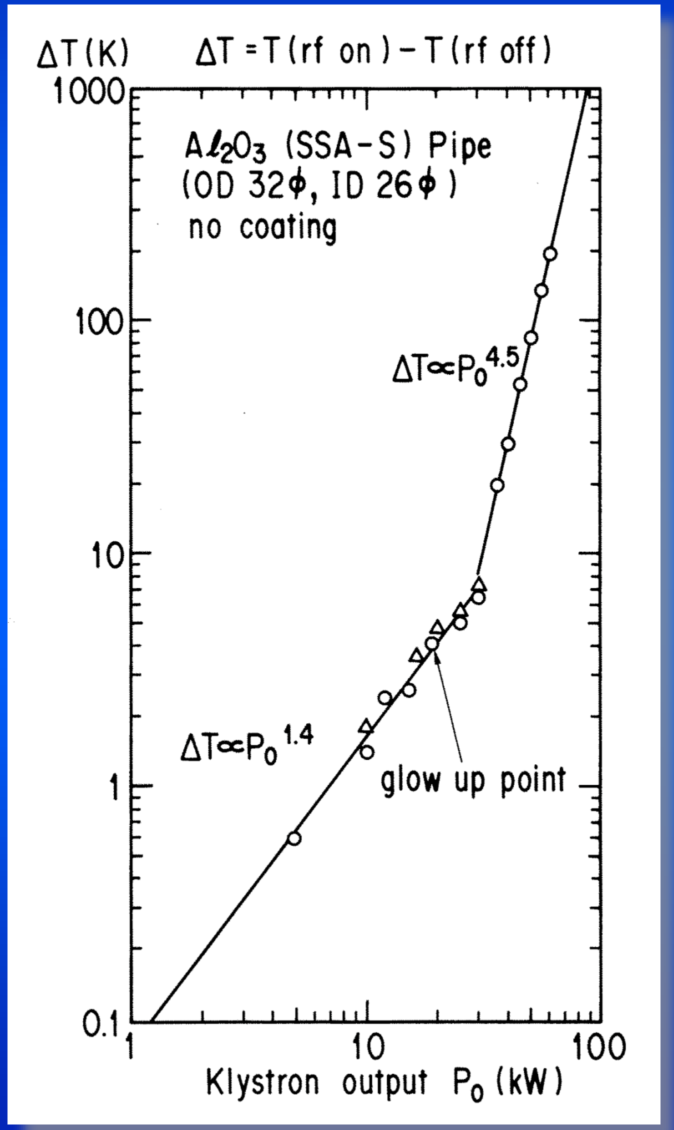
One can observe the tube and measure T from the top.
One can also observe the inner view of the tube from the side viewing port made of sapphire.

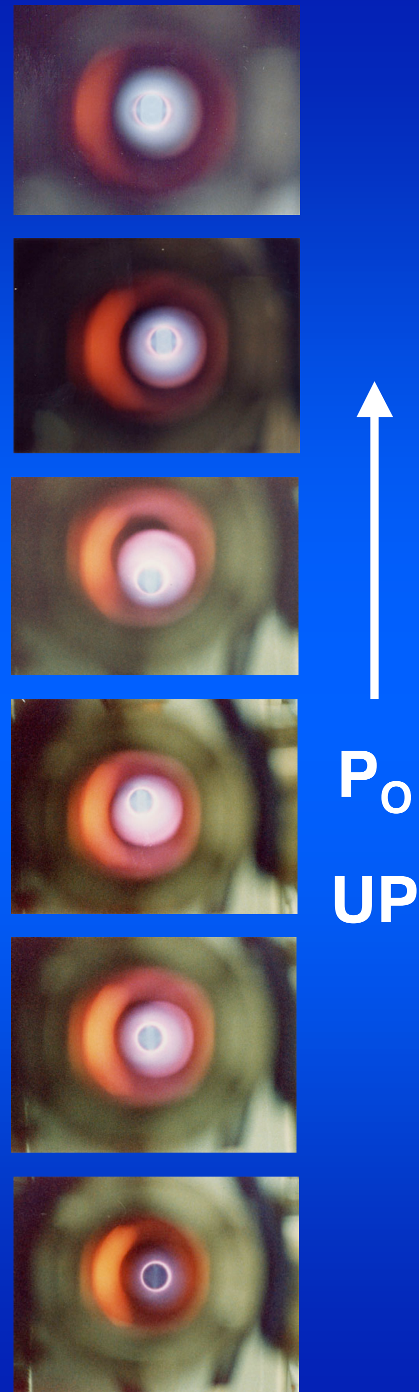
Temperature Increase Due to Multipactoring Caused by Large δ of Al_2O_3.

