# Properties of field emission dark current from Molybdenum and Titanium electrode


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# Background

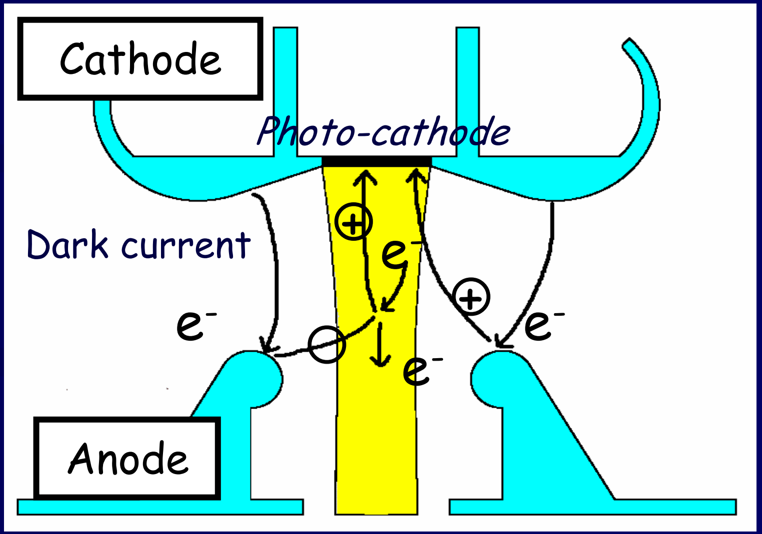
1) *For protection NEA surface from ions & molecules*

NEA surface is delicate and easily destroyed by small disturbances

Requirement

Base pressure < $10^{-9}$ Pa

Dark current < 10 nA



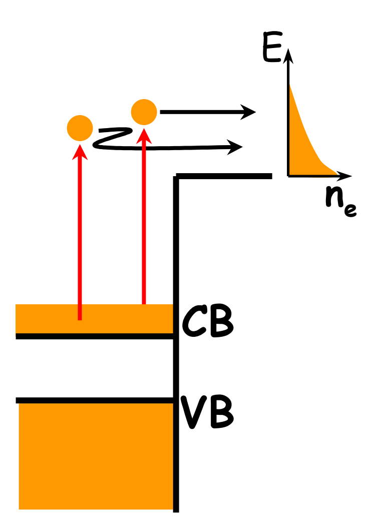

2) *For production of low emittance beam.*

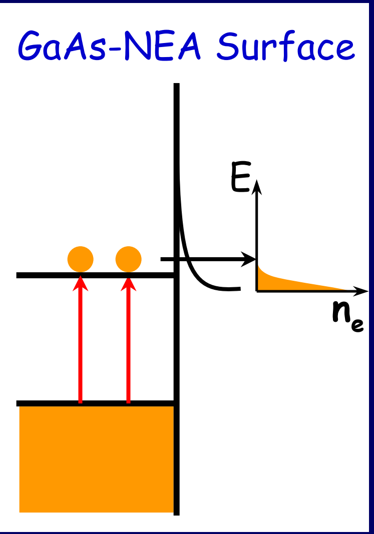
The initial emittance of electron beams extracted from NEA surface is very low.

For suppression of space charge effect …

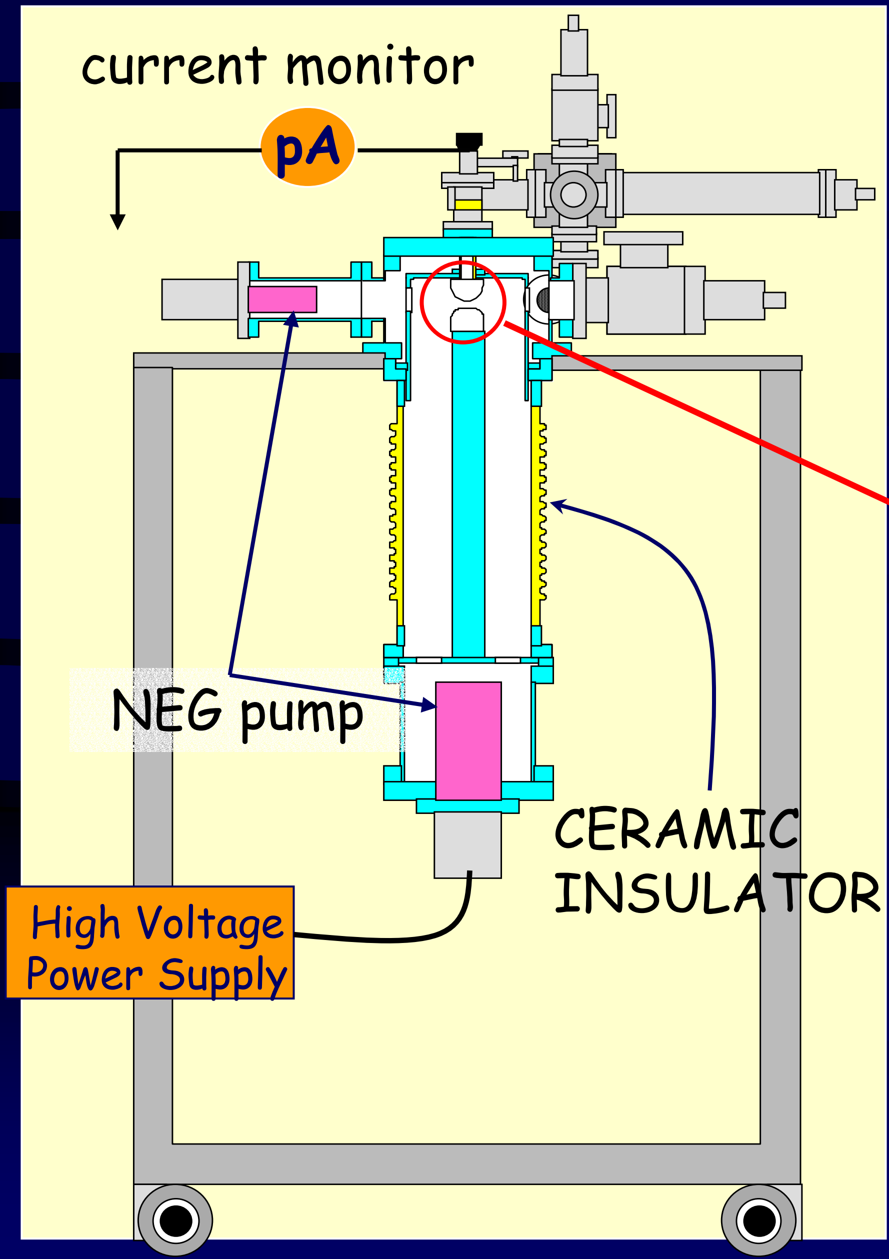
High Voltage ~ 500 kV

High field gradient ~ 10 MV/m



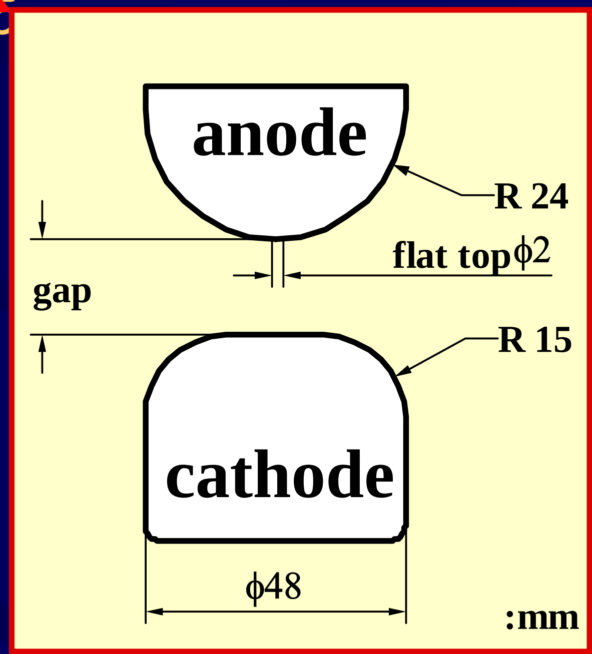



# High Field Gradient Test Stand




## Features

- Maximum field area : ~ 7 mm$^2$
  @Cathode surface
- Gap separation : 0～20 mm
- Base Pressure : ～ 7×10$^{-10}$ Pa
- HV power supply : ~ DC -100 kV
  ~ 200 MV/m
  @0.5

