# Investigations of the Charge Limit Phenomenon in GaAs Photocathodes

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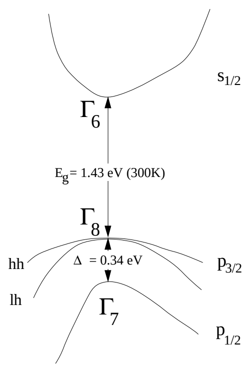
Outline:

Introduction
- Charge limit vs. doping concentration
- Polarization with high surface doping
- Possible solutions

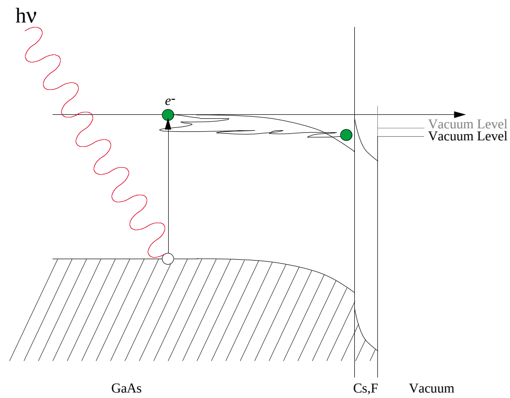
Summary

# Surface Charge Limit

## Charge output is not proportional to light intensity




GaAs band structure in vicinity of Γ point




NEA Surface

- Photon absorption excites electrons to conduction band
- Electrons can be trapped near the surface
- Electrostatic potential from trapped electrons raises affinity
- Increased affinity decreases emission probability
- Affinity recovers after electron recombination
- Increasing photon flux counterproductive at extremes

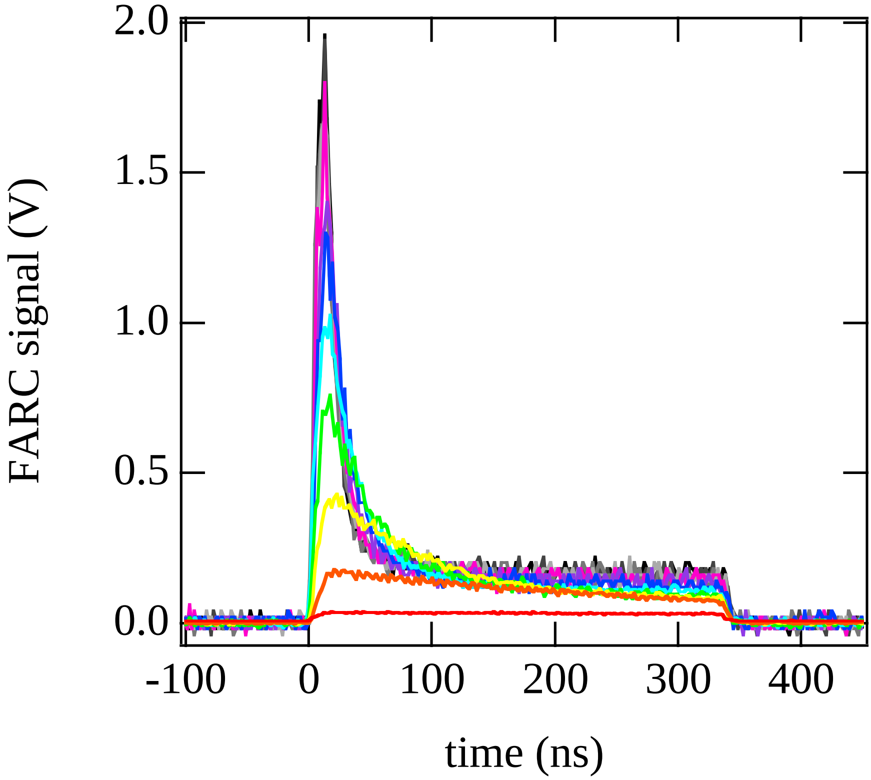

M. Woods, et al J. Appl. Phys. 9, 2295 (1994)

K. Togawa, et al Nucl. Instr. and Methods A365, 1 (1995)

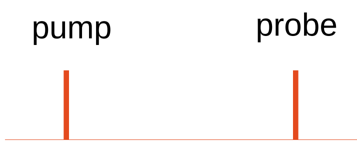
A.S. Jaroshevich, et al, 7th Int. Workshop on Polarized Gas Targets and PolarizedBeams, Urbana, USA (1997)

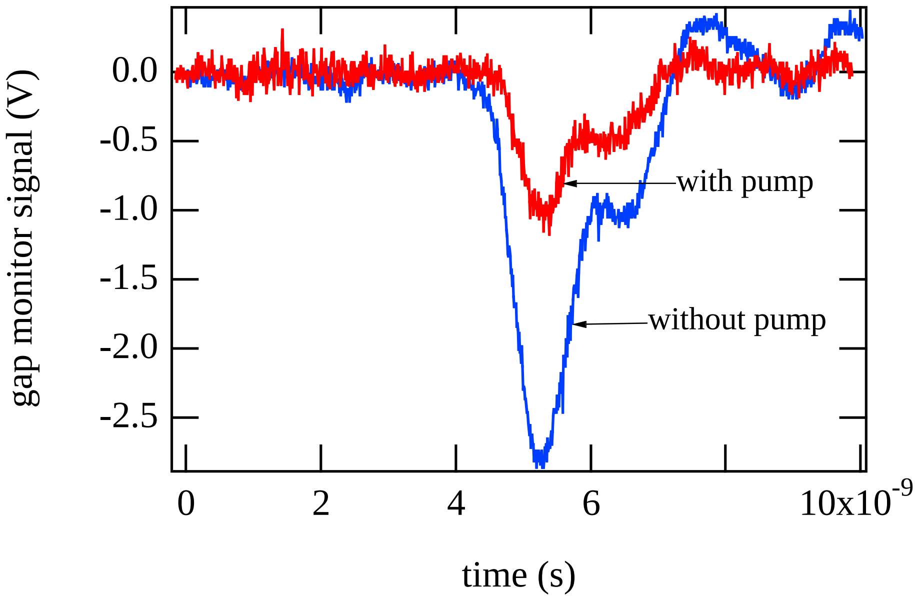
A. Herrera-Gomez, et al J. Appl. Phys. 79, 7318 (1996)

## ong Pulse Signal



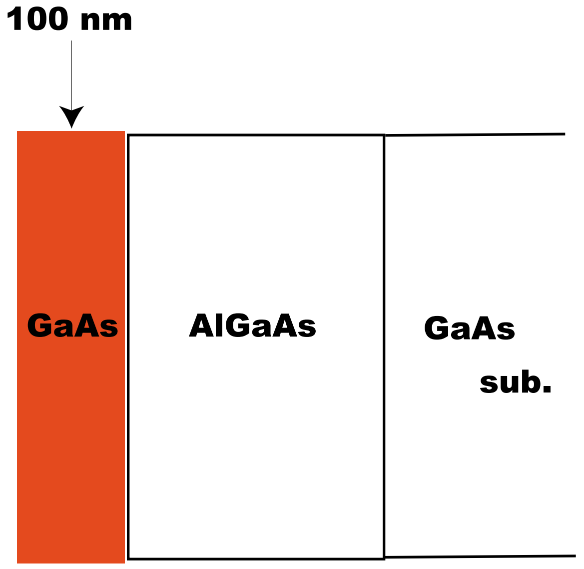

## robe Signal with/without Pump Pulse



# Charge Limit vs. Doping Concentration

## Sample: thin unstrained GaAs




## Doping concentration:

$5 \cdot 10^{18}$, $1 \cdot 10^{19}$, $2 \cdot 10^{19}$, $5 \cdot 10^{19}$ $cm^{-3}$