Ceramic tube broken.

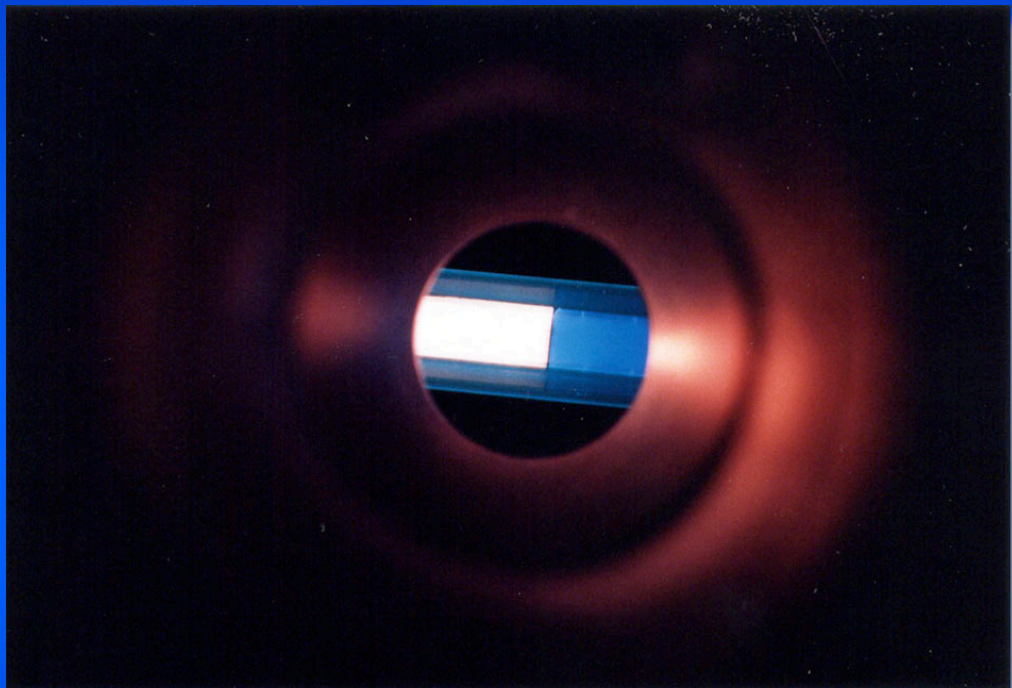


T measurement and side view of plasma.