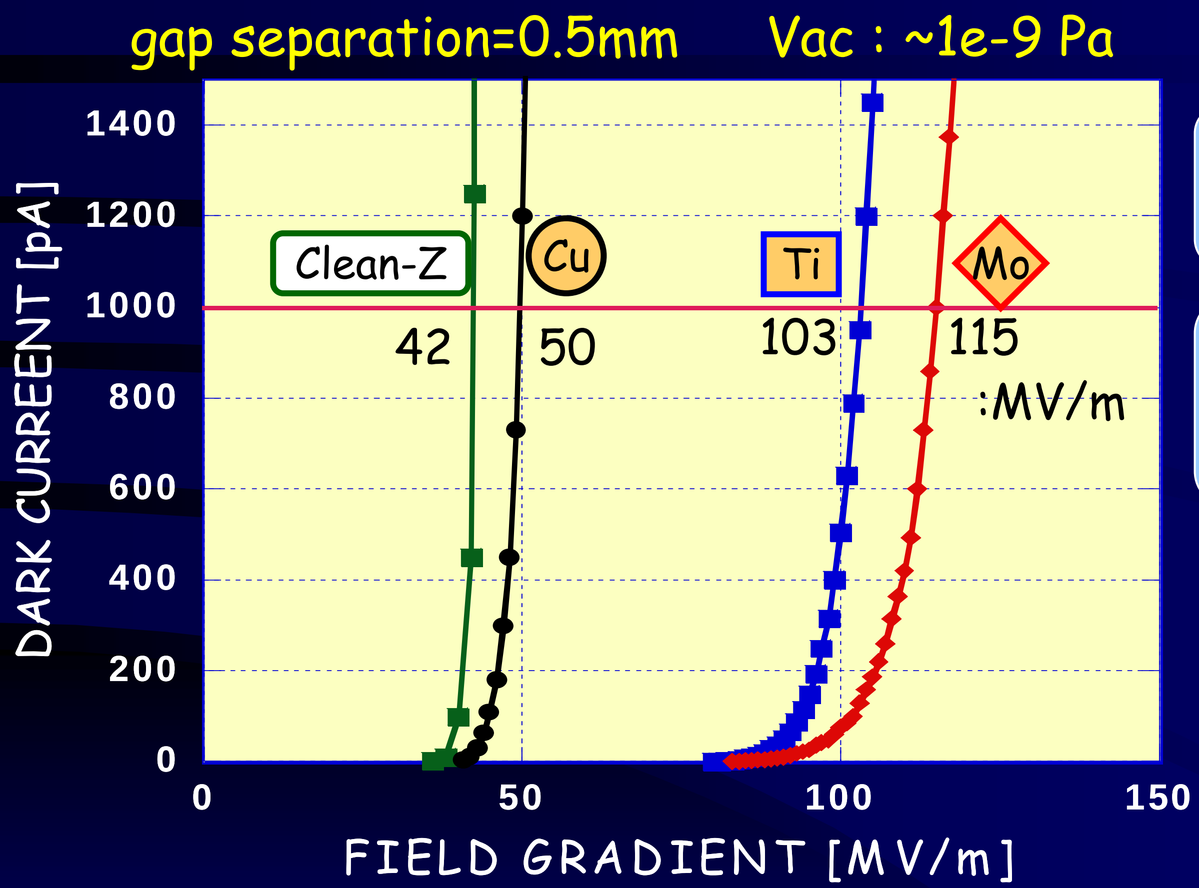


# Preparation of Electrodes

| Material | Surface | Rinsing | Ra |
|---|---|---|---|
| pure-Ti (JIS grade-2) | Buff polishing | HPR* (80 kg/cm$^2$、5 min) | < 0.1 $\mu$m |
| Mo (poly-crystal 5N) | Diamond paste Buff polishing | HPR (80 kg/cm$^2$、5 min) | < 0.1 $\mu$m |

*HPR: high pressure ultra-pure water rinsing


# Dark Current Dependence (Electrodes Material)




Researched materials

Clean-Z (Re-Melted SUS316L)
Electro-buff polishing

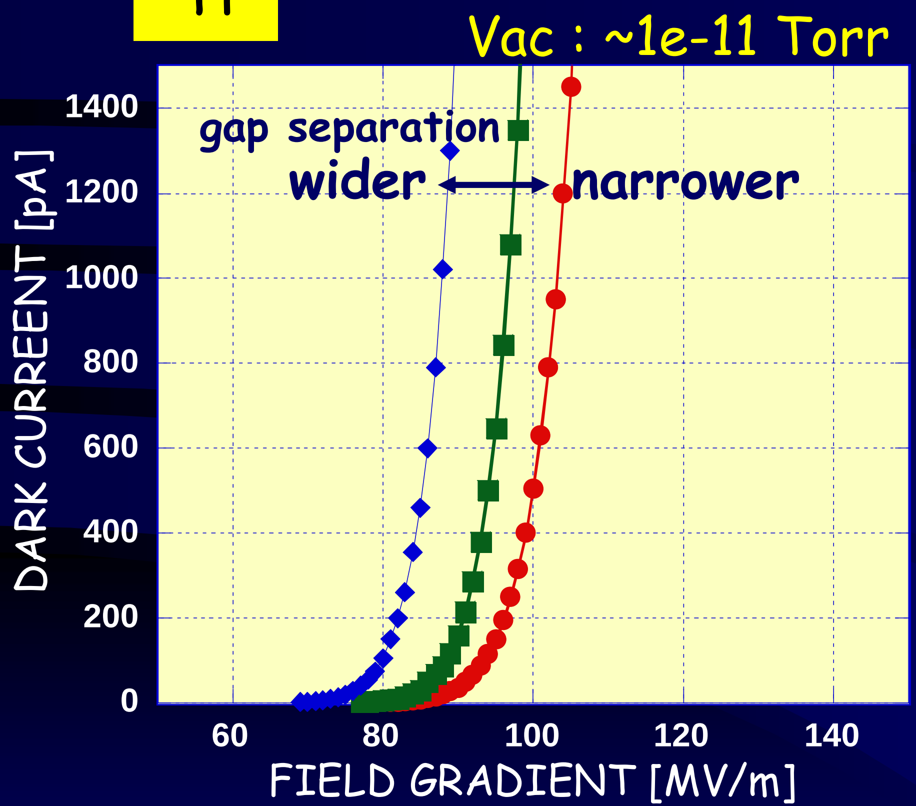
Copper (OFHC)
precision diamond machining
( no polishing )

