ROHM AND HAAS ELECTRONIC MATERIALS
MICROELECTRONIC TECHNOLOGIES

Shot Noise, LER and Quantum Efficiency of EUV Photoresists

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- **Introduction**
- **EUV and DUV Base Titration Experiments**
- **Poisson Statistics of LER *vs.* E_{size}**
- **LER Simulation Model**
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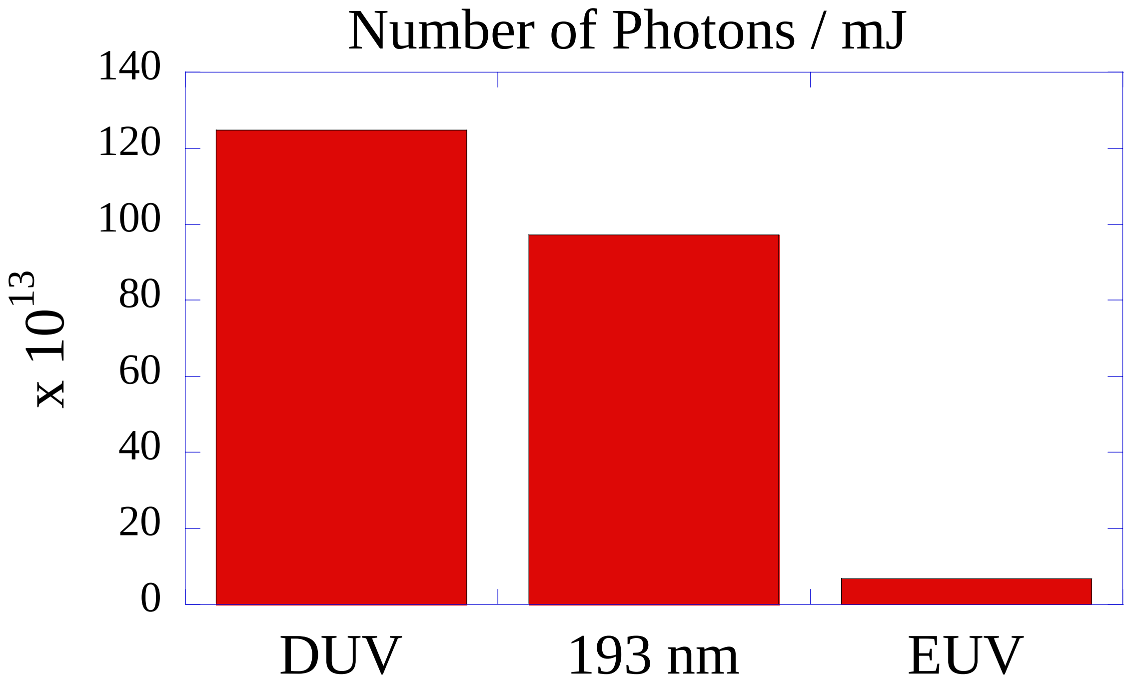
I. Introduction

The 45 nm Node will require EUV Resists with Low LER and E_{size}:

LER = 2 nm

E_{size} = 2-15 mJ/cm^2



Shot Noise Limit[1] =

Limit imposed by statistical probability of underexposing a pixel

(1) Neureuther & Wilson J. Vac. Sci. Tech. **1988**.

Shot Noise Limits

In 1998, John Hutchinson[2] compared ***Shot Noise Limits*** of 193 nm and EUV resists using a theoretical model of LER.

	193 nm	13 nm (EUV)
Shot Noise Limit (10 mJ/cm^2):	1 nm	8 nm LER
(1 mJ/cm^2):	5 nm	25 nm LER

Without considering secondary electrons or acid diffusion effects.

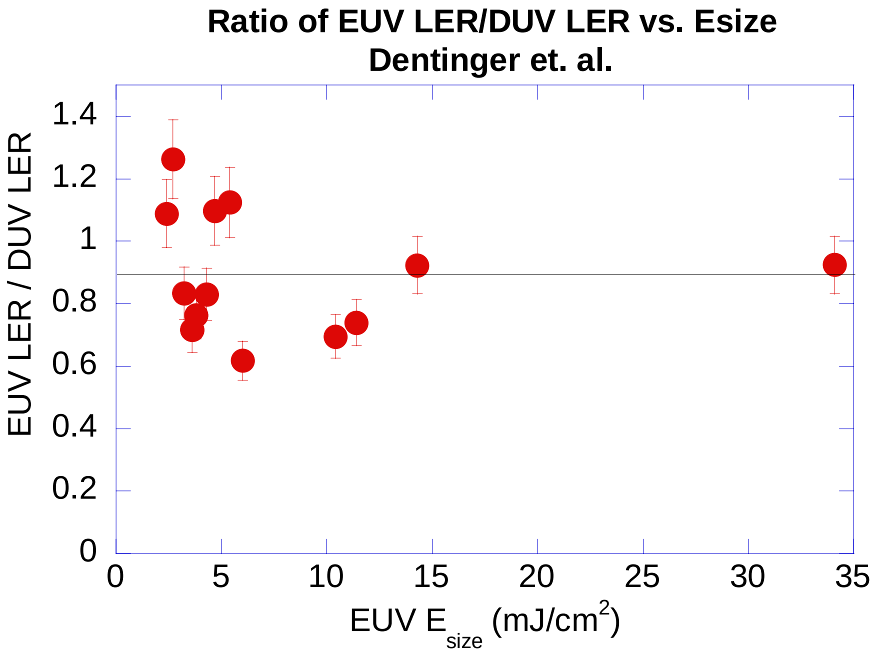
More recently,[3] several excellent papers considered role of shot noise in limiting the ability to print contact hole arrays.

(2) Hutchinson, SPIE **1998**

(3) O'Brien SPIE **2001**, Cobb SPIE **2003**, Lee SPIE **2003**

Shot Noise Limits

In 2002, Dentinger et. al.[4] compared the LER of 25 resist formulations using DUV and EUV exposures. Ratio of LER_{EUV} *vs.* LER_{DUV} showed no statistically significant increase in EUV LER as photospeed is increased.



Authors' Reasoning:

Since DUV has 12X more absorbed photons than EUV and the LER ratios do not change with Dose:

Shot noise does not effect LER down to 3 mJ/cm^2

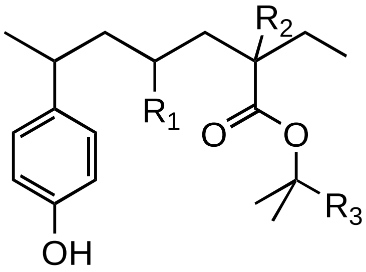
Absorbed Photons = E_{size} x Abs x Photons/mJ