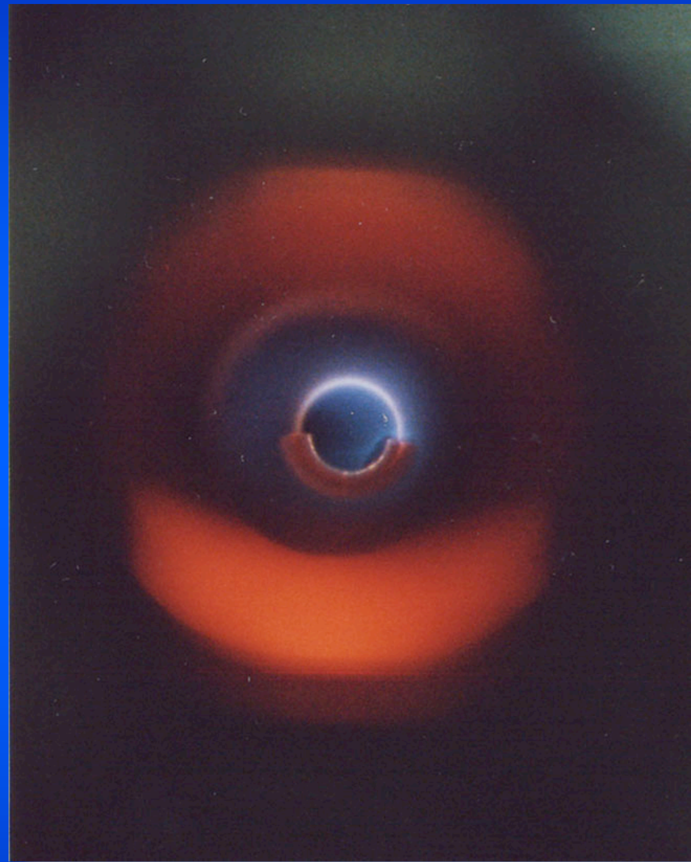
Suppression of Multipactoring by TiN Coating.



Left sample
Al_2O_3
without coating
(NC)