## Laser:

**Flash-lamp pumped Ti:sapphire**

**Pulse length: 100 ~ 350 nsec**

**YAG pumped Ti:sapphire**

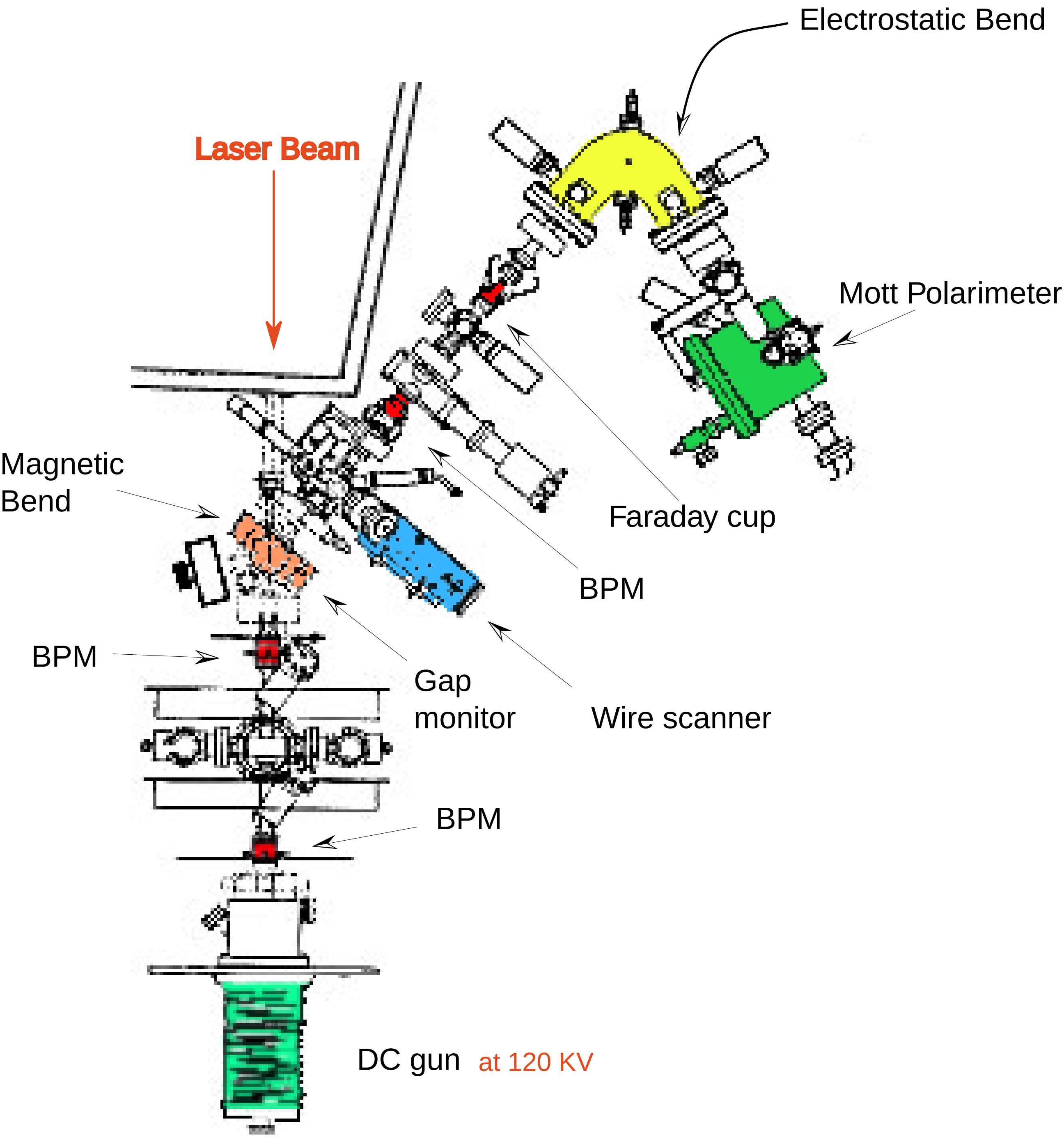
**Pulse length: 2 nsec**

**Two pulses with variable time separation**

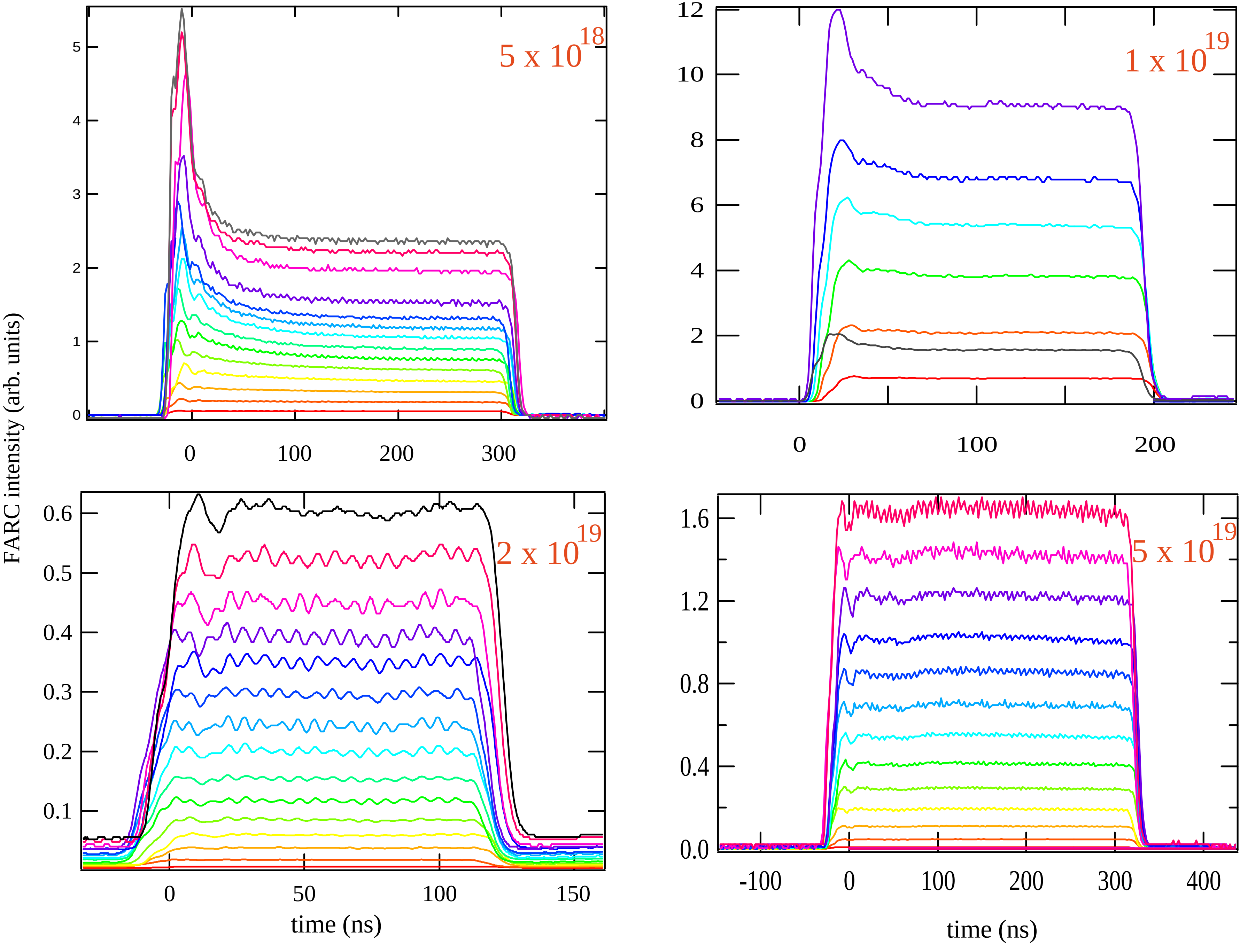
**-- Pump-probe technique**

**$\lambda$ = 850 nm**

# Gun Test Laboratory

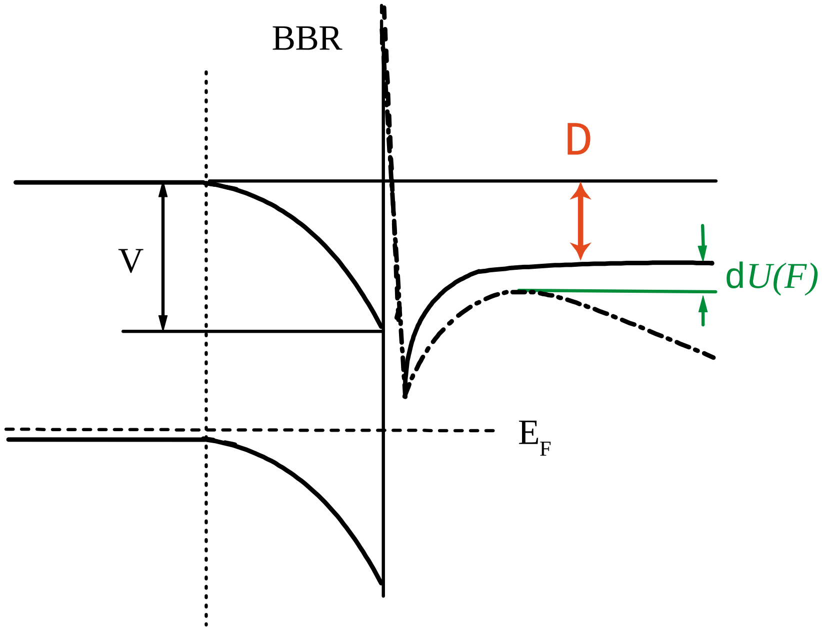