(4) P. M. Dentinger, et. al. SPIE **1998**

Materials

Experimental Resists based on EUV-2D

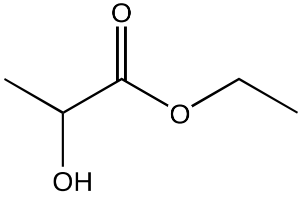
Polymer

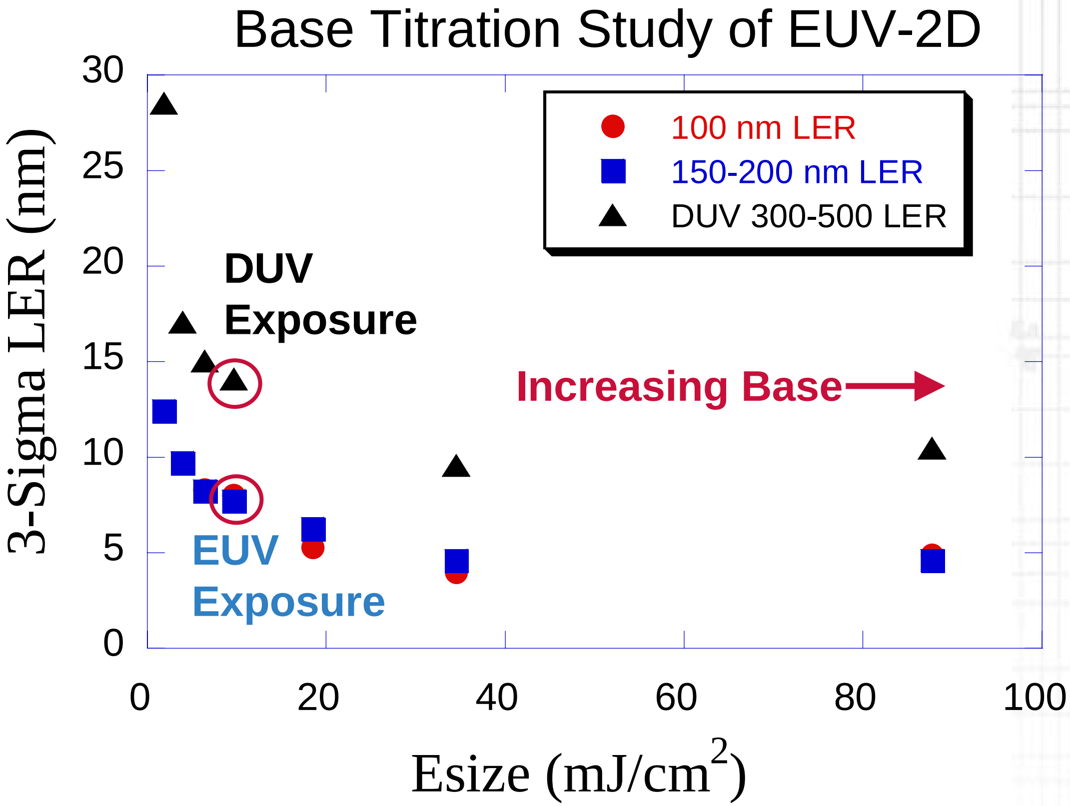


Inhibiting Onium PAG $Ar_nE^+ X^-$

Non-Nucleophilic Base
[Base]/[PAG] = 0 to 75%

Ethyl Lactate Solvent





100 nm Dense for EUV and 200 nm Dense for DUV

II. Base Titration Allowed Us to Study:

Relationship between LER and E_{size} for Both EUV and DUV

Statistical Analysis of LER vs. E_{size}

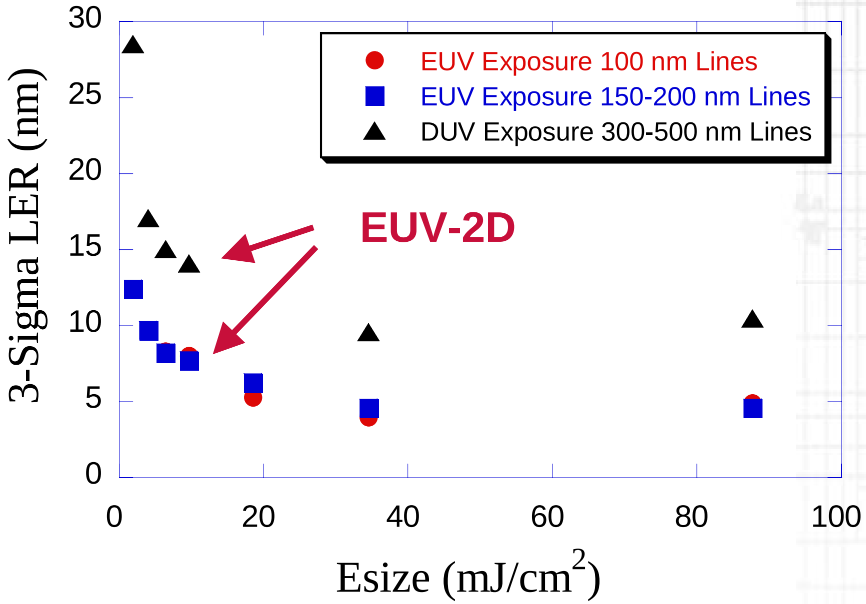
Poisson Statistics

Acid - Base Simulation Program

Written for this Paper

Quantum Efficiency

C-Parameter	(Szmanda Method)
OD	(2004 SPIE Paper)



100 nm Dense for EUV and 200 nm Dense for DUV

Other Resist Systems

III. Poisson Statistics of LER vs. E_{size}

Poisson Statistics Apply to Absorption of Incident Photons: $\sigma_N = \sqrt{N}$

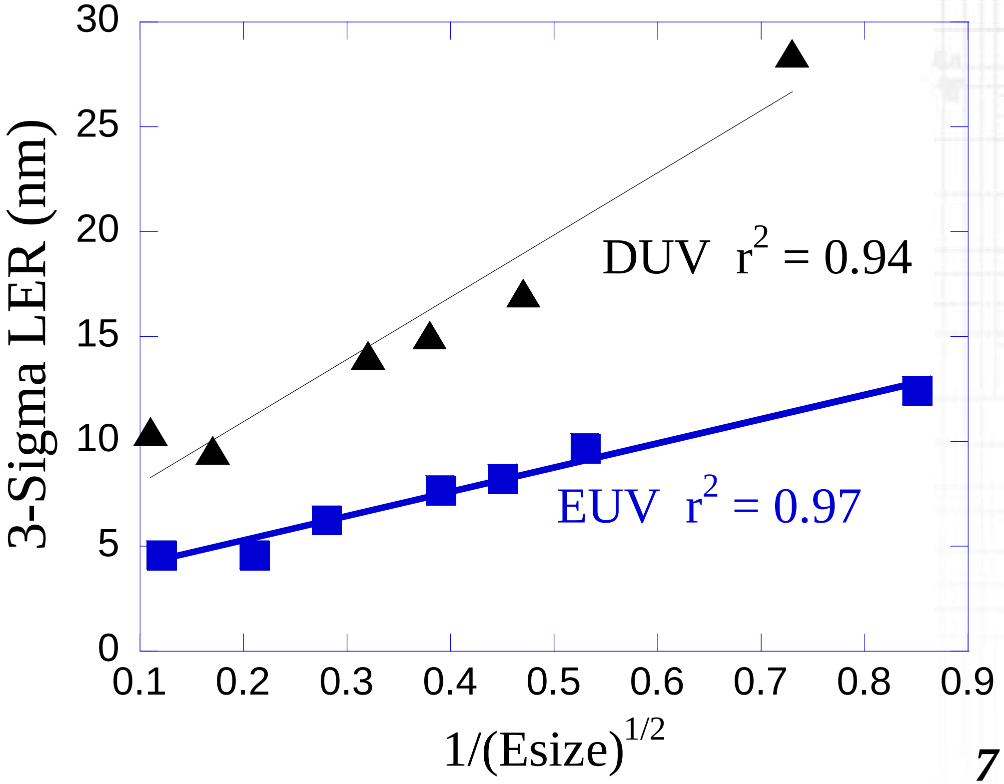
N = number of absorbed photons per volume element ∝ dose.