Right sample
Al_2O_3
with 120 Å TiN

P_O 50 kW、 P 3.2 x 10^{-6} Torr



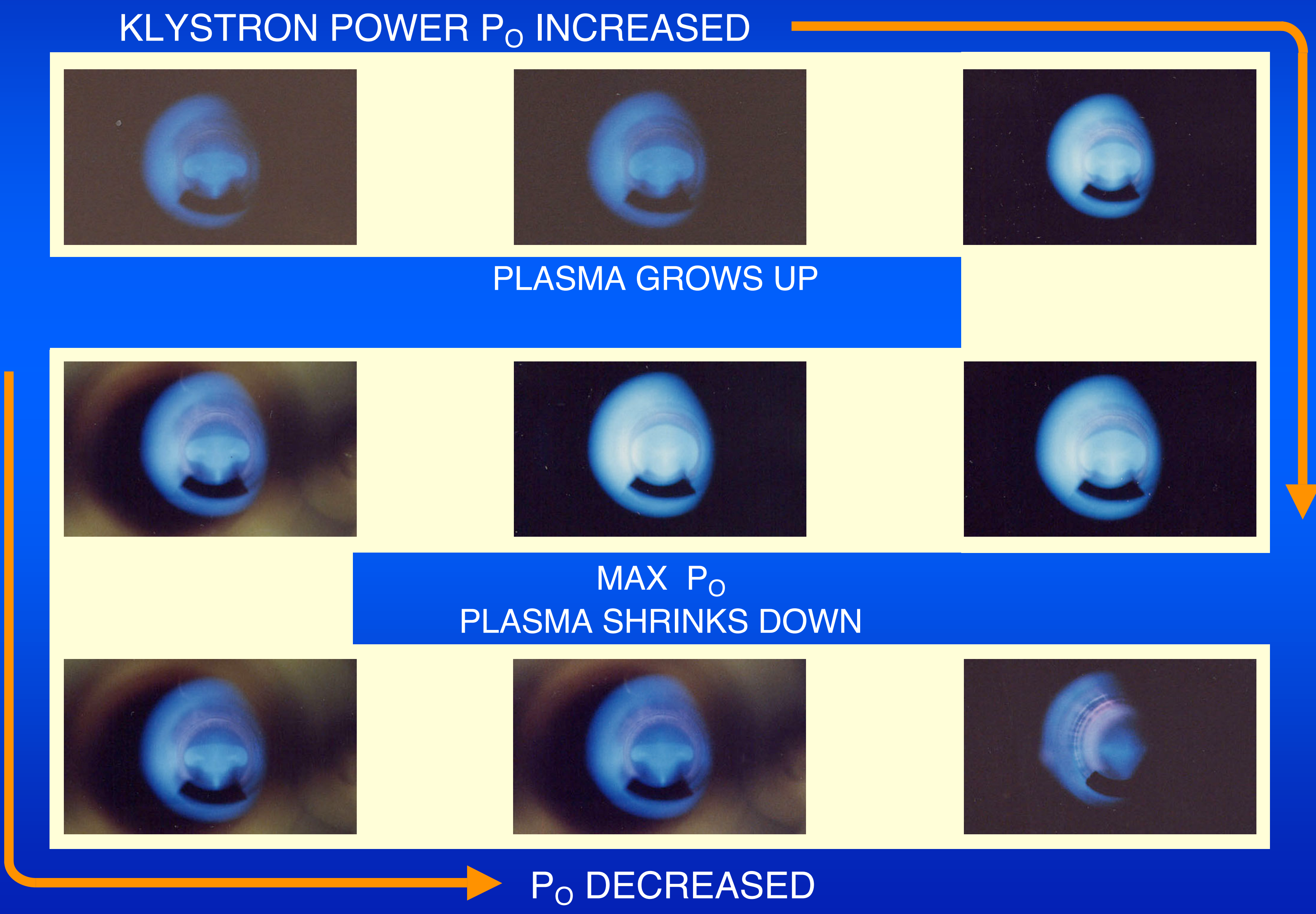
Left
100 Å TiN

vs

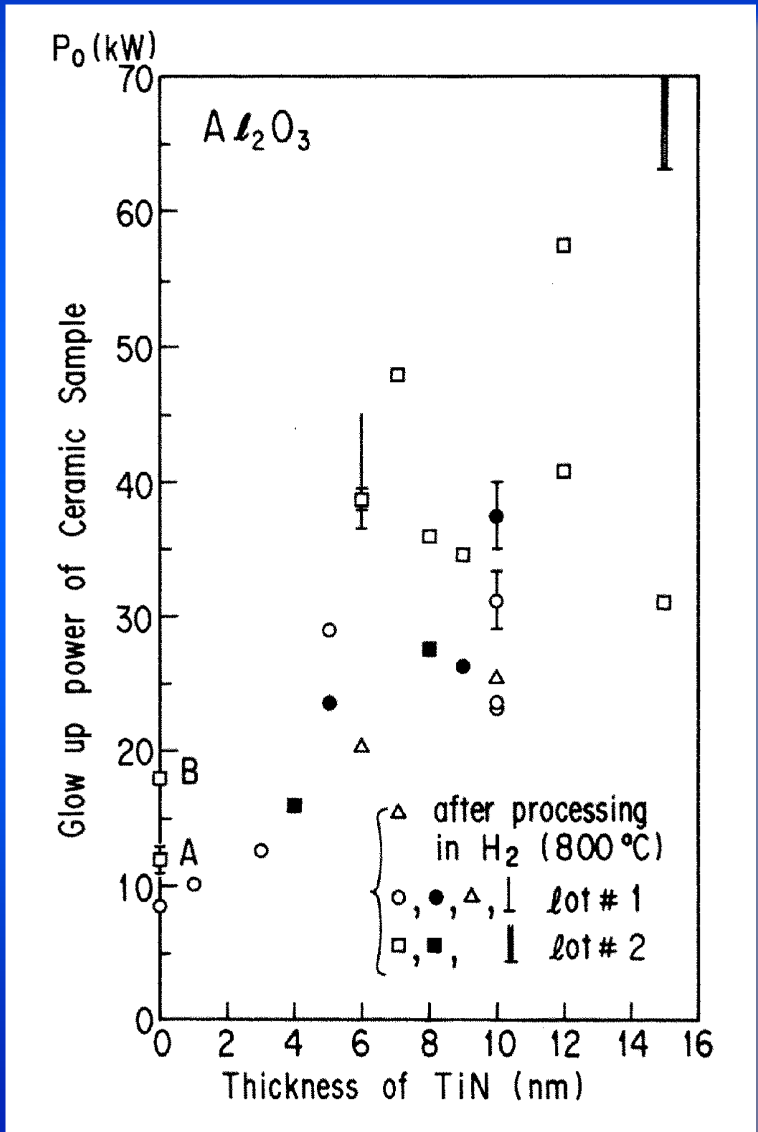