Ti and Mo
Only (diamond) buff polishing

# Dark Current Dependence of Gap Separation

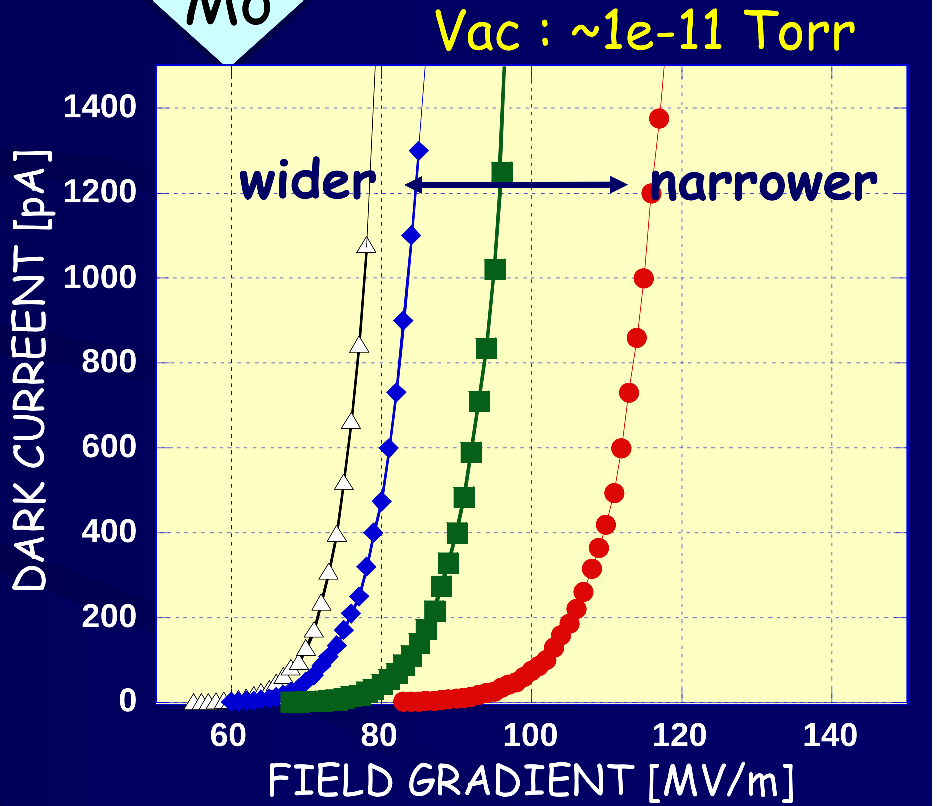
Gap separation: (●) : 0.5mm, (■) : 0.75mm, (◆):1.0mm, (▲):1.25mm