Side wall roughness ∝ relative variation

$$LER \propto \frac{\sigma_N}{N} = \frac{1}{\sqrt{N}} \propto \frac{1}{\sqrt{dose}}$$

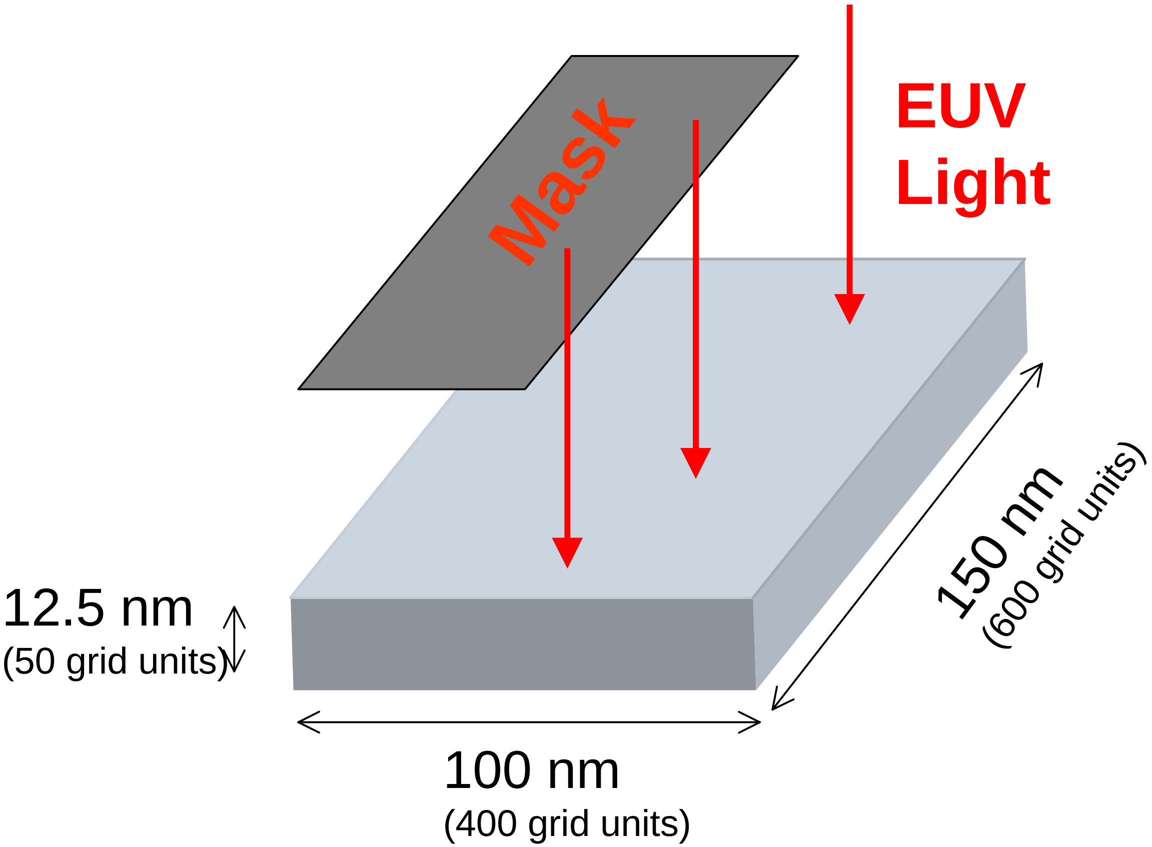
Base titration curves show the statistics of shot noise.

Why do both EUV and DUV show the same linear behavior?