Right
NC

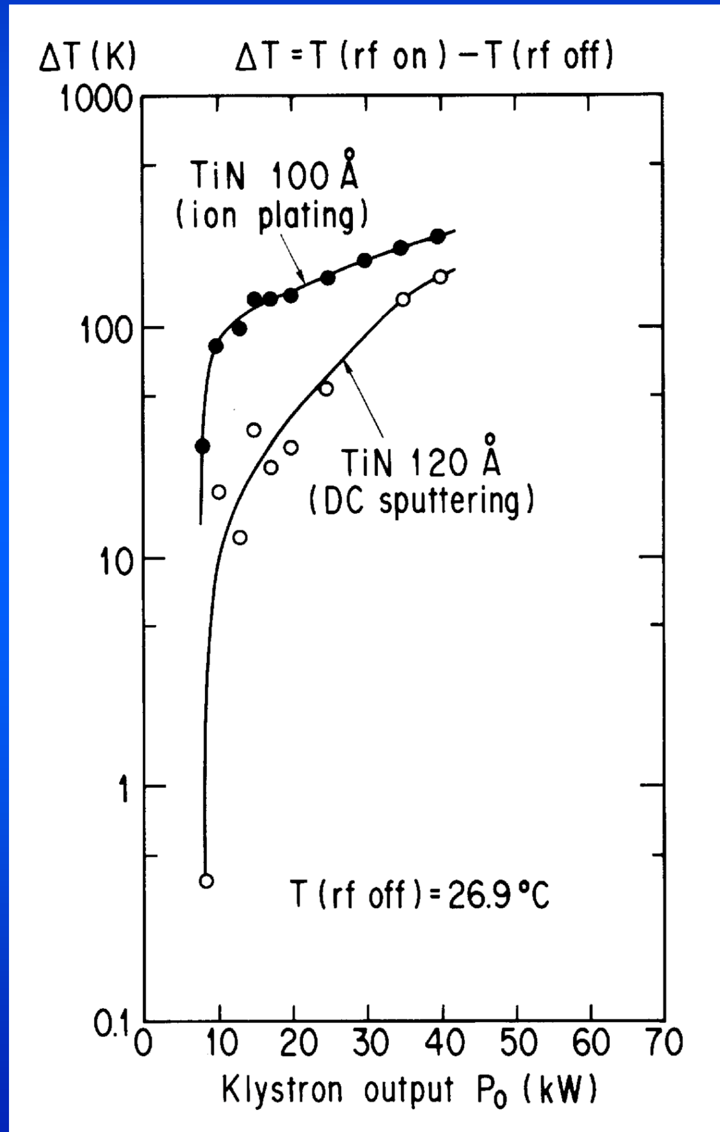
P_O 25.7 kW

Inner View of The Quartz Tube from The Side Viewing Port Made of Sapphire. Alumina Samples are Installed Inside.