Ti




Ti is less sensitive for gap separation

Mo

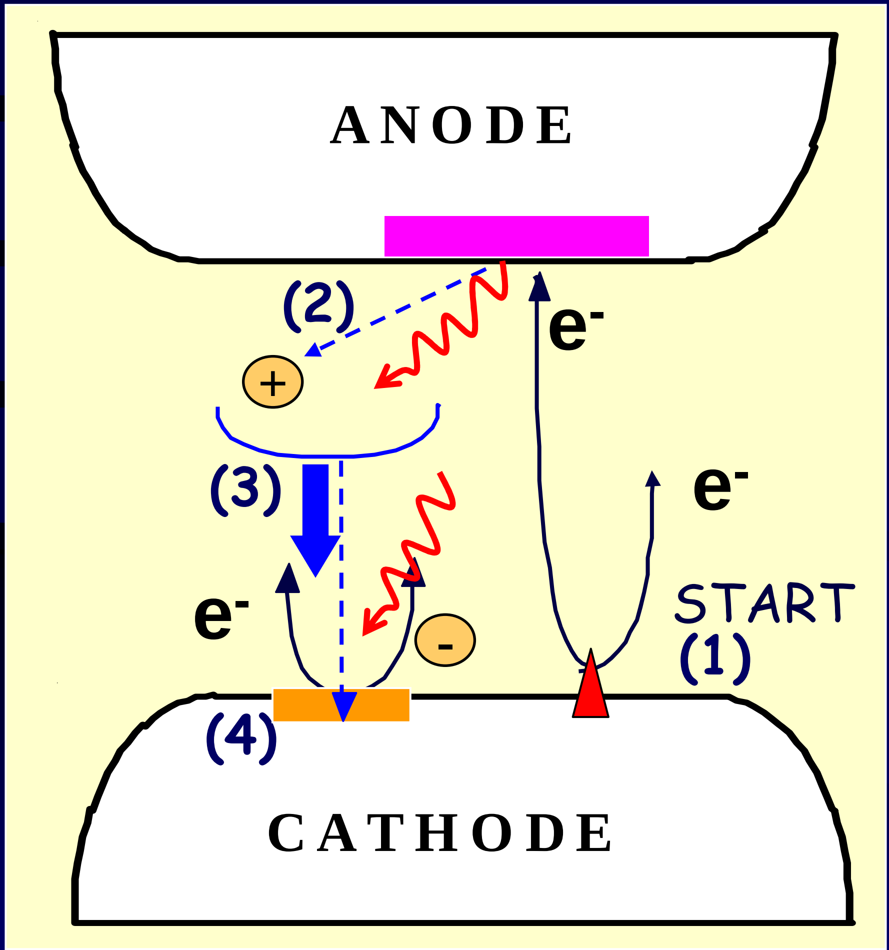



Mo is more sensitive for gap separation

# Enhancement of Field Emission Dark Current

Dark current = Primary field emission + Enhanced emission

F-N theory




**(1)** Primary field emission

**(2)** Production of ions a part of stimulated molecules, X-ray by electron bombardment

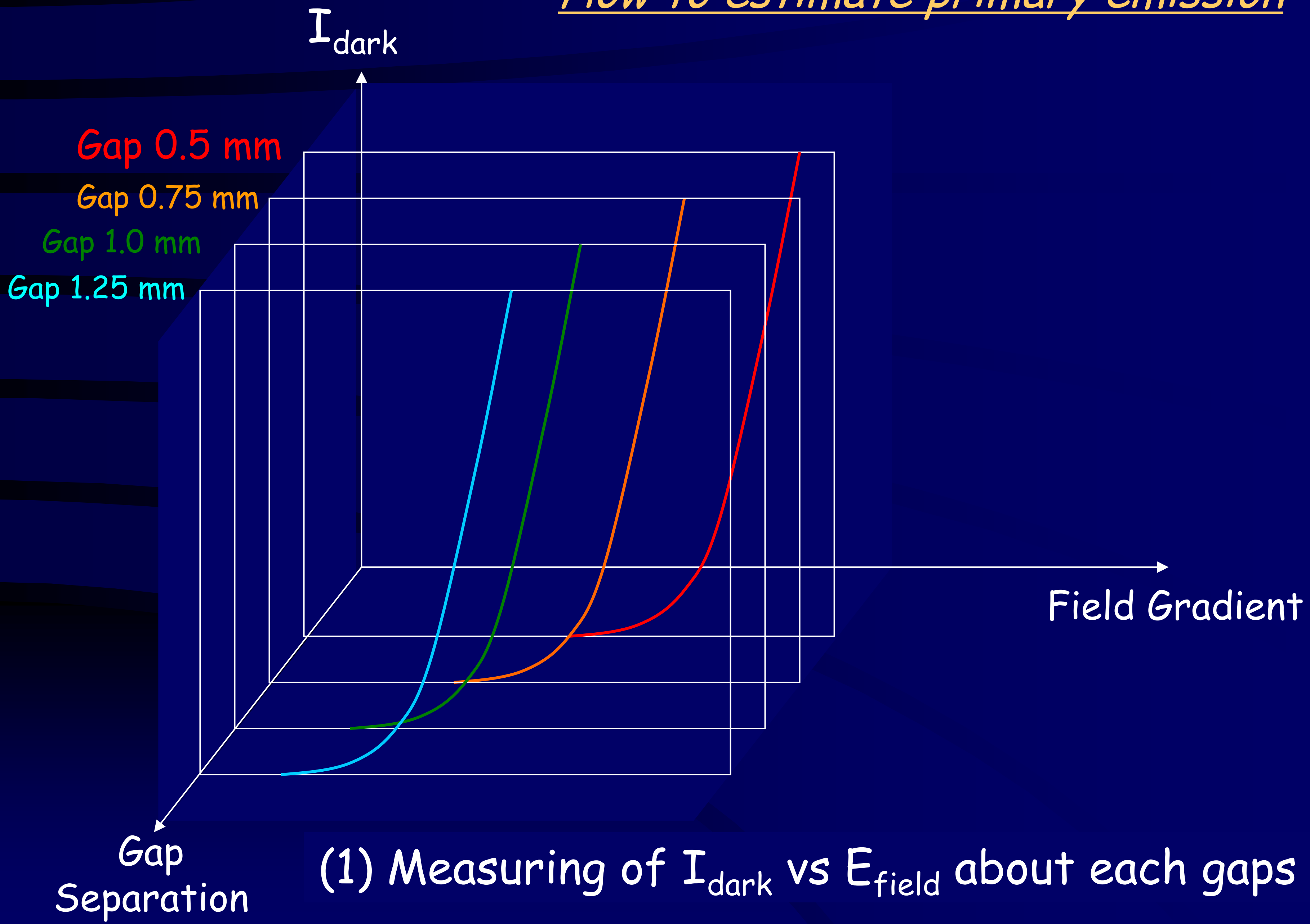
**(3)** Ion Back bombardment, incidence of X-ray to the cathode

**(4)** Secondary electron emission

Feedback

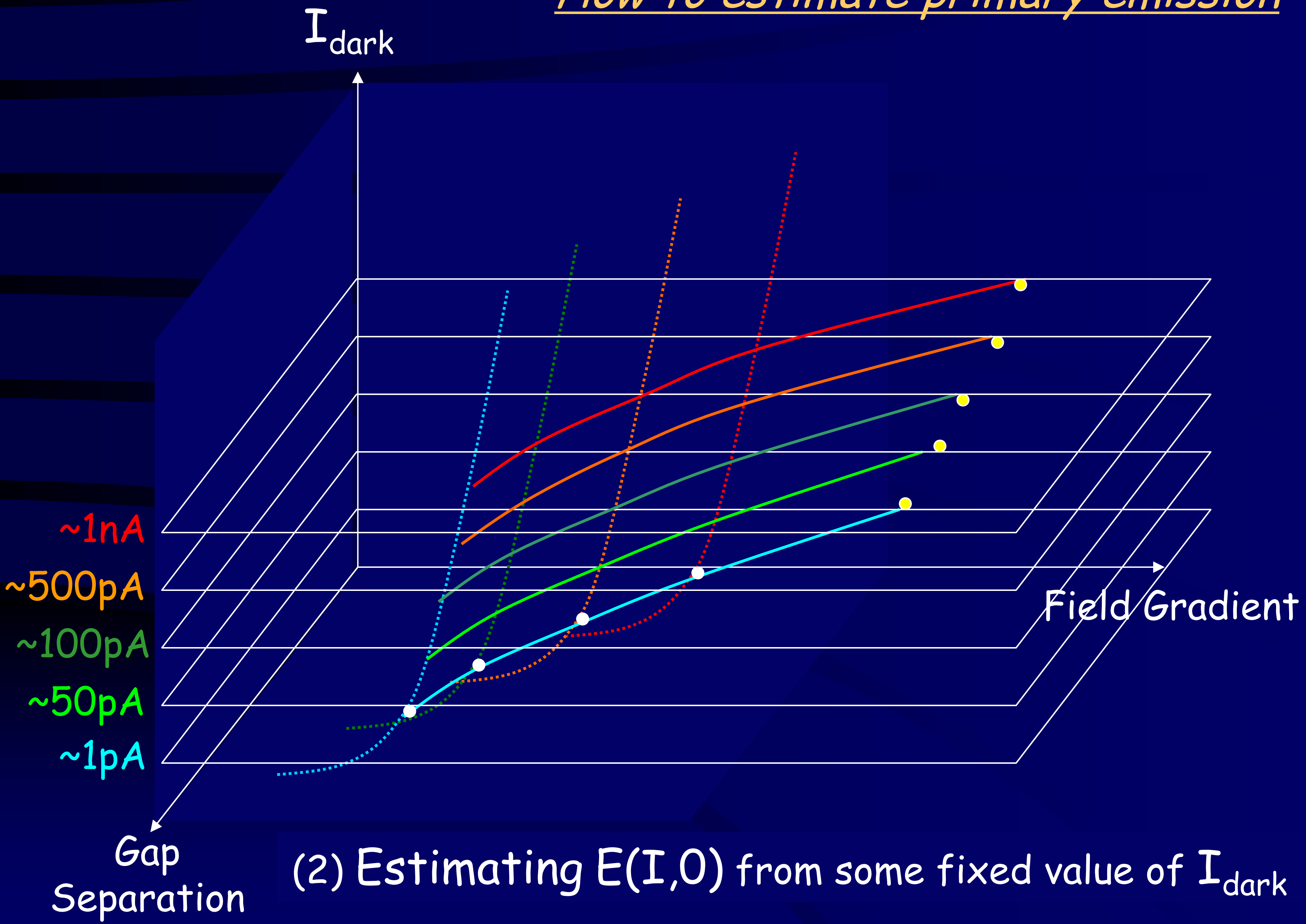
Enhancement effects are influenced by acceleration voltage