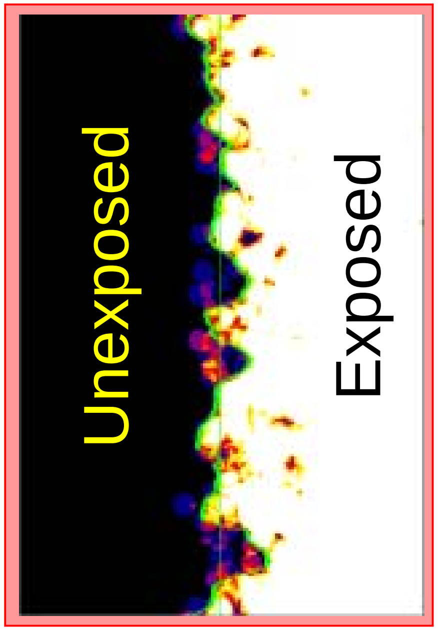


IV. LER Simulation Model

Schematic of Model



Output of Model

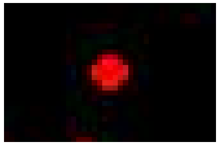


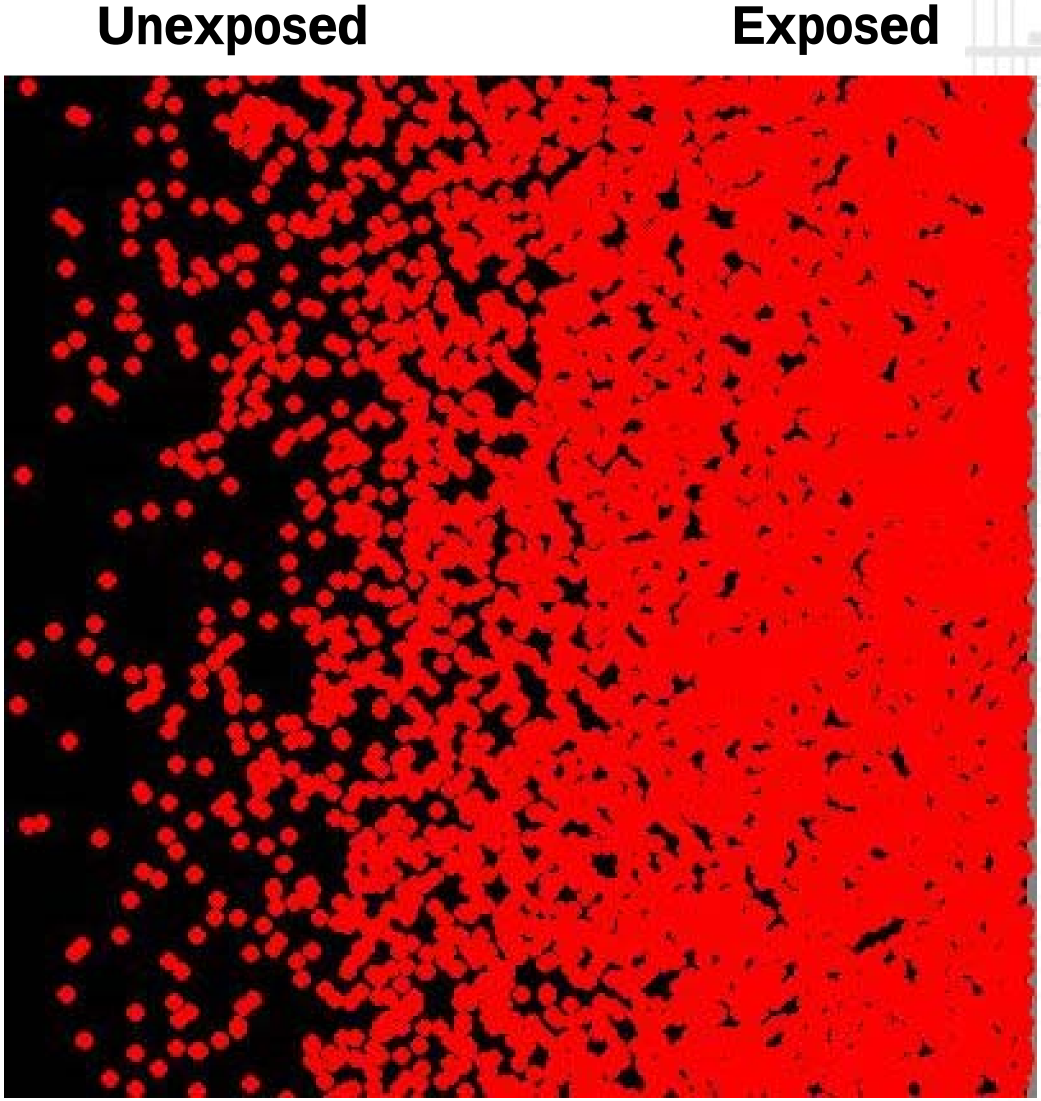
Simulation Steps

Aerial Image

10 mJ/cm^2 exposure

1 Photon =



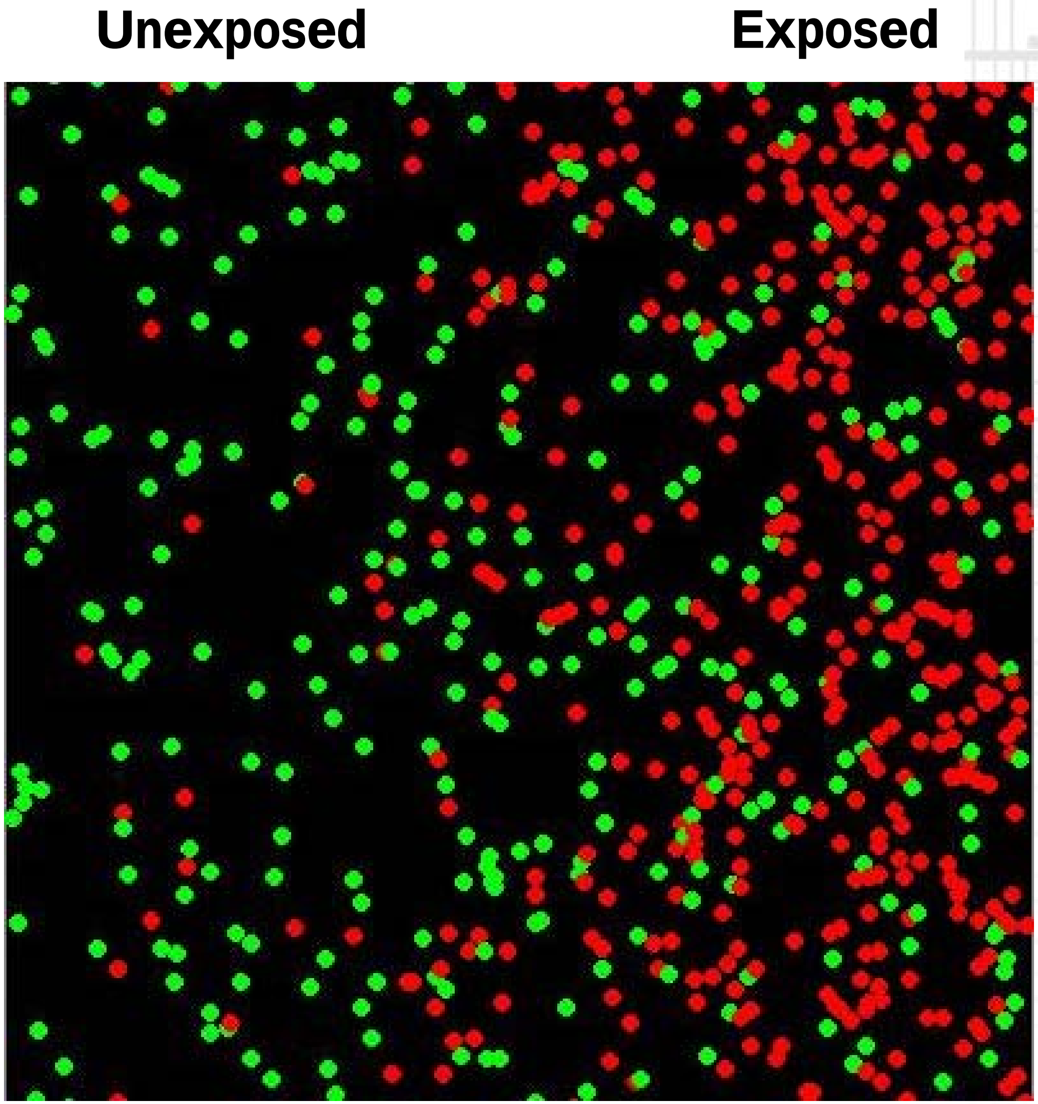


Simulation Steps

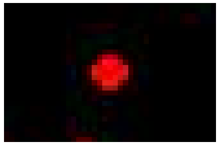
Acid & Base Positions

10 mJ/cm² exposure

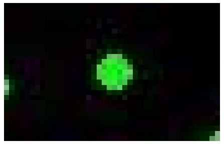
2.5Å film slice



1 Acid =



1 Base =



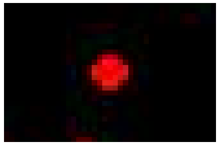
Simulation Steps

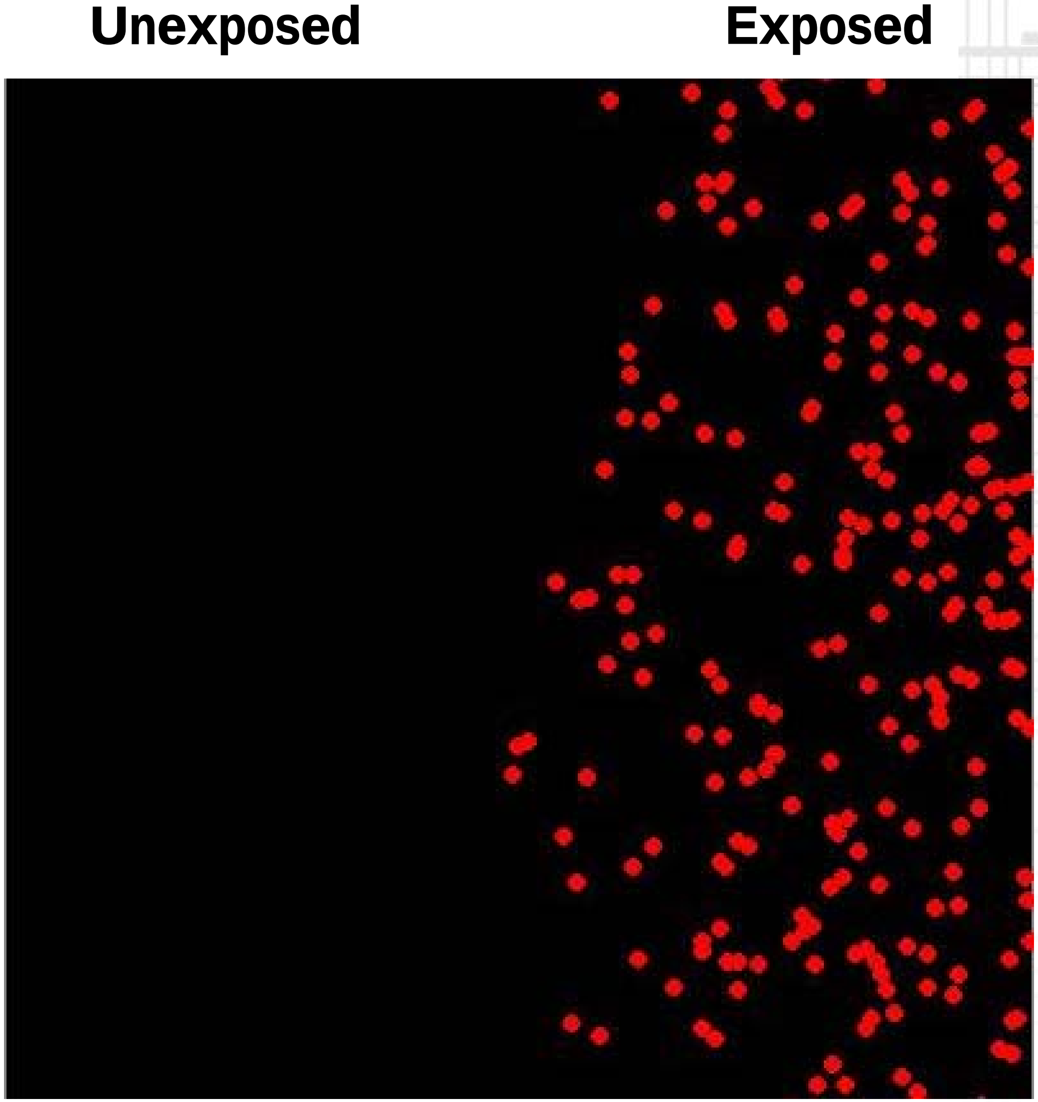
Acid Latent Image After Base Quench