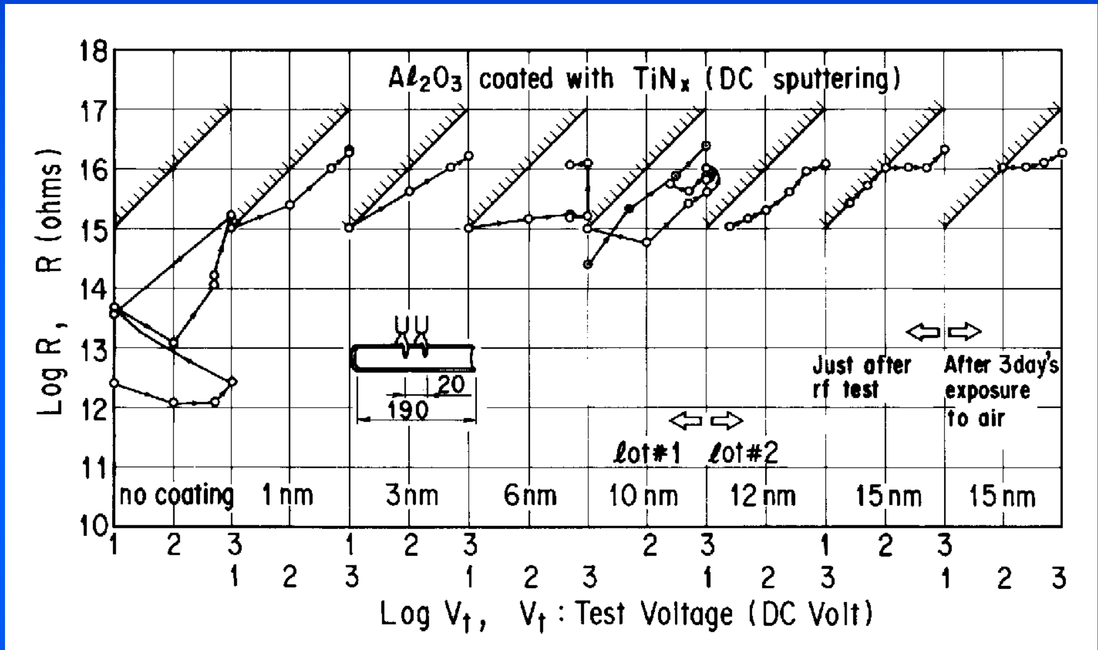


Optimum Coating Method and Optimum Thickness Determined by Bench Test.





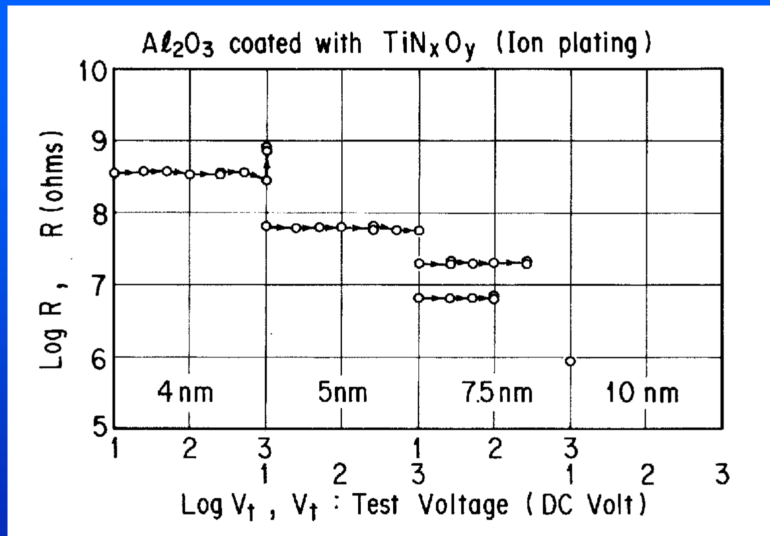
In Parallel, Measurements Were Also Made on DC Resistance of Standard Shaped Samples.



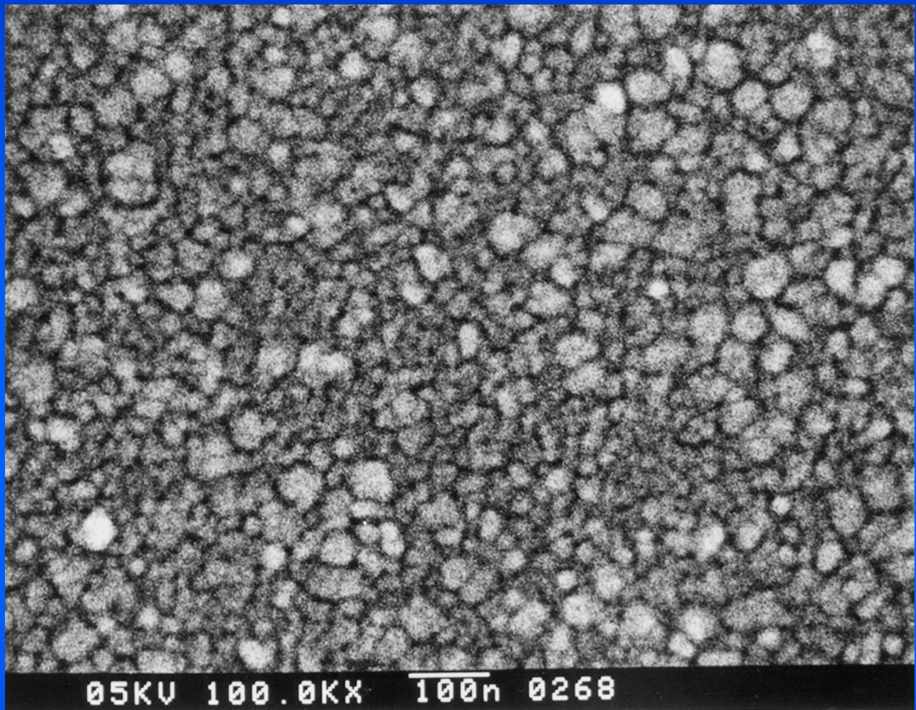
TiNx (more precisely speaking, TiNxOyCz)