# Faraday Cup Signal



# Subashiev's Charge Limit Model based on Surface Photovoltage

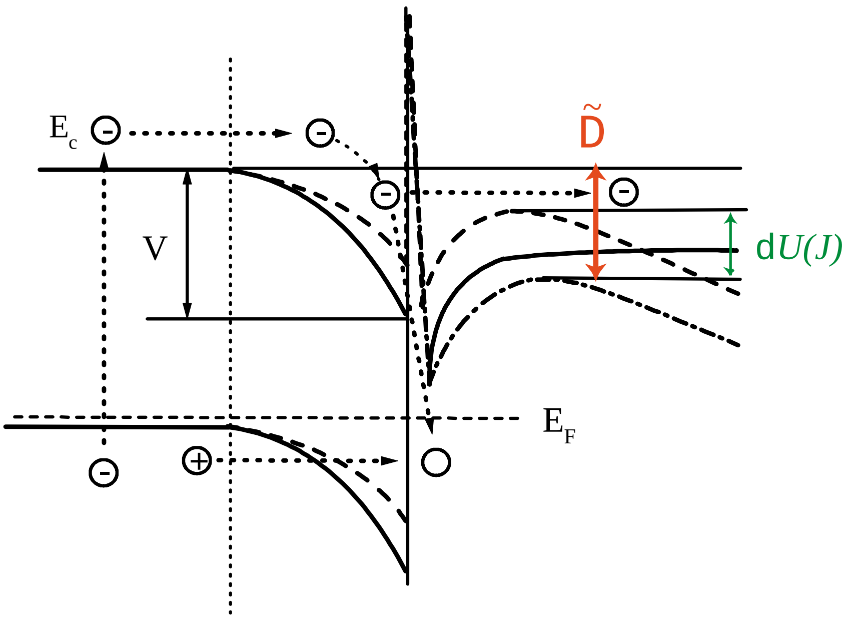
## Bias effect on Yield "Shottky effect"




$$\frac{dY}{Y} = + \frac{dU(F)}{\Delta}$$

$$dU(F) = \sqrt{\frac{q F (\varepsilon_s - 1)}{4 \pi \varepsilon_0 (\varepsilon_s + 1)}}$$

## Photovoltage effect on Yield




$$\frac{dY}{Y} = - \frac{dU(J)}{\tilde{\Delta}}$$

## Restoring Current

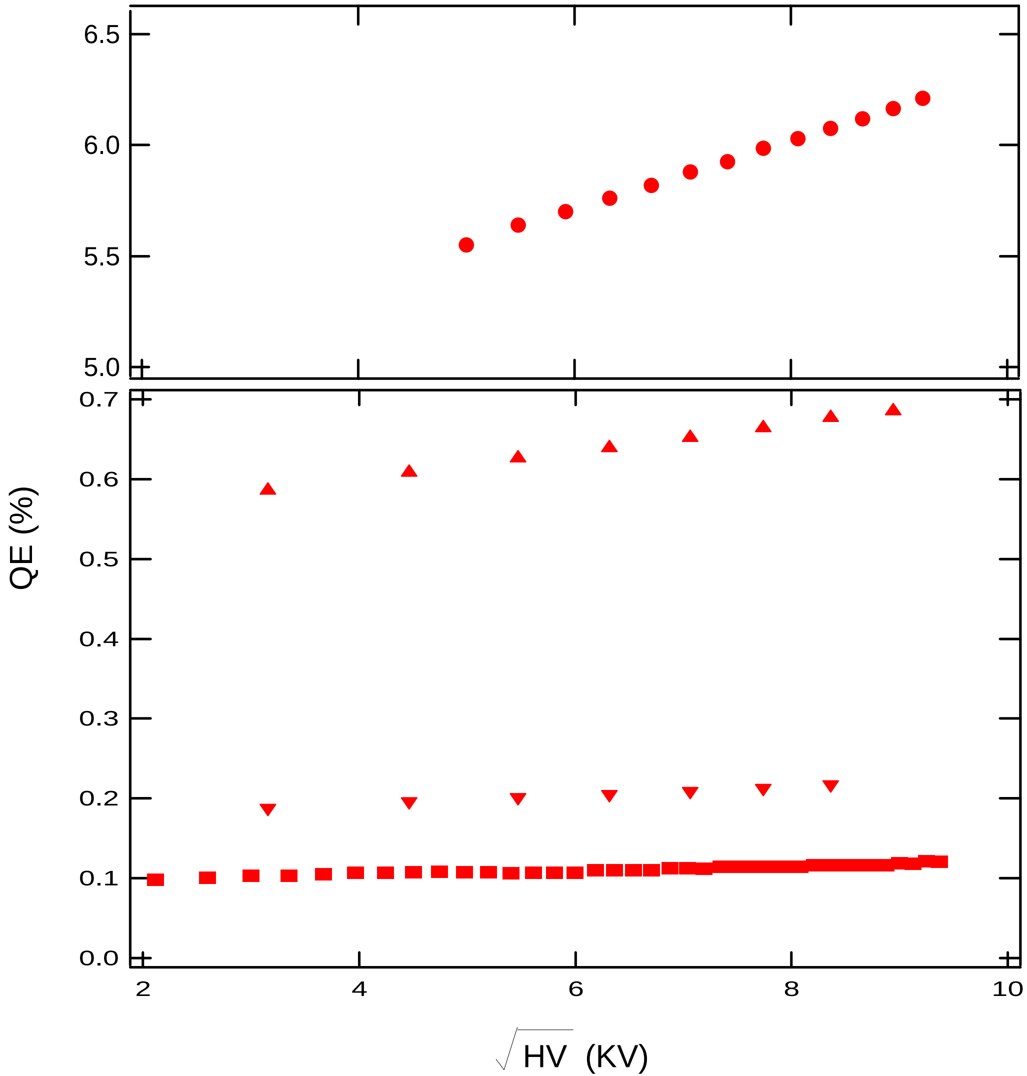
$$j(U) = j_0 \left[\exp(U / E_0) - 1\right]$$