10 mJ/cm² exposure

2.5Å film slice

1 Acid =



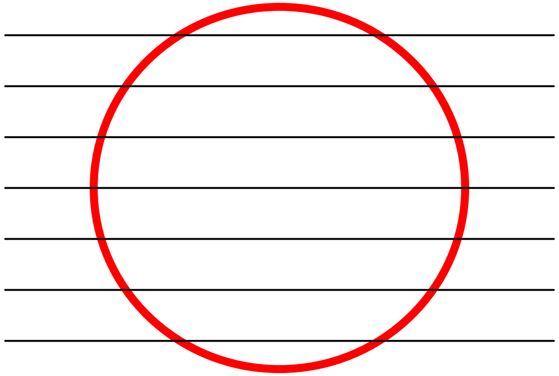


Simulation Steps

Deblocked Latent Image,

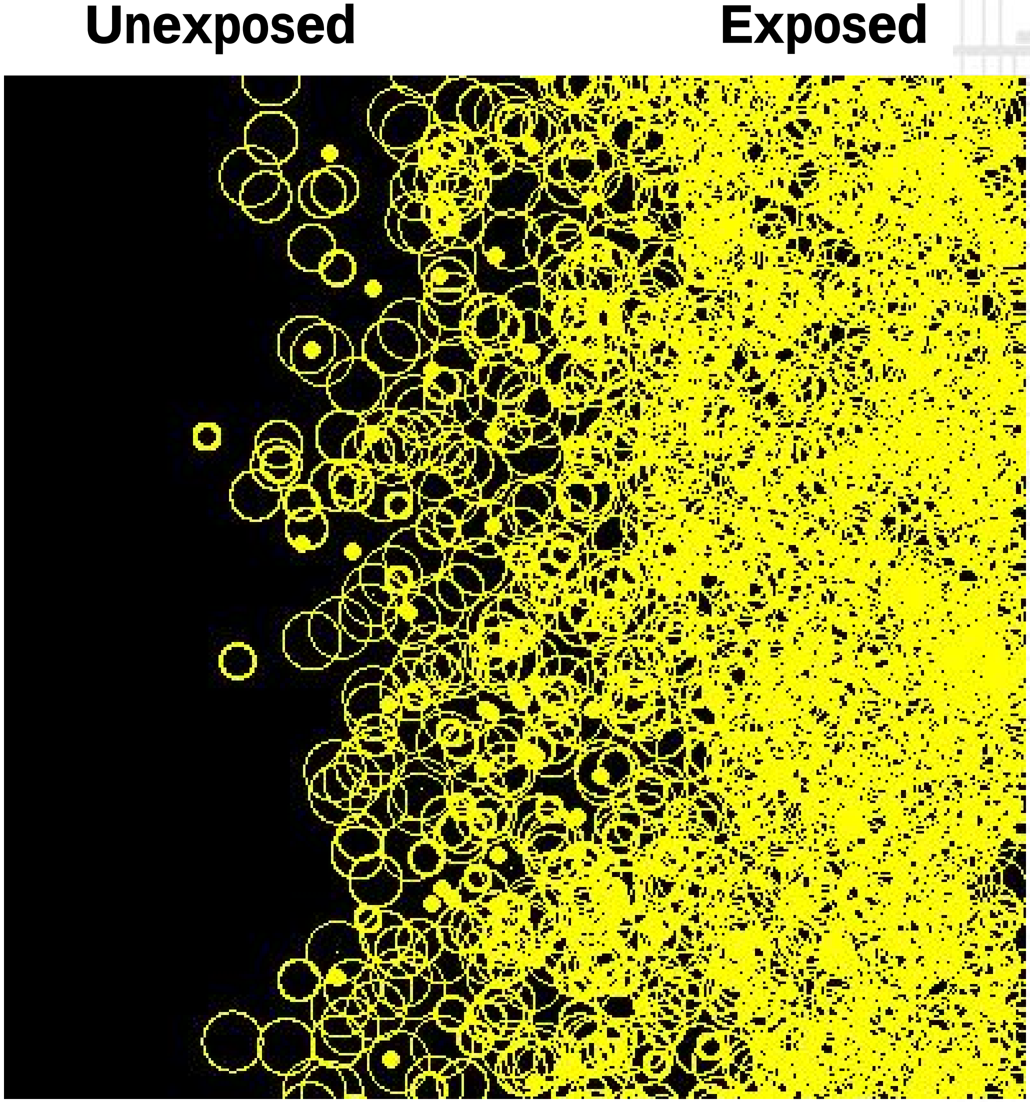
After acid diffusion

1.5 mJ/cm² exposure



2.5Å film slice

$R_{diffusion} = 32$Å



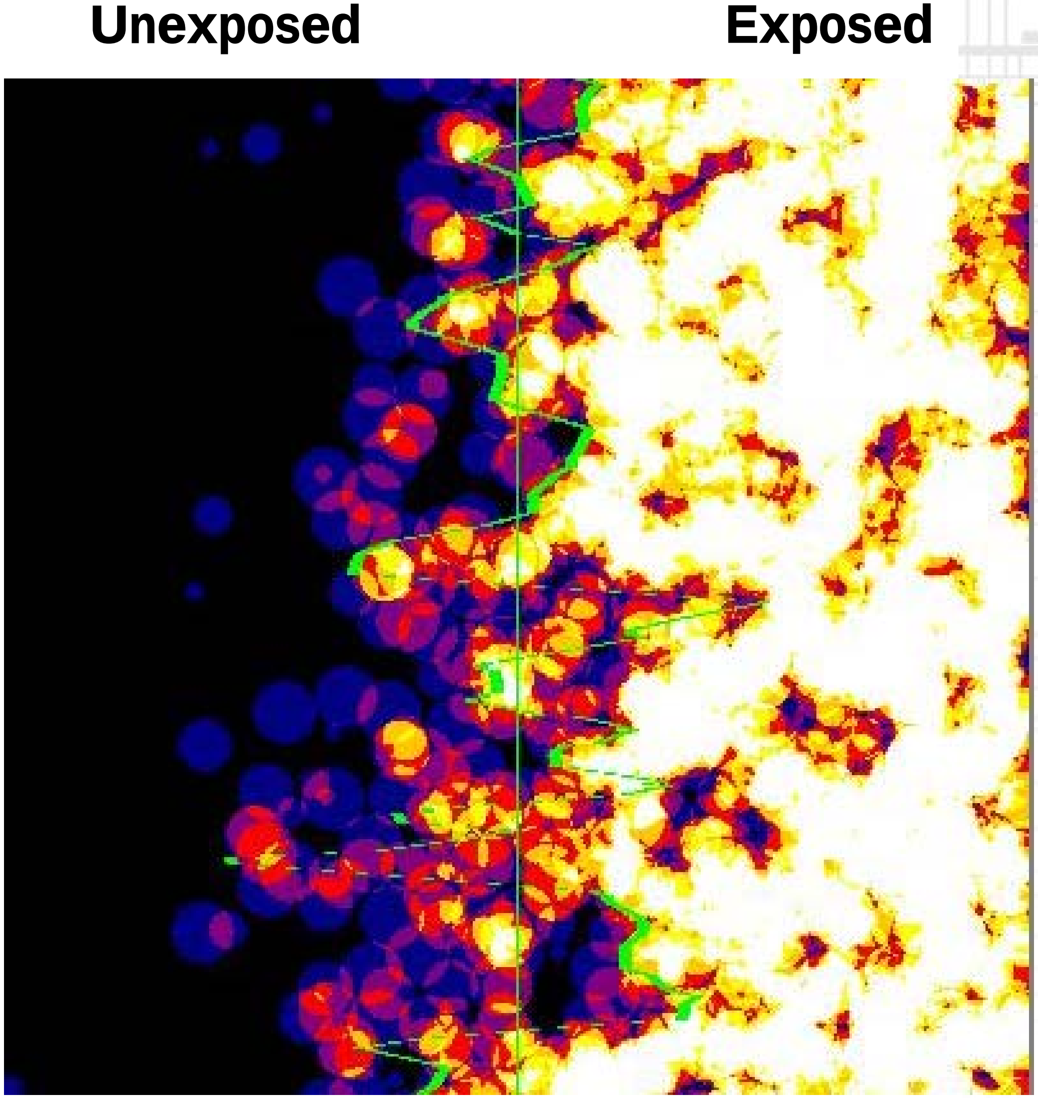
Simulation Steps

Deblocking Density by Overlapping Spheres

1.5 mJ/cm^2 exposure

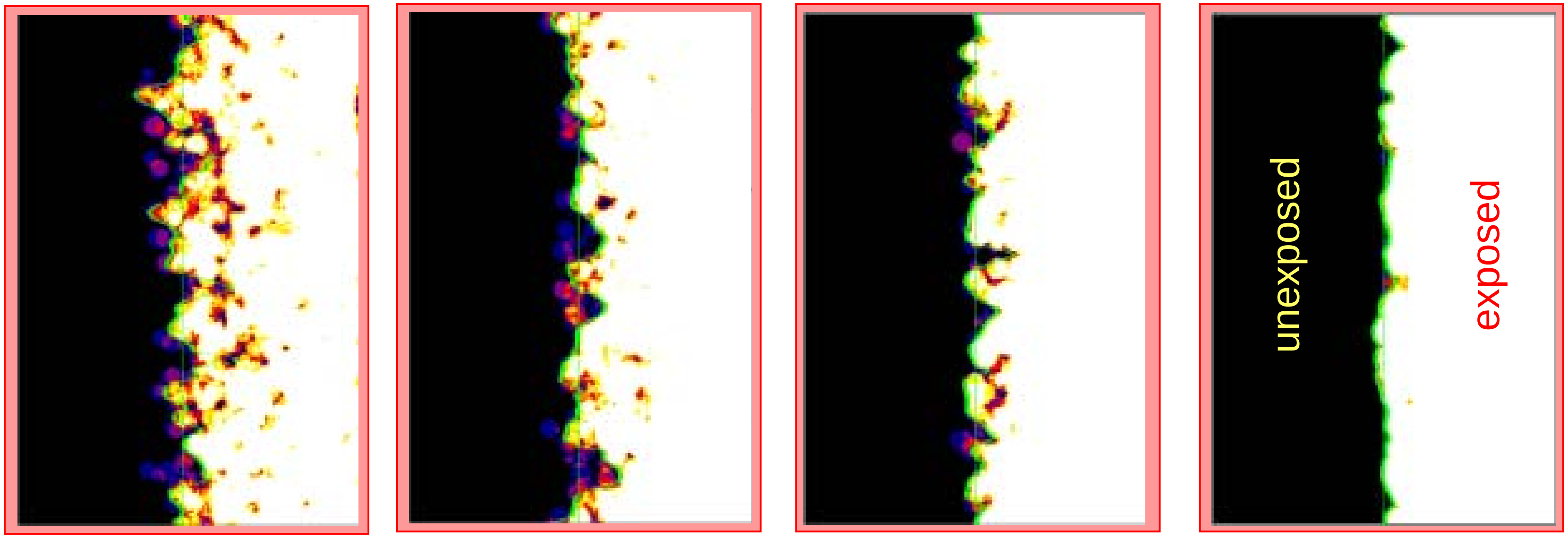
2.5Å film slice

$R_{diffusion}$ = 32Å



Simulation Results

Dose: 1.5 3 8 27 mJ/cm^2

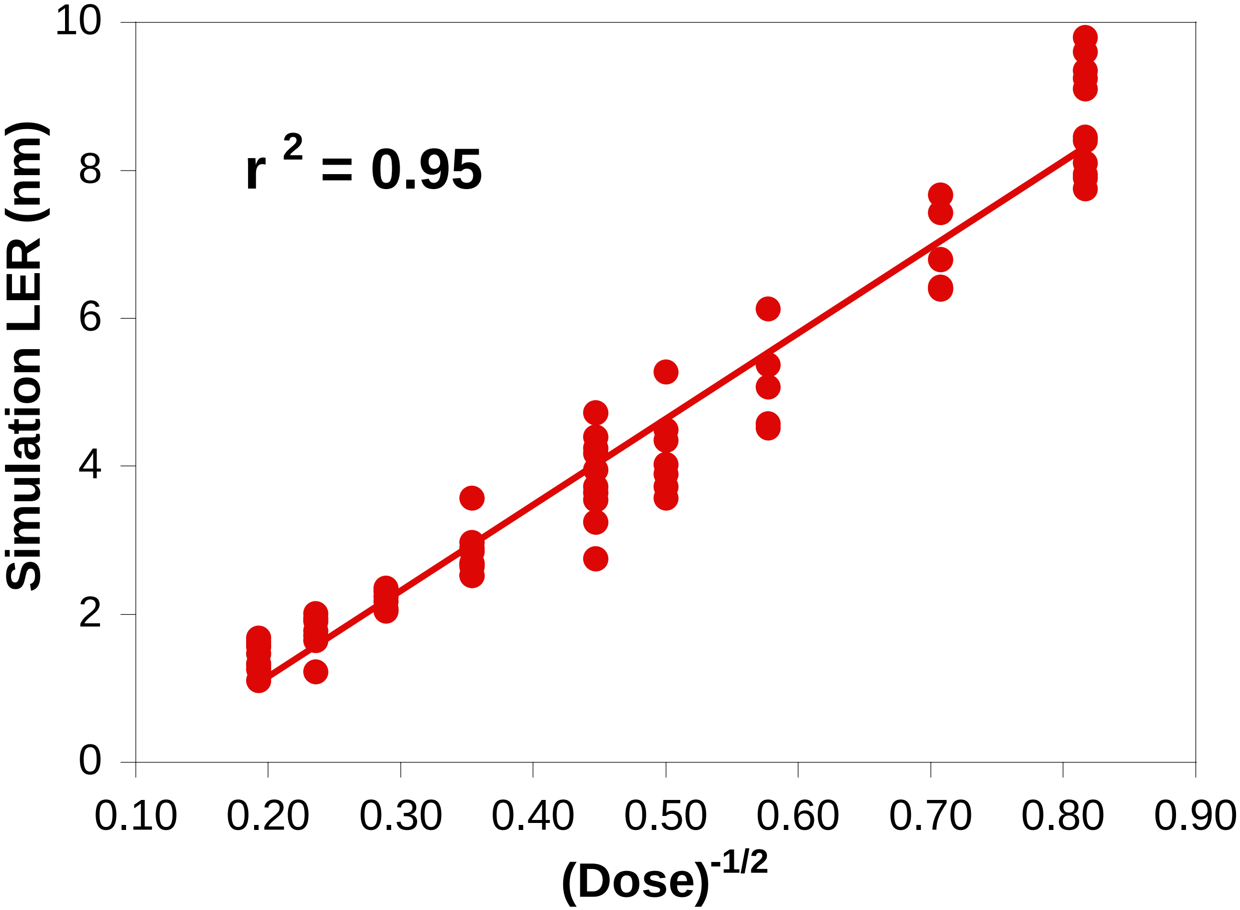


LER: 9.3 nm 5.4 nm 2.9 nm 1.6 nm

Increasing Base →

Simulated LER Results