# *How to estimate primary emission*



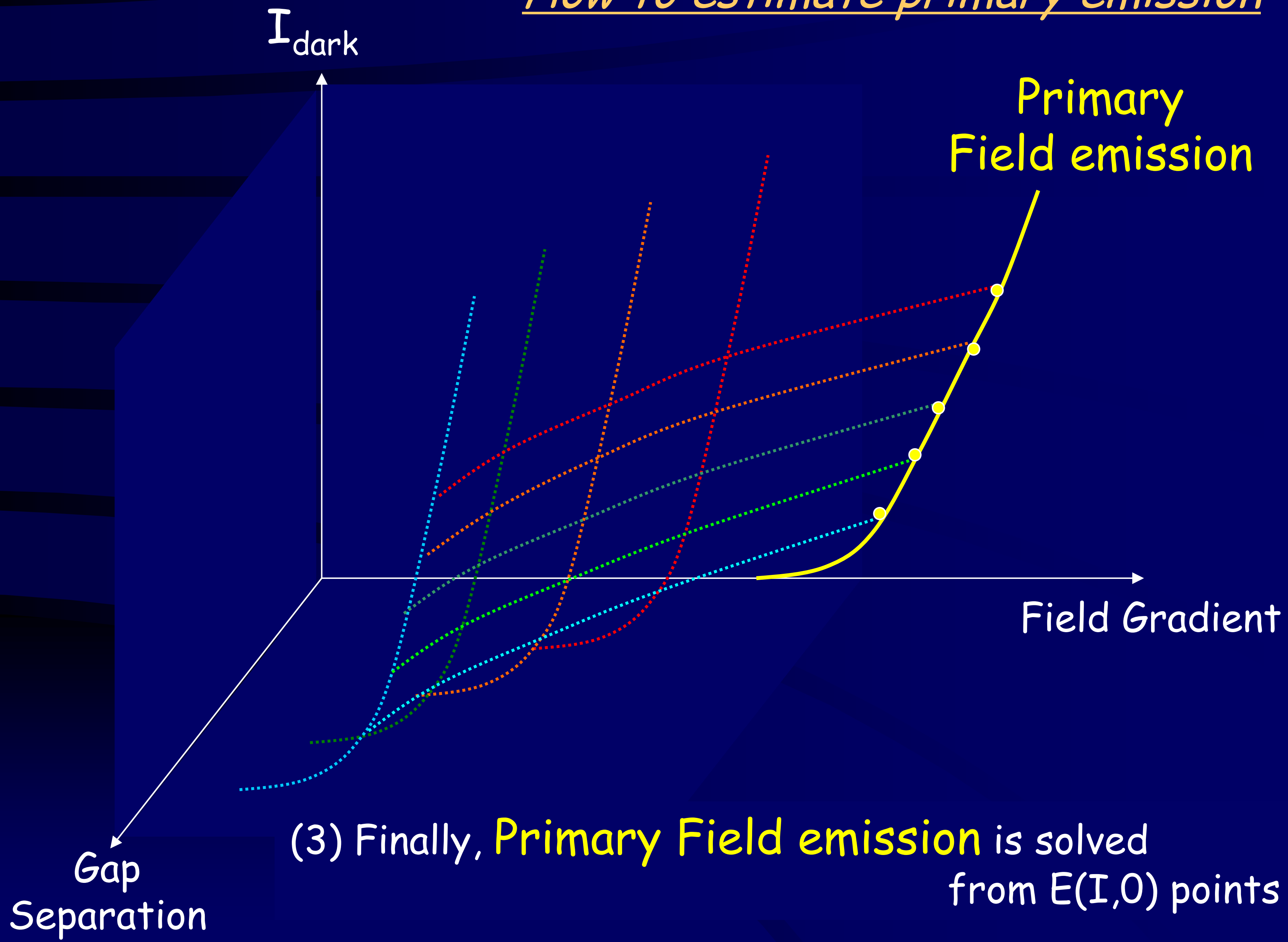

(1) Measuring of $I_{dark}$ vs $E_{field}$ about each gaps

# How to estimate primary emission




(2) Estimating E(I,0) from some fixed value of $I_{dark}$

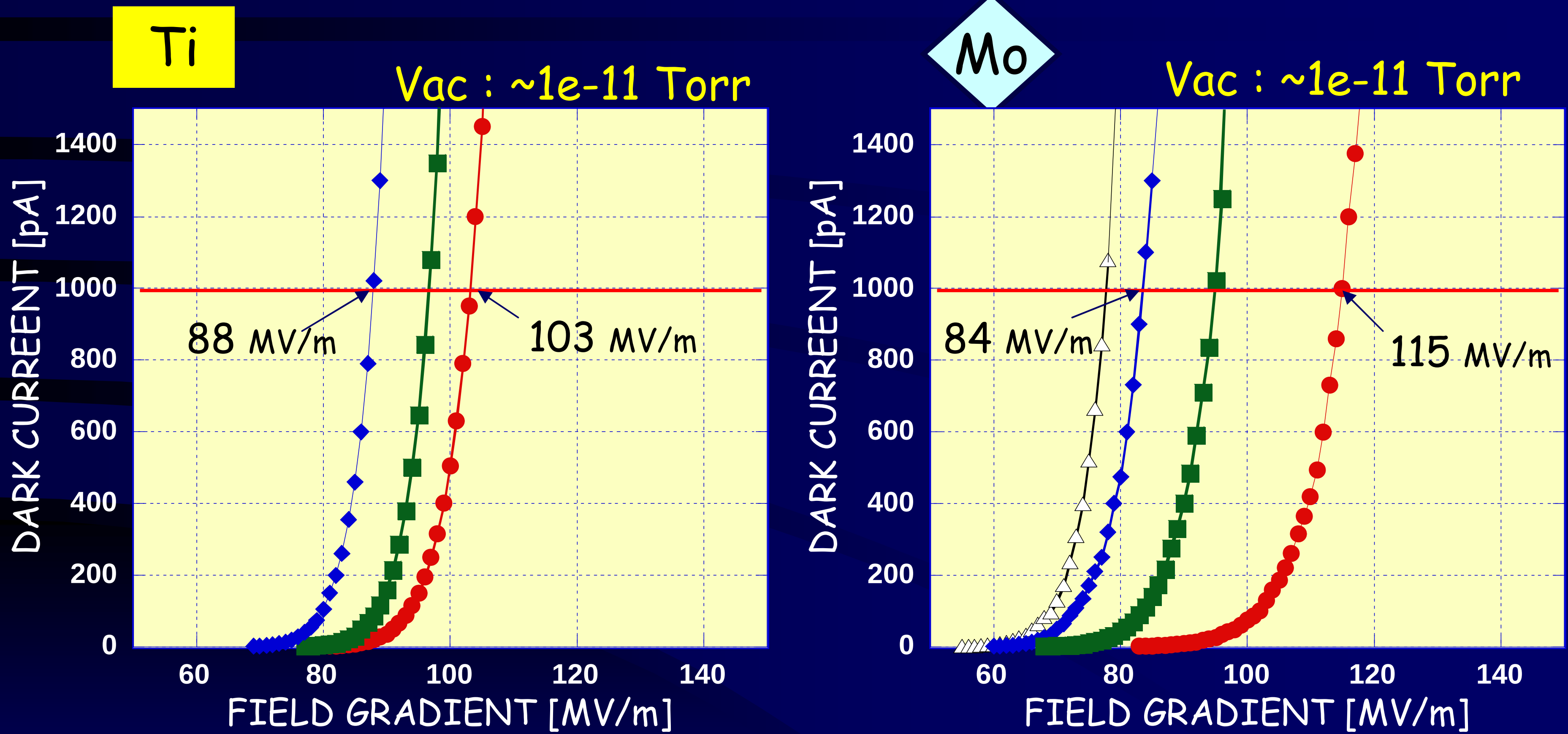
# How to estimate primary emission




(3) Finally, Primary Field emission is solved from E(I,0) points

# Dark Current Dependence of Gap Separation

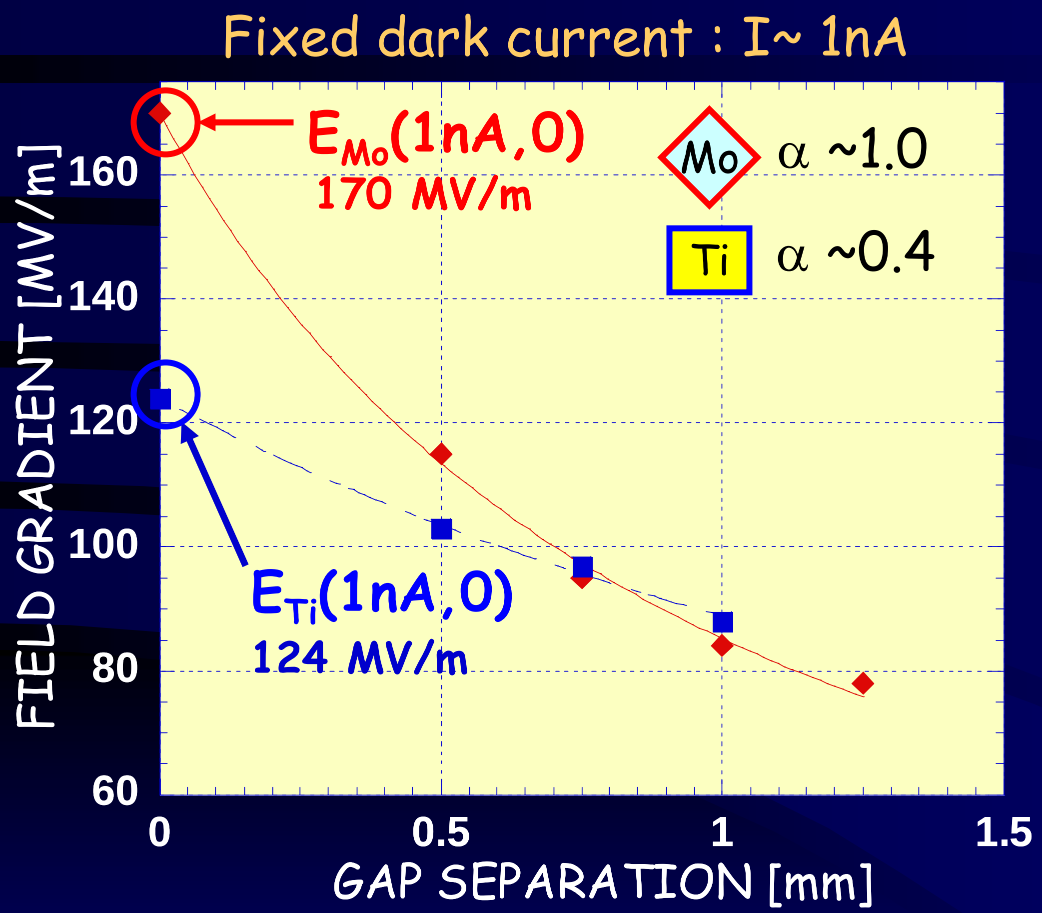