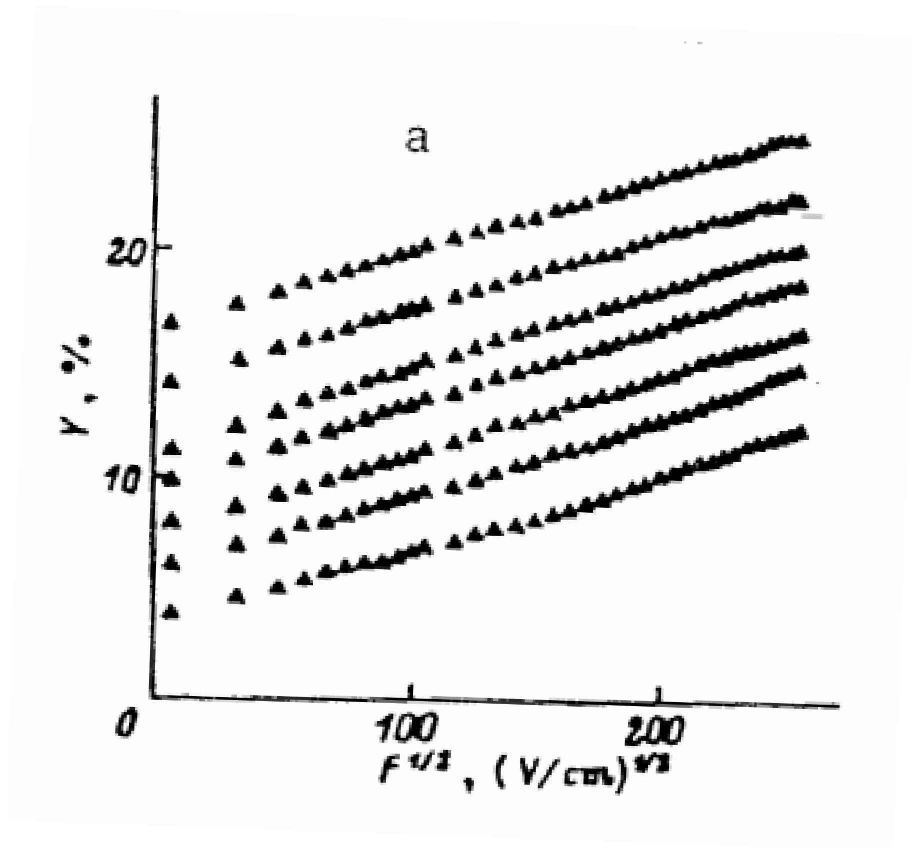
# Bias Effect on Quantum Yield

$$\frac{dY}{Y} = + \frac{dU(F)}{\Delta}$$

$dU(F) = 47\ meV$ @ $120\ KV$

$\Delta \sim 135\ meV$




A.S. Terekhov et al, Sov. Phys.-Solid State 38, 196 (1996)

## The time variation of the photovoltage:

$$C\frac{dU}{q^2 dt} = \alpha d(1-R)J - j(U)$$

*C*: surface capacitance
α: absorption coefficient
*d*: cathode thickness
*R*: surface reflectivity

$$\frac{Y}{Y_0} = 1 + \frac{E_0}{\tilde{\Delta}} \ln\left[\frac{1 + J/\tilde{j}_0 \exp[-(1+J/\tilde{j}_0)\frac{t}{\tau}]}{(1+J/\tilde{j}_0)}\right]$$