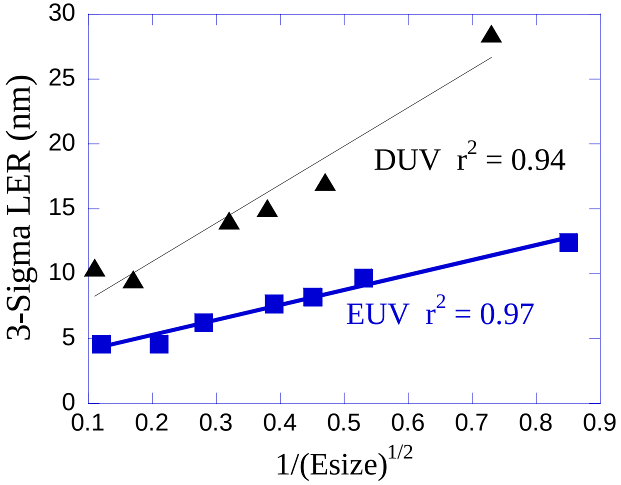
Excellent Fit of $(\text{Dose})^{-1/2}$



Simulated Results in Agreement with Experimental Work

Number and Distribution of Acids Define LER *vs.* $(\text{Dose})^{-1/2}$ Behavior

V. Quantum Efficiency



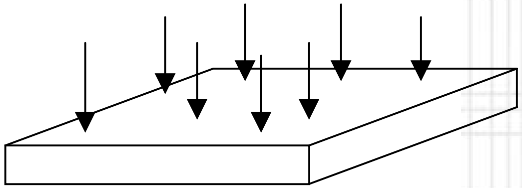
Why do both EUV and DUV show the same linear behavior?

$$\textbf{Quantum Efficiency} = \frac{\text{Number of Acids Generated}}{\text{Number of Photons Absorbed}}$$

V. Quantum Efficiency

Photons Absorbed

0.1 mJ/cm²
EUV Photons



1 cm x 1 cm x 125 nm
EUV-2D

Need to Know:

- Absorption 125 nm (41%)
- Number of EUV Photons / mJ/cm² (6.7×10^{13})