e.g. x : 1.1, y : 2.3, z : 1.9

Oxygen intentionally added during plating.

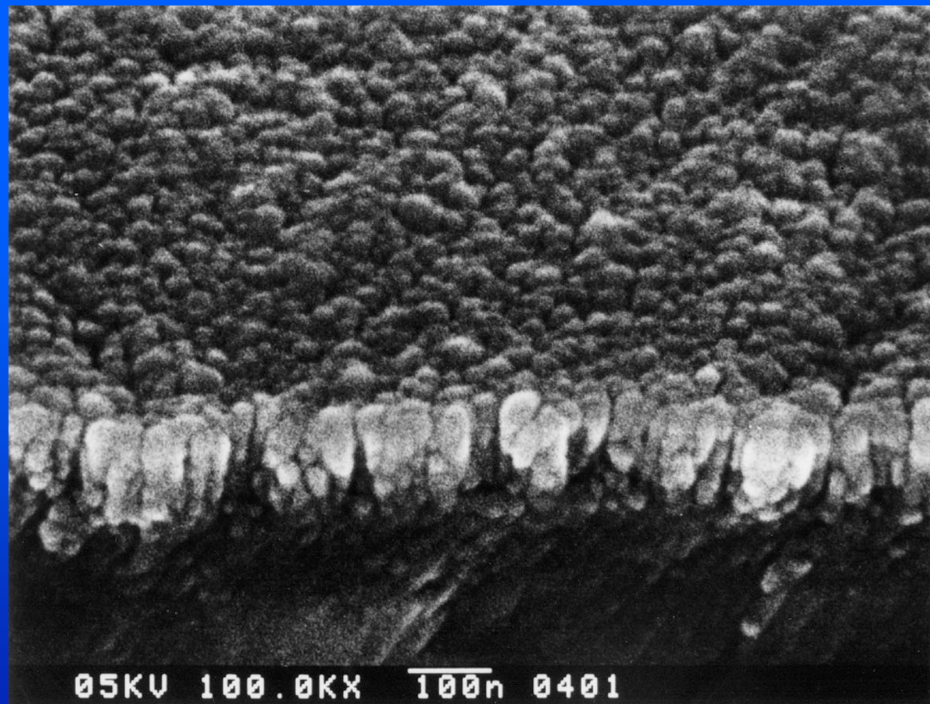


SEM Photos of Microscopic Structure of Our TiNxOy Films Coated on Al_2O_3 Substrates.



Very high resistivity is ensured by oxygen rich grain boundary layers of TiNxOy.

TiN grows up in island or columnar Form.