Photovoltage Build-up Time

$$T = \frac{\tau}{(1+J/\tilde{j}_0)}$$

Photovoltage relaxation time

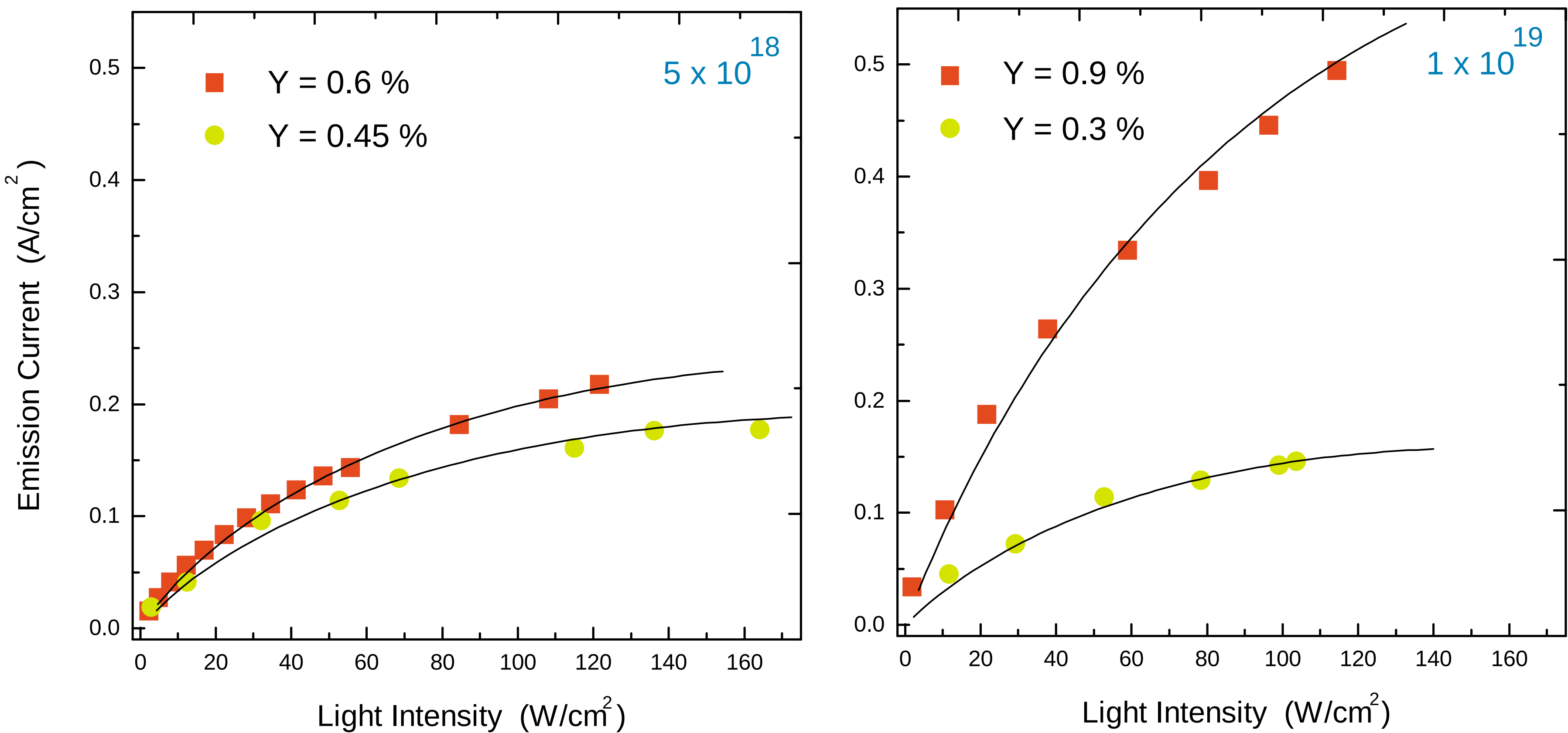
$$\tau = \frac{E_0 C}{q^2 j_0}$$

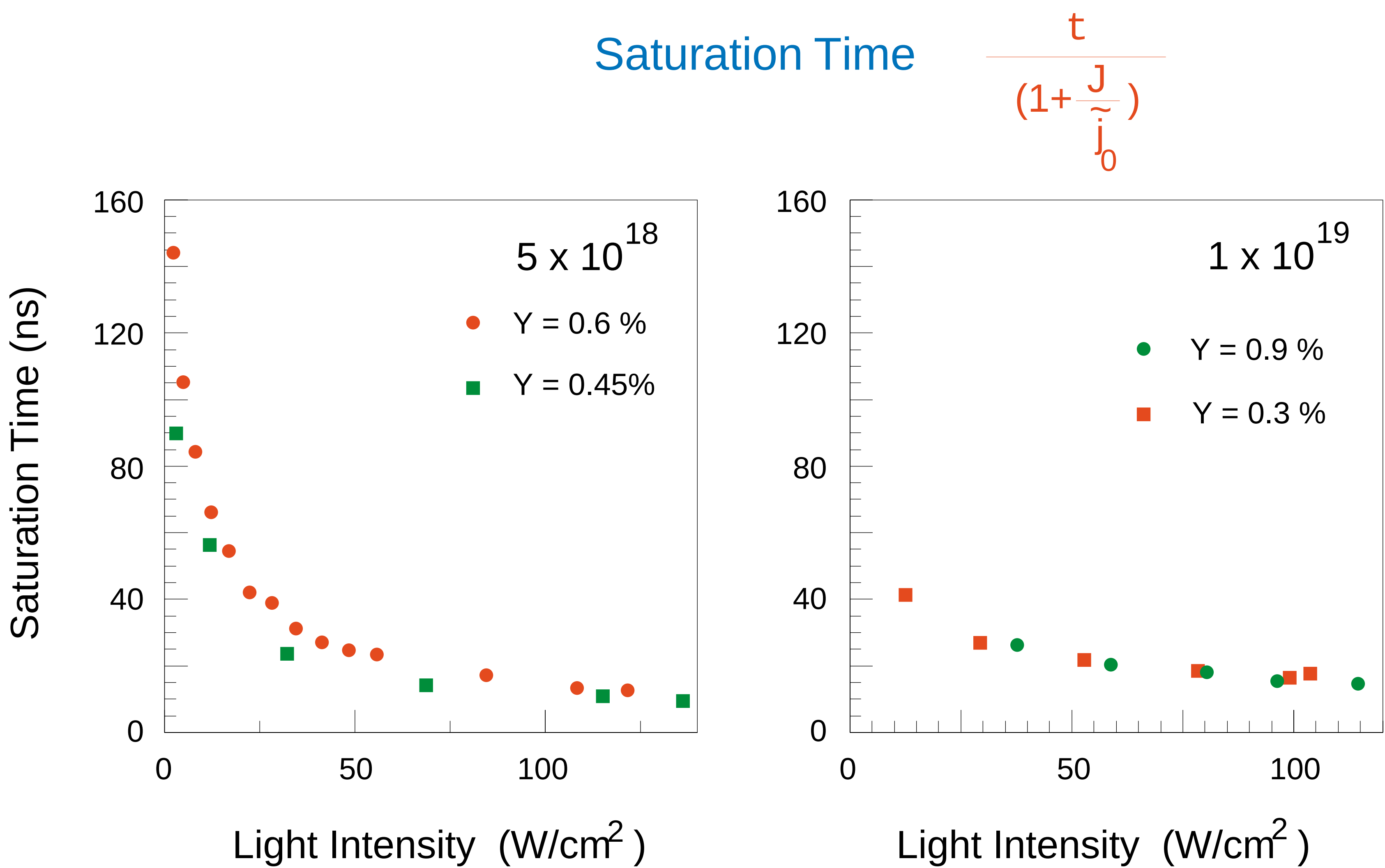
Saturation Yield

$$\frac{Y}{Y_0} = 1 - \frac{E_0}{\tilde{\Delta}} \ln(1 + J/\tilde{j}_0)$$

# Saturation Current

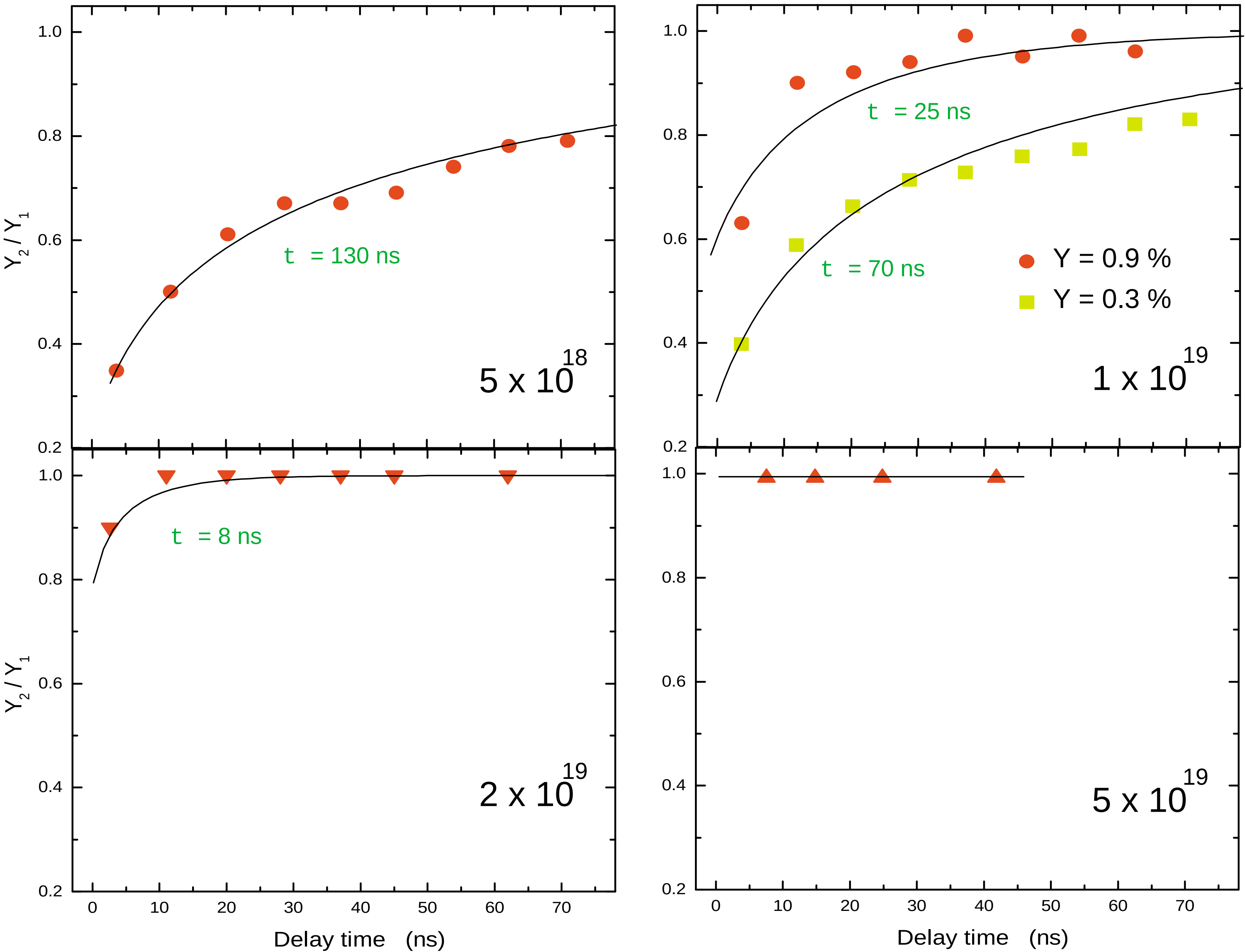
$$J \left[ 1 - \frac{\tilde{E}}{\tilde{D}} \ln\left(1 + \frac{J}{\tilde{j}_0}\right)\right]$$





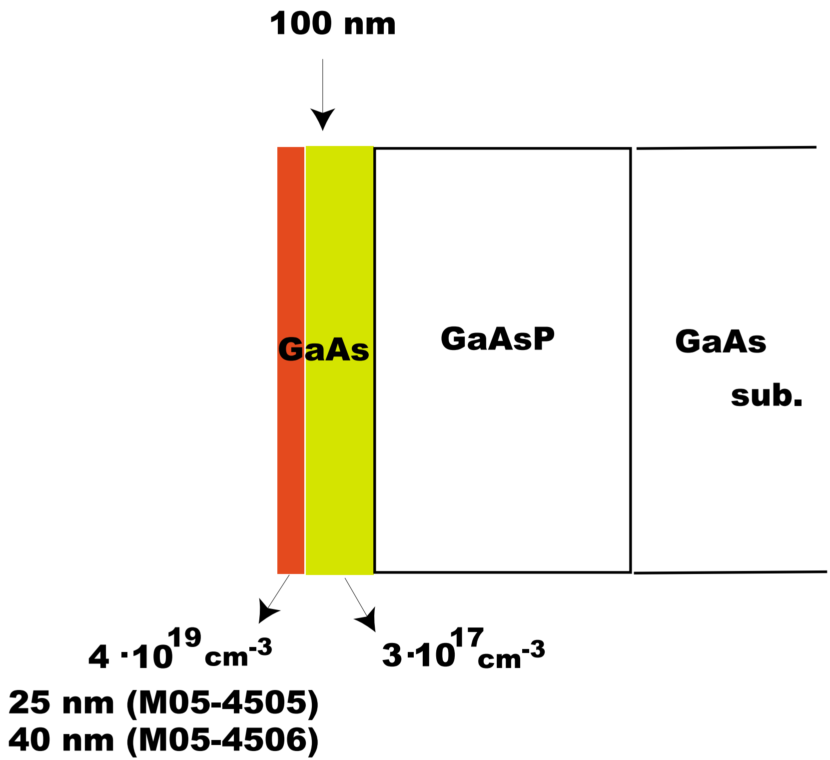
Saturation Time
t / (1+ J / j̃_0)
Saturation Time (ns)
5 x 10^18
Y = 0.6 %
Y = 0.45%
1 x 10^19
Y = 0.9 %
Y = 0.3 %
0
40
80
120
160
0
50
100
Light Intensity (W/cm^2 )
Light Intensity (W/cm^2 )