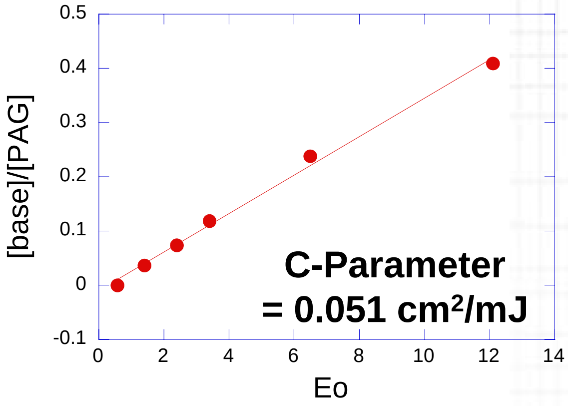
Photons Absorbed $= (0.1\ \text{mJ/cm}^2)(0.41)(6.7 \times 10^{13}\ \text{mJ/cm}^2)$

Acids Generated

Need to Know:

- C-Parameter
- [PAG]
- Avogadro's Number

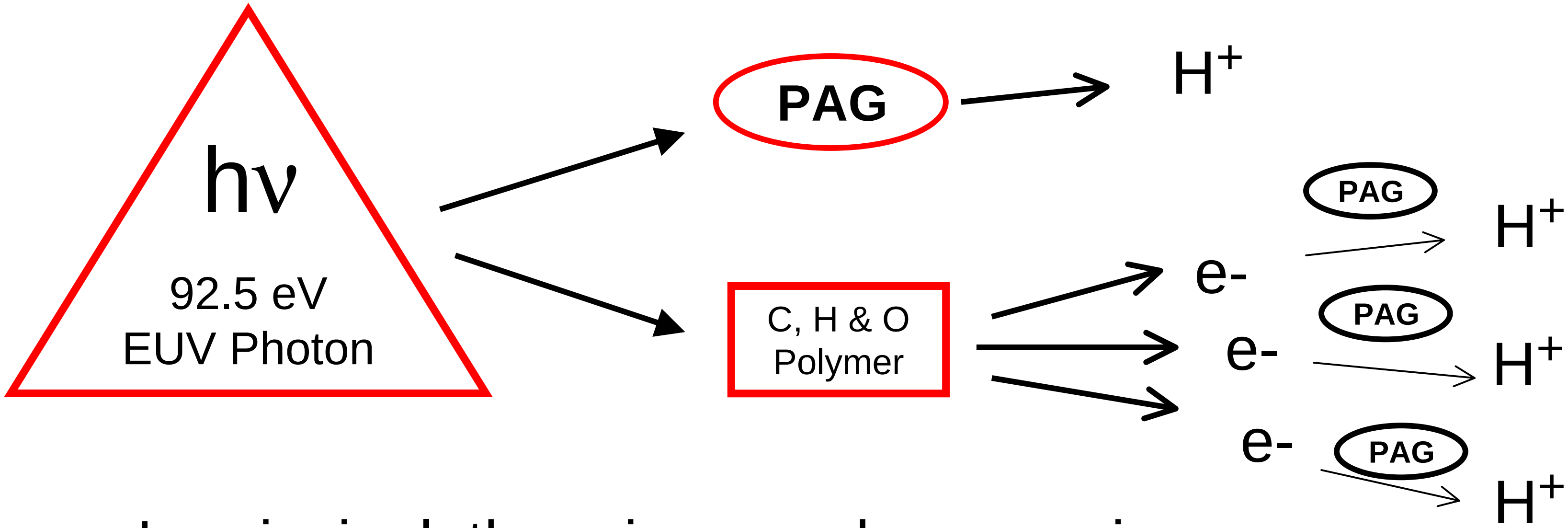
$$= [\text{PAG}](1 - e^{(-CE)})(6.02 \times 10^{23})$$



Szmanda's Base Titration Method

Quantum Efficiency of EUV-2D at DUV and 193 nm

	OD (1/um)	C-Parameter	Φ
DUV	0.37	0.037	0.33
193 nm	24.5	0.12	0.14



In principal, there is enough energy in an EUV photon to activate ~20-30 PAGs

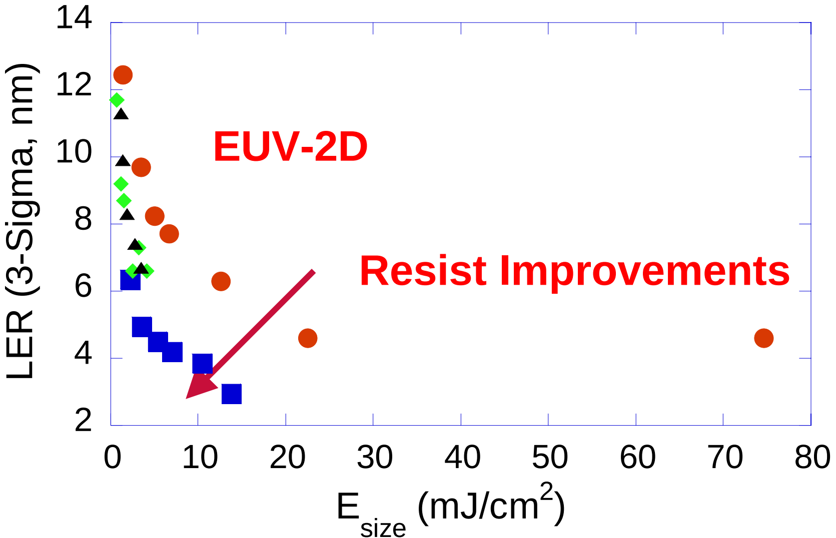
Quantum Efficiency of EUV-2D is 2.1!