Gap separation: (●) : 0.5mm, (■) : 0.75mm, (◆):1.0mm, (▲):1.25mm




Ti is less sensitive for gap separation

Mo is more sensitive for gap separation

# Separation of Primary Field Emission from Total Dark Current



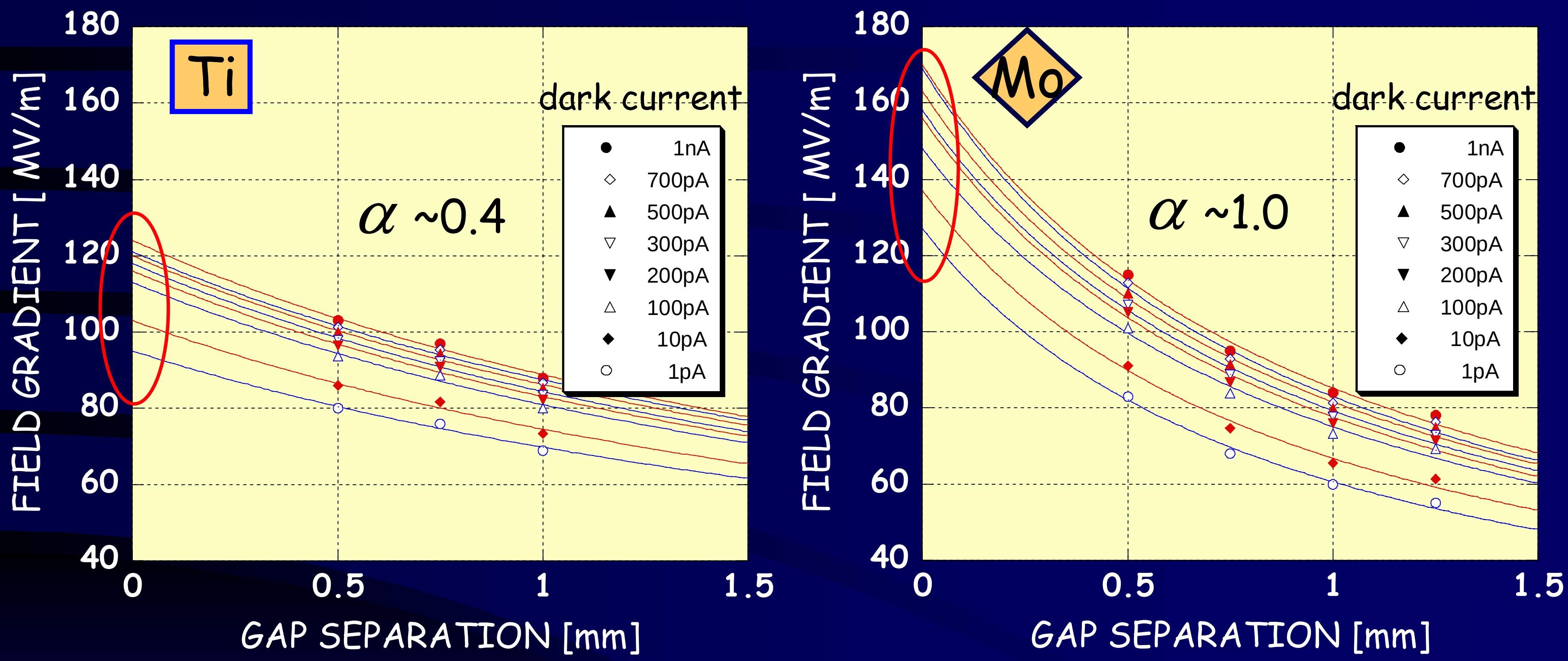

Fixed

$$E(I,d) = \frac{E(I,0)}{1 + \alpha \cdot d}$$

d: gap separation [m]
I: dark current [A]
$\alpha$ : gap coefficient [$m^{-1}$]