# Charge Restoration



# Polarization with High Surface Doping

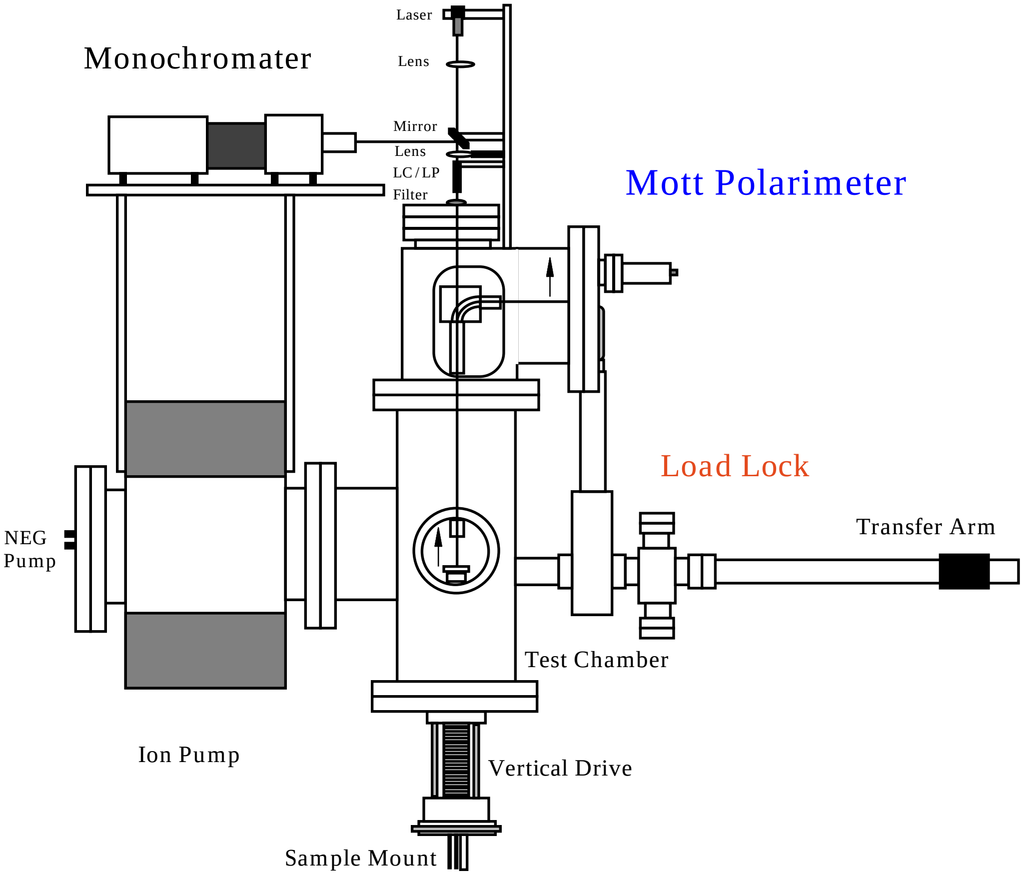
## Sample:  strained GaAs



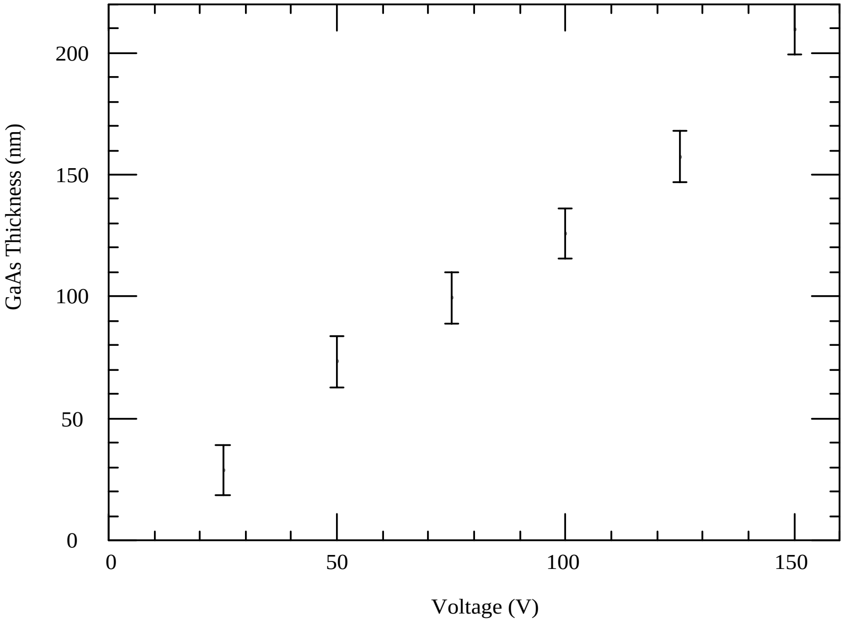

**High doped layer thickness is reduced by anodization.**

**Polarization is measured as a function of the high doped layer thickness.**

# Cathode Test System with a load-lock



# Anodization rate

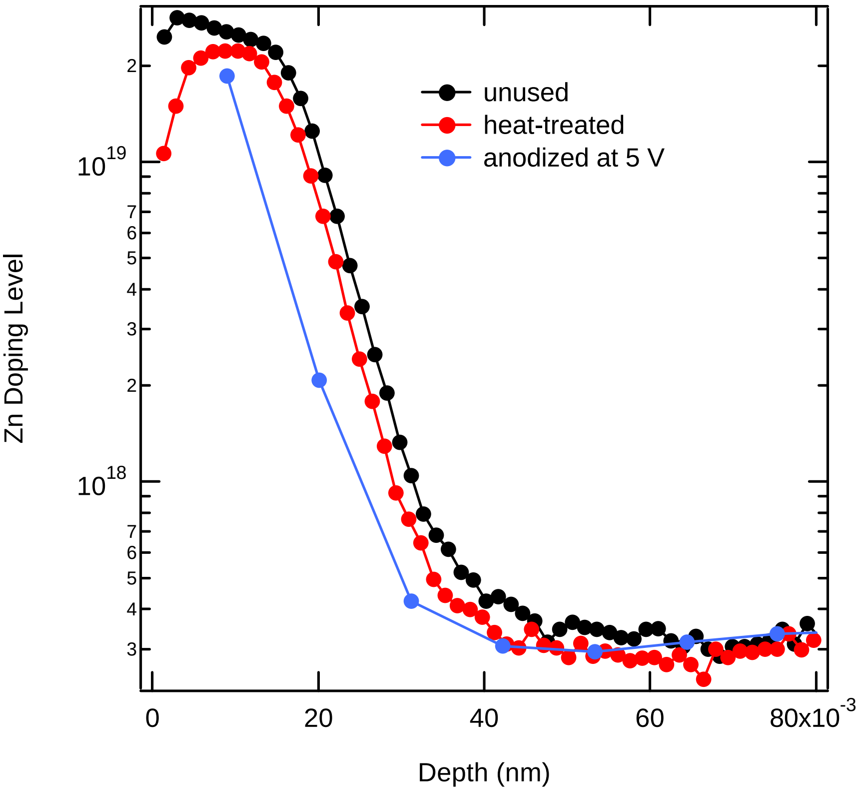