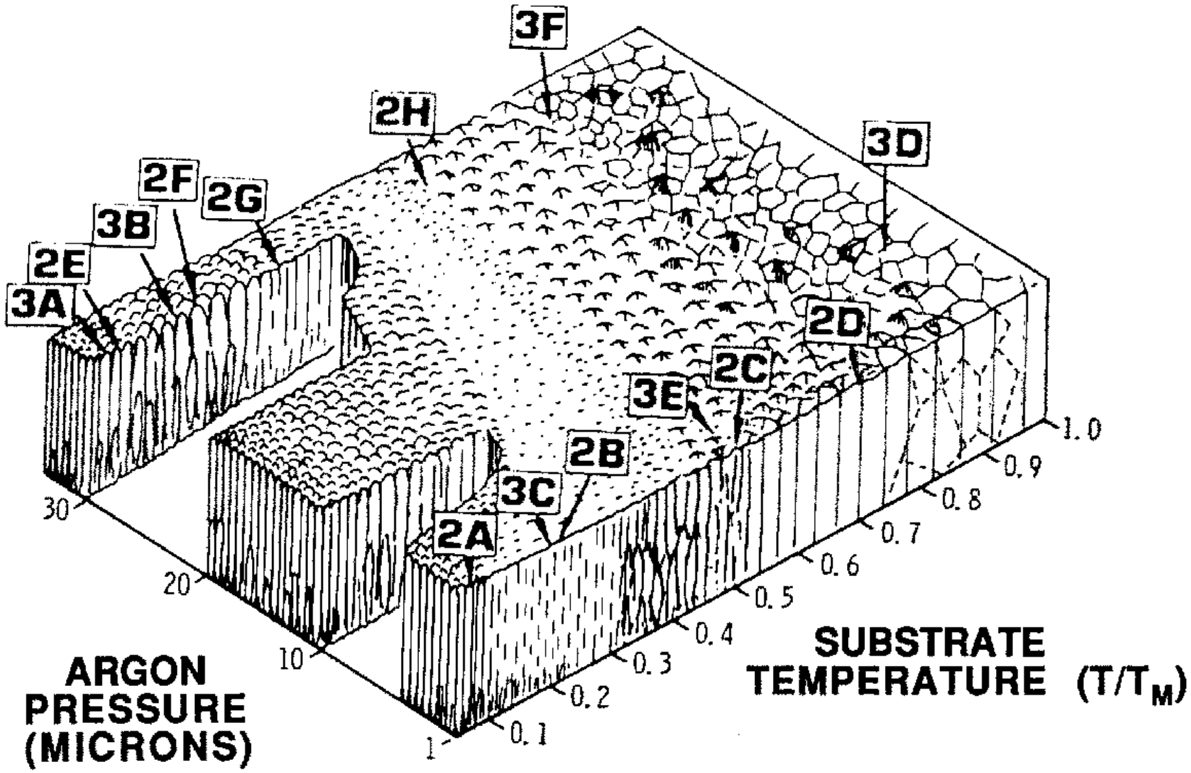


Important Points about Anti-Multipactoring Coating :

1) Quality of film depends on equipment as well as method of coating. Samples made by DC reactive sputtering in HVac always superior to those by ion plating performed in oilless UHV system.

2) TiN_xO_y is one of the best materials. R is very high and even increases with thickness and with exposure to rf field. Pure TiN is rather worse because of its high metallic conductivity.

3) Optimum thickness for UHF use is 50~300 Å. The thicker, the better if it's below 150 Å . 60 Å is adopted for input couplers and T-tubes. 100 Å tried for V-tubes (KEK and LEP) and excellent results obtained, too.



Schematic representation of dependence of coating structure on substrate temperature and argon pressure.

(Movchan - Demchishin - Thornton Model)

J. A. Thornton, J. Vac. Sci. Technol. 11, 666 (1974).

The effect of H_2 processing (800°C, 10min) on glow up point (P_0 in kW)

Specimen	Before processing	After processing	After rf aging
60Å TiN_x	≥ 36.2	18.7	20.3 ± 0.2 (rf 67min, max 45.3kW)
100Å TiN_x	23.3 ± 0.1	22.0	25.1 (rf 208min, max 60kW)
30Å CrO_x	28.0	21.5	21.5 (rf 77min, max 45.2kW)
50Å CrO_x	35.5 ± 2.5	20.7	21.0 (rf 100min, max 50kW)

RF aging is effective on TiN_x coating, but not on CrO_x coating.