$\alpha$ value is related to the enhancement effect

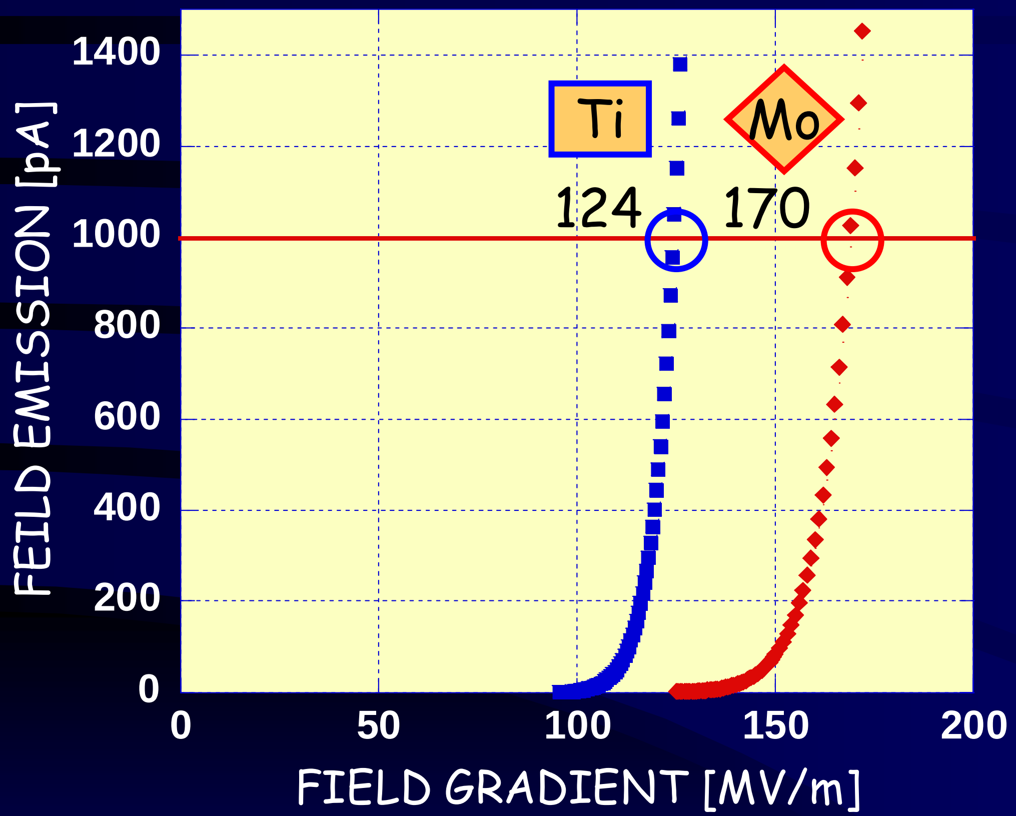
# Separation of Primary Field Emission from Total Dark Current




Enhancement factor α is hardly depended on the dark current values

→ α is peculiar to material properties ?

# Result of Primary Field Emission



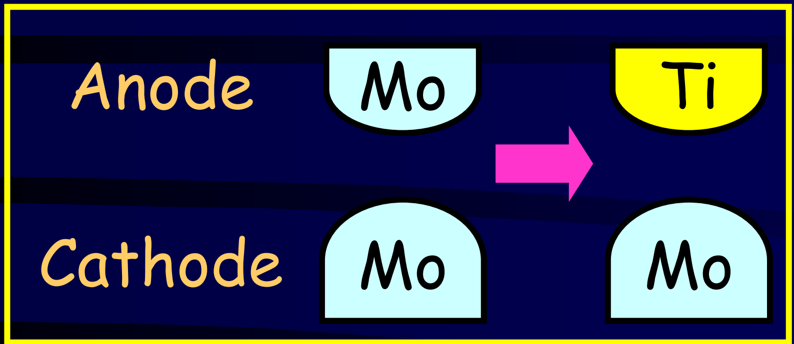

Primary field emission vs. field gradient

| | Ti | Mo |
|---|---|---|
| α | 0.4±0.02 | 1.0±0.04 |

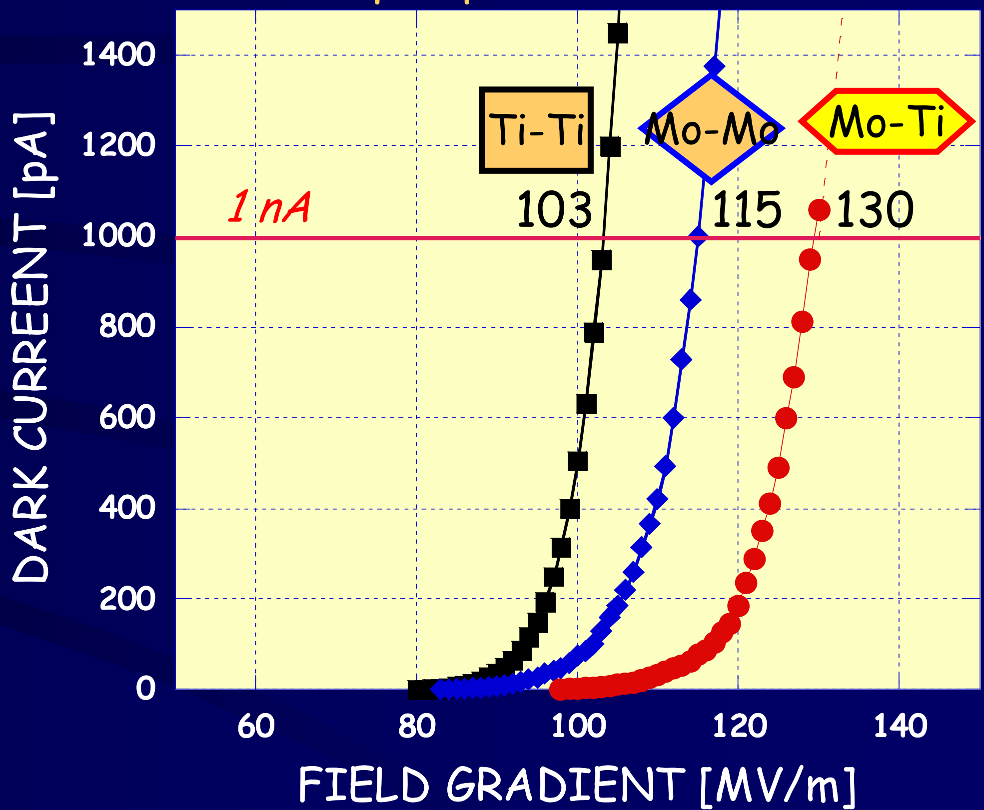
(1) Mo exhibits low primary field emission

(2) The enhancement effect is weak for Ti

# Performance of Mo cathode - Ti anode




Gap separation 0.5 mm




From the result of
Mo-Ti electrodes …

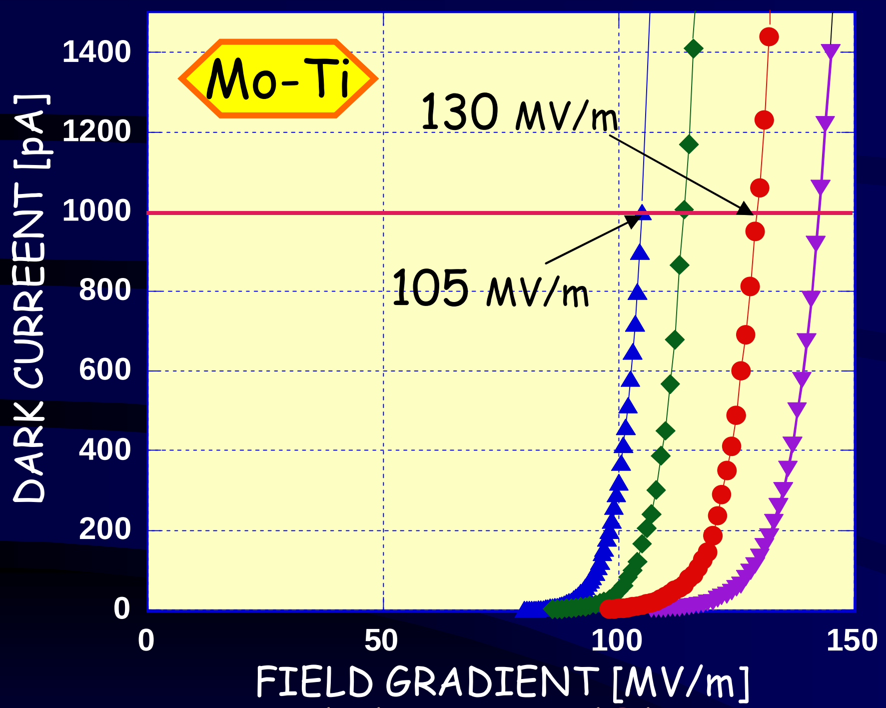
(1) Ti is good for anode material compared with Mo-Mo