**13.1 Å / V**

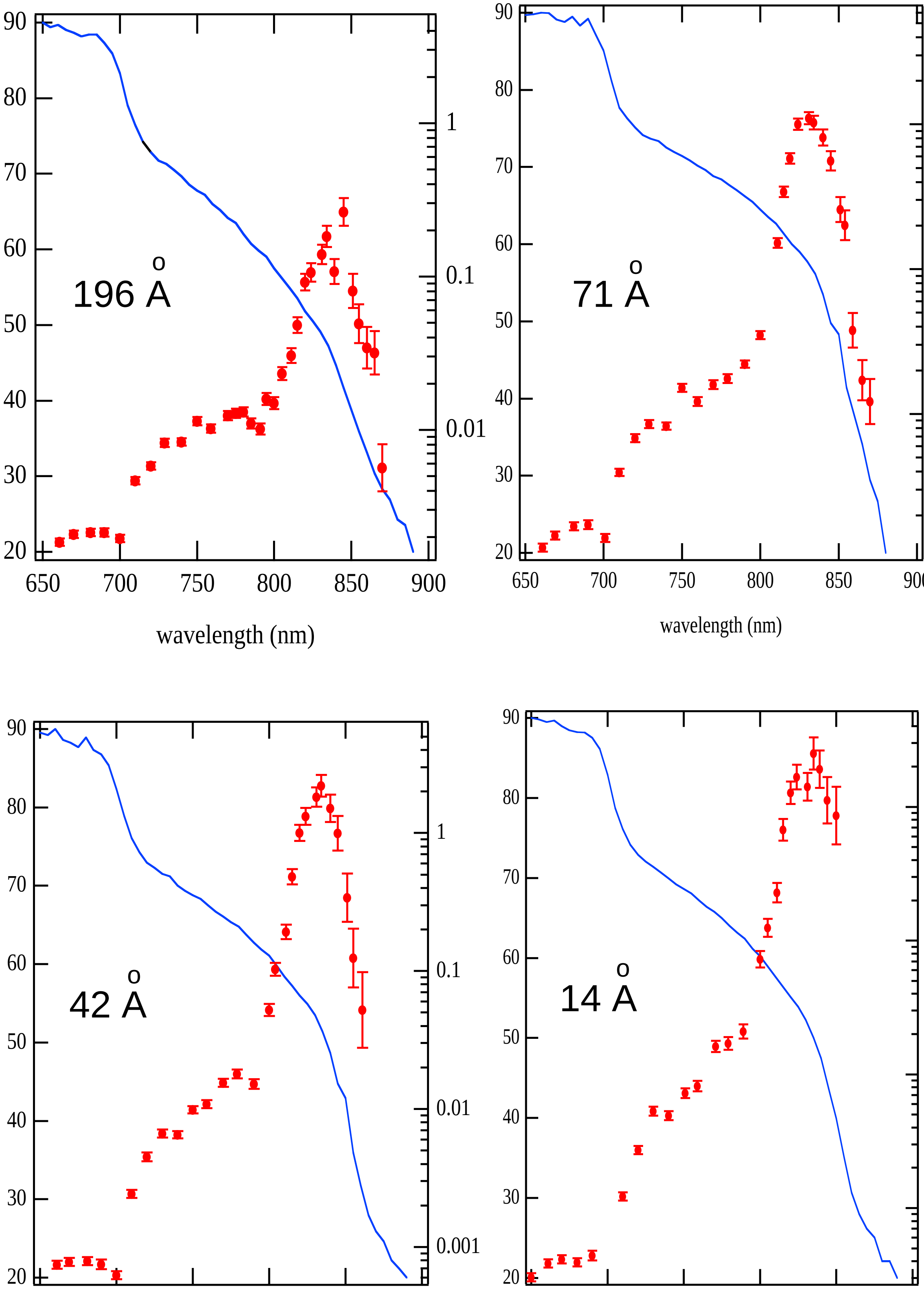
# SIMS Analysis

**GaAs evaporation rate at "600 C" : ~ 4 Å / 1hr**

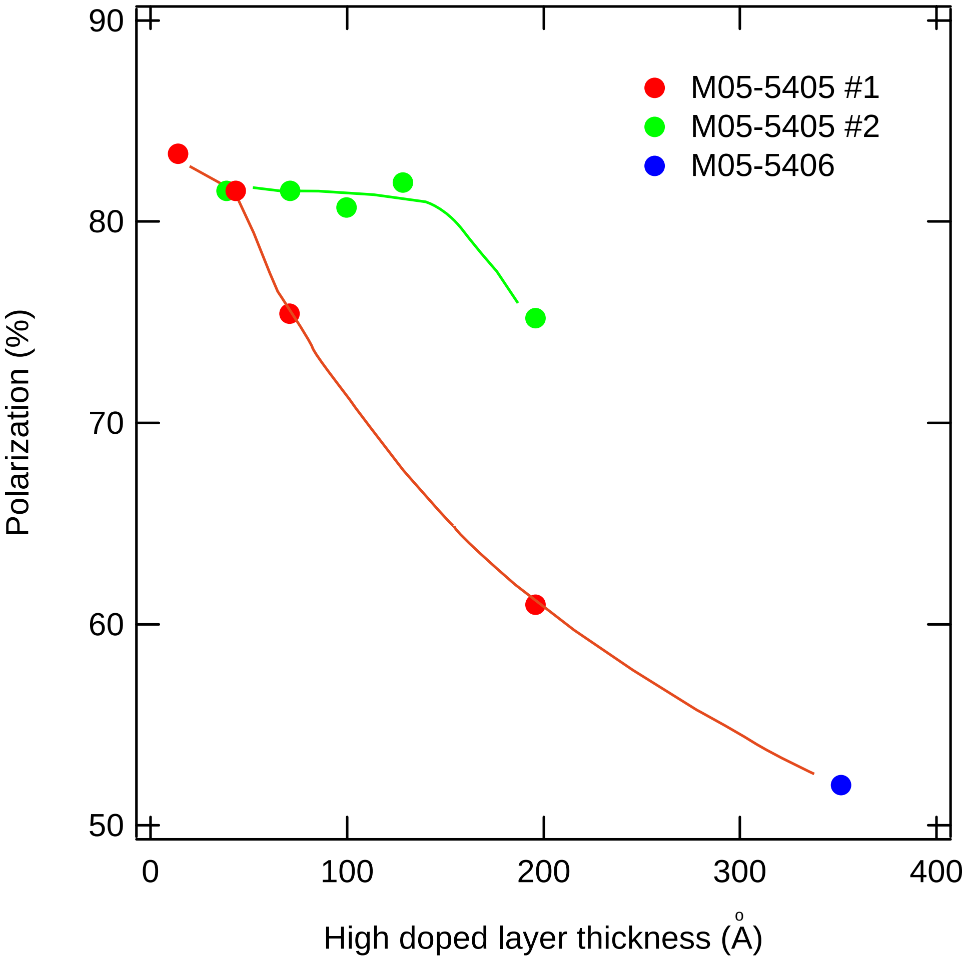
**Anodization rate at 5 V : 14.9 Å**



# Polarization and QE Measurements



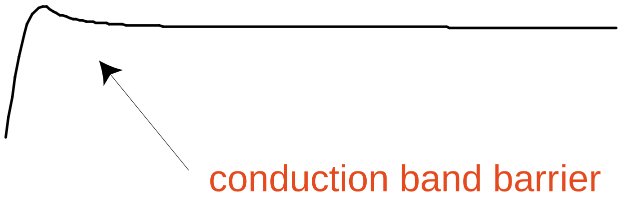
# Polarization vs High Doped Layer Thickness




~80 % polarization with 50 ~ 100 Å of high surface doping.