Wavelength	E_{size} (mJ/cm^2)	# of Photons in 1 mJ/cm^2 x 10^{13}	Absoption of 125 nm	Quantum Efficiency	Number of Acids Generated @ E_{size} x 10^{13}
EUV	**6.7**	**6.7**	**0.41**	**2.08**	**38.2**
DUV	**9.7**	**125**	**0.10**	**0.33**	**40.6**

The number of acids generated at EUV and DUV are the same!

The LER vs. E_{size} Curves for both EUV and DUV are described by Shot Noise (Poisson) Statistics: $\mathrm{LER} \propto \mathrm{Dose}^{-1/2}$

VI. Is EUV Limited by Shot Noise?



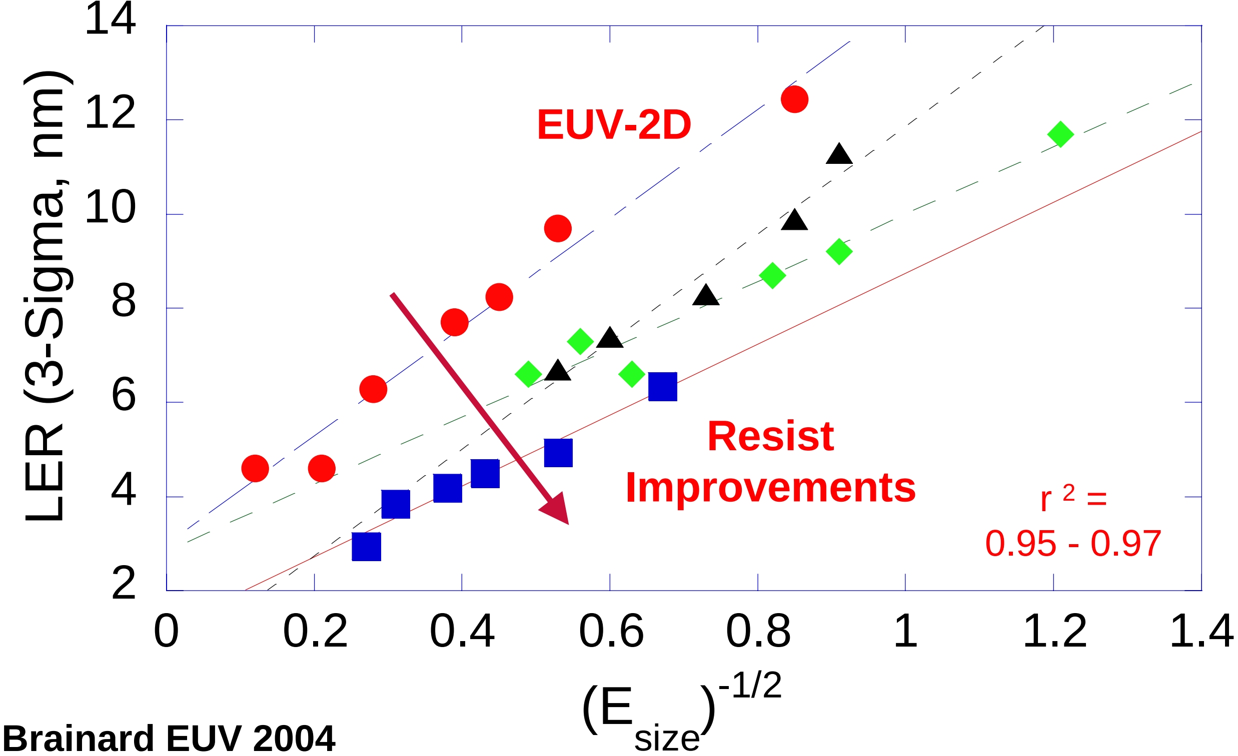
No Hard Barrier Yet

Although EUV-2D

follows a LER *vs.* E_{size} pattern

defined by

shot noise statistics,



New improved resists show

that performance is not

limited by shot noise

VII. Conclusions

Shot Noise observed at DUV and EUV for all resist systems

LER follows Poisson Statistical Rules: **LER $\propto$ Dose$^{-1/2}$**

Although EUV-2D follows a LER *vs.* E_{size} pattern defined by shot noise (Poisson) statistics, resists can be made with better LER/Sensitivity performance

Earlier studies of shot noise and LER either predicted:

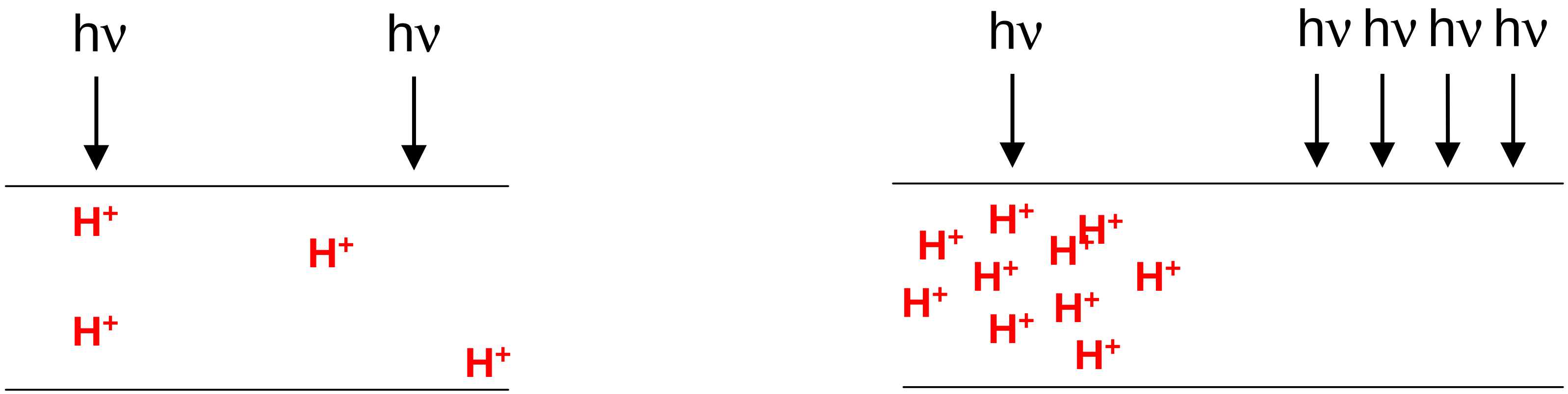
- Catastrophic LER failure, or
- Shot noise barrier not yet encountered

We conclude that shot noise statistics have been with us all along in DUV and EUV

What Don't We Know?

How are multiple acids from a single photon arranged?

Will this arrangement affect LER?



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