(2) Mo is good for cathode material compared with Ti-Ti

The dark current was well suppressed by changing anode Mo to Ti

# Performance of Mo cathode - Ti anode

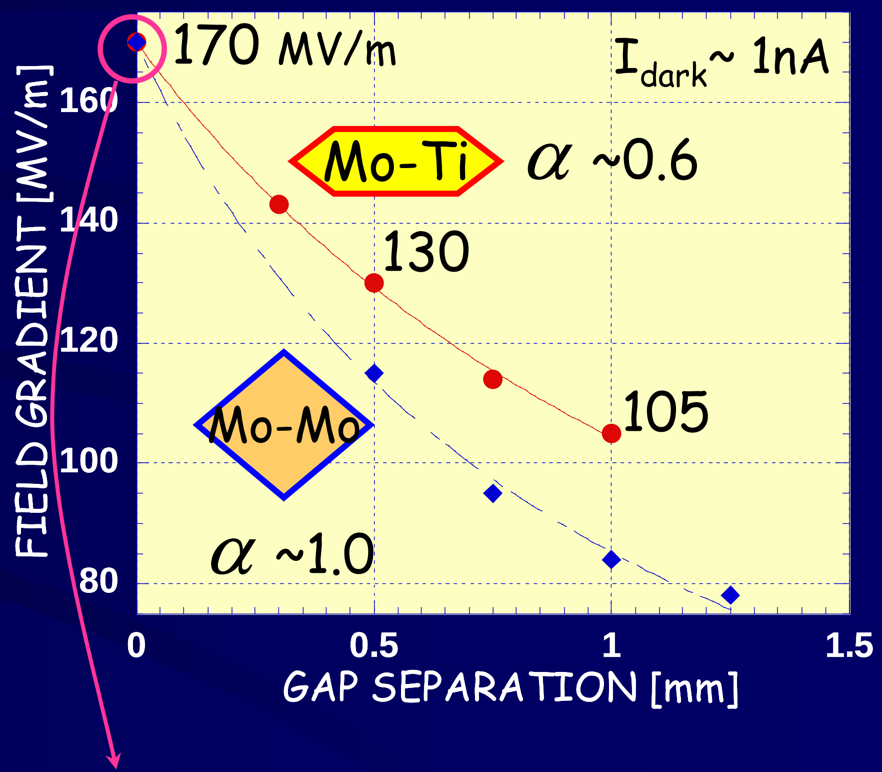
Dependence on gap separation




(▼) : 0.3mm, (●) : 0.5mm,

(◆) : 0.75mm, (▲):1.0mm,

Fitting and extrapolation of data points for Mo-Mo and Mo-Ti




Zero gap performance is only depended on a cathode condition

# Summary

The separation of the primary field emission from total dark current is possible by measuring dependence of gap separation.

| | ( cathode – anode ) Ti-Ti | Mo-Mo | Mo-Ti | |
|---|---|---|---|---|
| Primary field gradient* (MV/m) | 124 | 170 | 170 | *(I=1nA) |
| Gap coefficient $\alpha$ | 0.4 | 1.0 | 0.6 | Enhancement effect |

- Ti is good for suppression of enhancement emission.
- Mo is good for low primary emission.

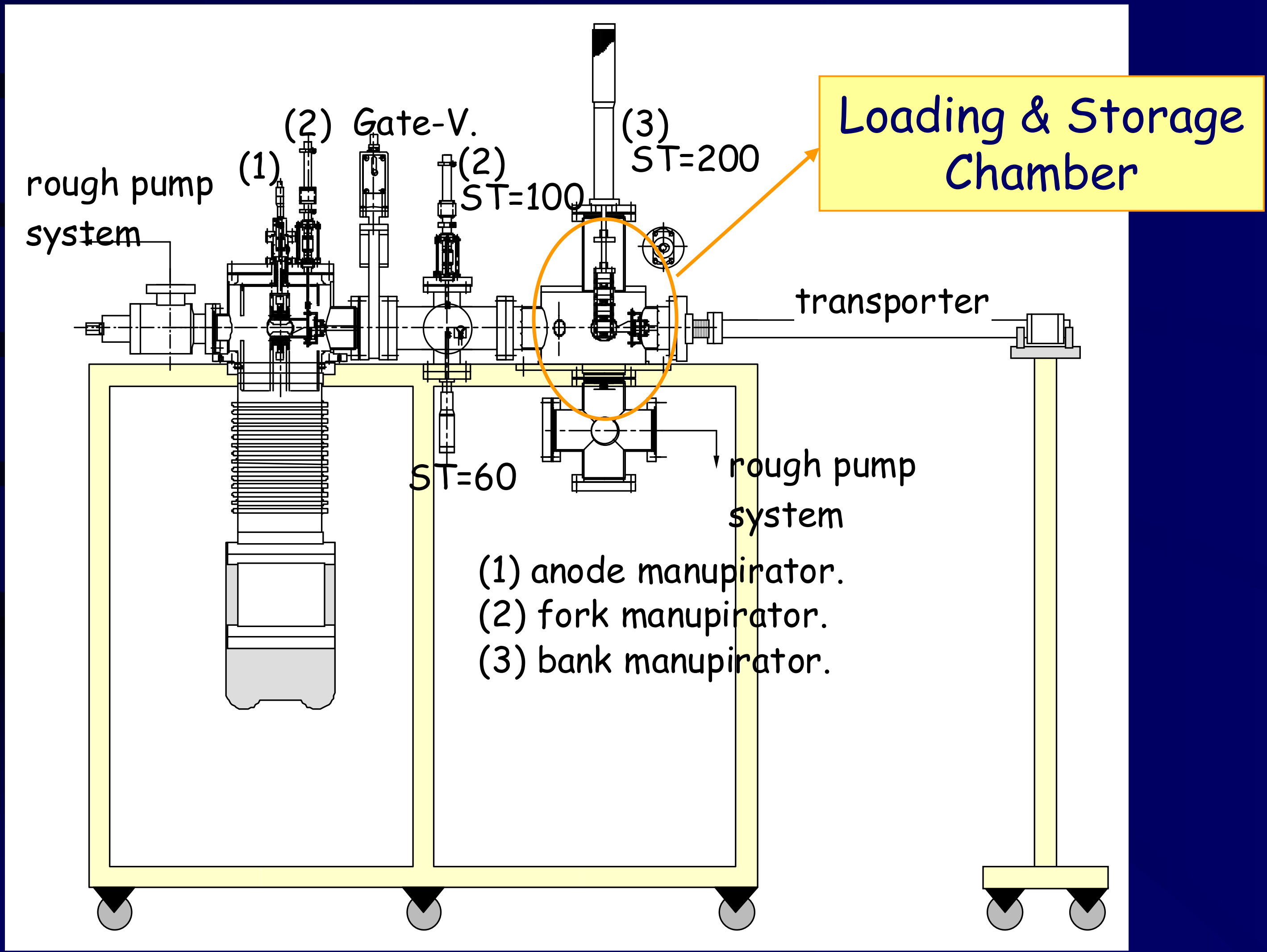
**Mo-Ti is the best configuration of reduction dark current.**

(cathode-anode)

The details will be published in N.I.M.-A after few month.

# Feature Plan

## New High Gradient test stand with a Load-lock System



# New High Gradient test stand with a Load-lock System