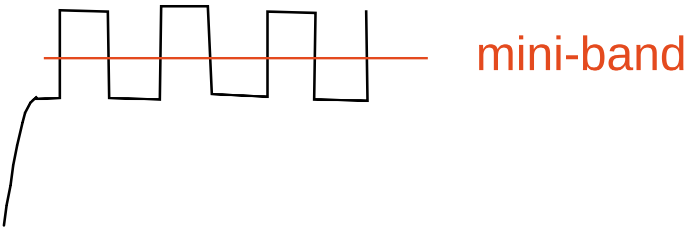
# Possible Solutions for Charge Limit

- Strained GaAs with high surface doping




- Strained GaAsP with high surface doped GaAs cap

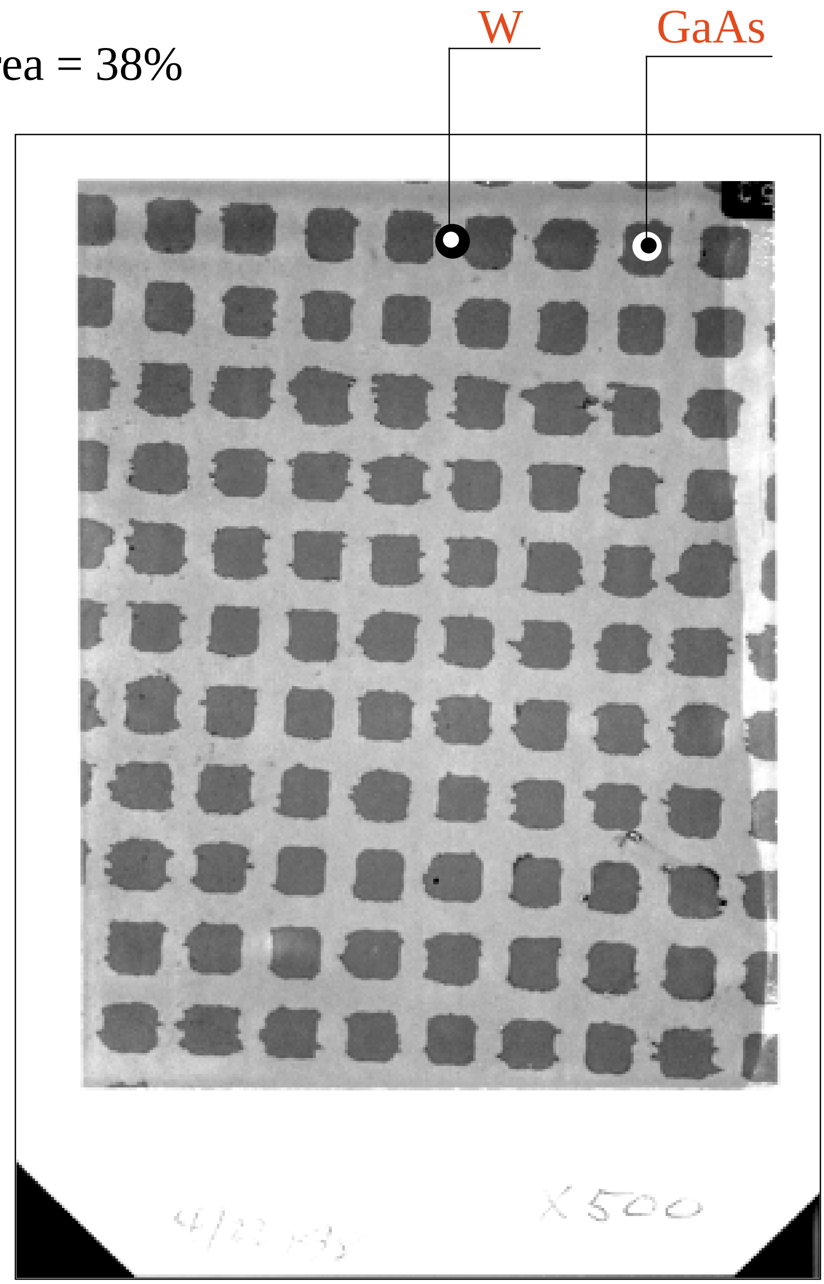

- Superlattice - Nagoya Group



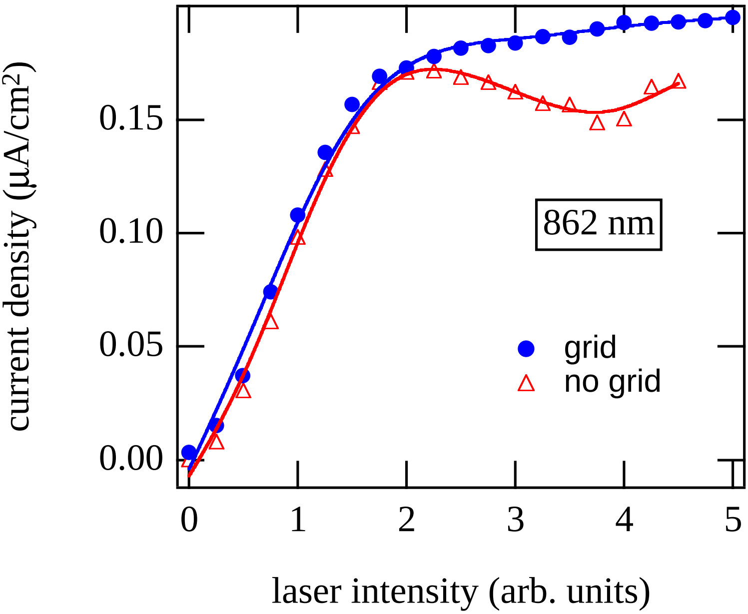

- Metalic Grid

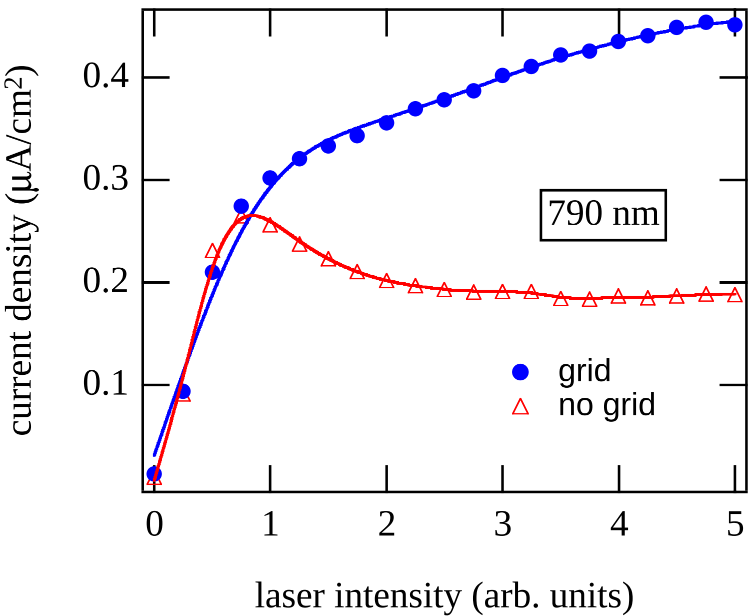
# Charge Bleedoff Grid

- Tungsten choosen for robustness and for low reactivity
- Lithographic techniques used for deposition
- Line width = 10 μm with 23 μm spacing
- Line height = 30 nm
- Clear area = 38%

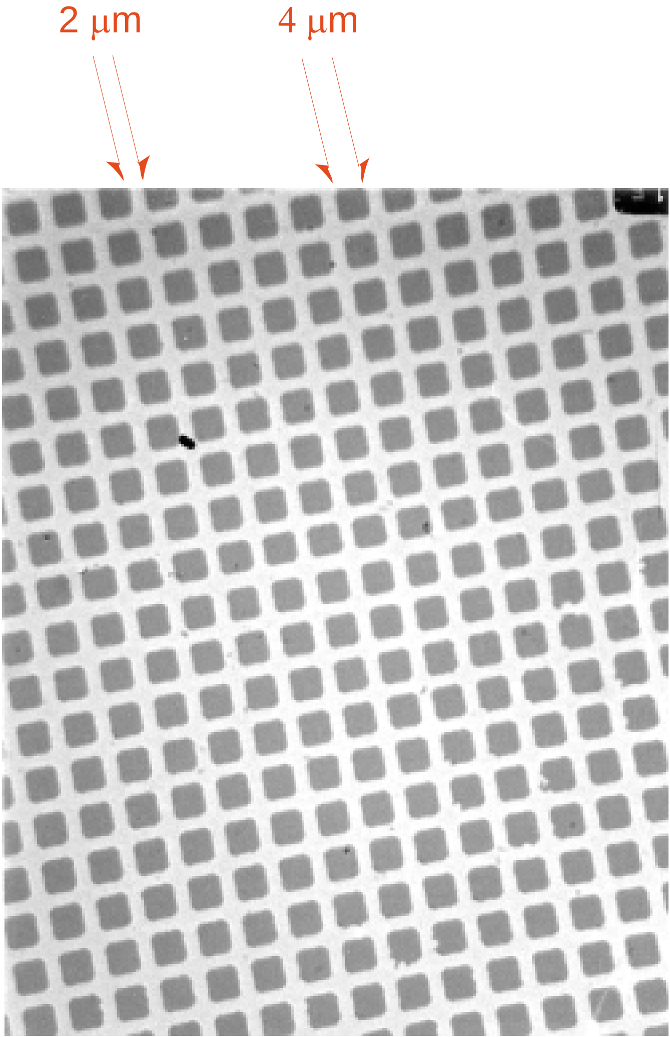


# Current density enhancement using W grid
# QED 100 nm unstrained GaAs
# $1x10^{18}/cm^3$ Be doping



# Depositting Finer Grid on GaAs



# Summary

• Systematic study of the charge limit effect has been completed.

• Experimental results are in good agreement with Subashiev's model based on the surface photovoltage effect.

• The surface photovoltage effect diminishes at the doping concentration of $2 \times 10^{19}$ $cm^{-3}$.

• Possible solutions to the charge limit problem are described.