Resist Exposure and Development (Development Rate Monitor)

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3-29-2005 lec_drm.ppt

OUTLINE

INTRODUCTION

Measurement of the development rate of photoresist versus time gives a host of information about the resist, developer, reflections from the substrate and system parameters such as gamma.

MODELING OF EXPOSURE IN PHOTORESIST

Complex Index of Refraction of Photoresist **n^ = n -jK**

K = a l /4 p **is the extinction coefficient**

n = real part of the index of refraction

λ = wavelength

The absorption constant a

a **= A m(z,t) + B**

where m is the relative amount of photoactive inhibitor at position z and time t

A is the exposure dependent parameter

B is the exposure independent parameter

An optical sensitivity parameter C relates the destruction of inhibitor local irradiance, I

$$\frac{dm(z,t)}{dt} = -I(z,t)\ m(z,t)\ C$$

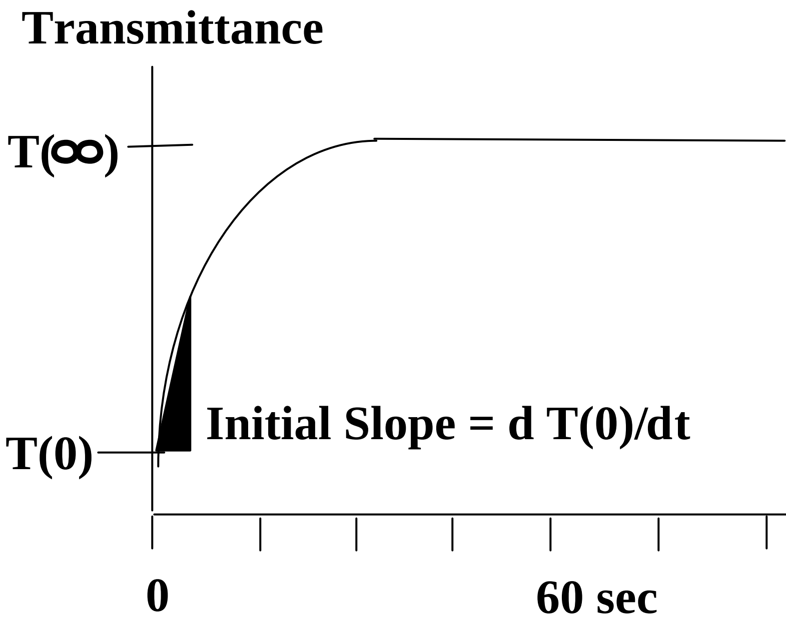
Dr. Fred H. Dill, IBM, IEEE Transactions on Electron Devices vol. ED-22, July 1975

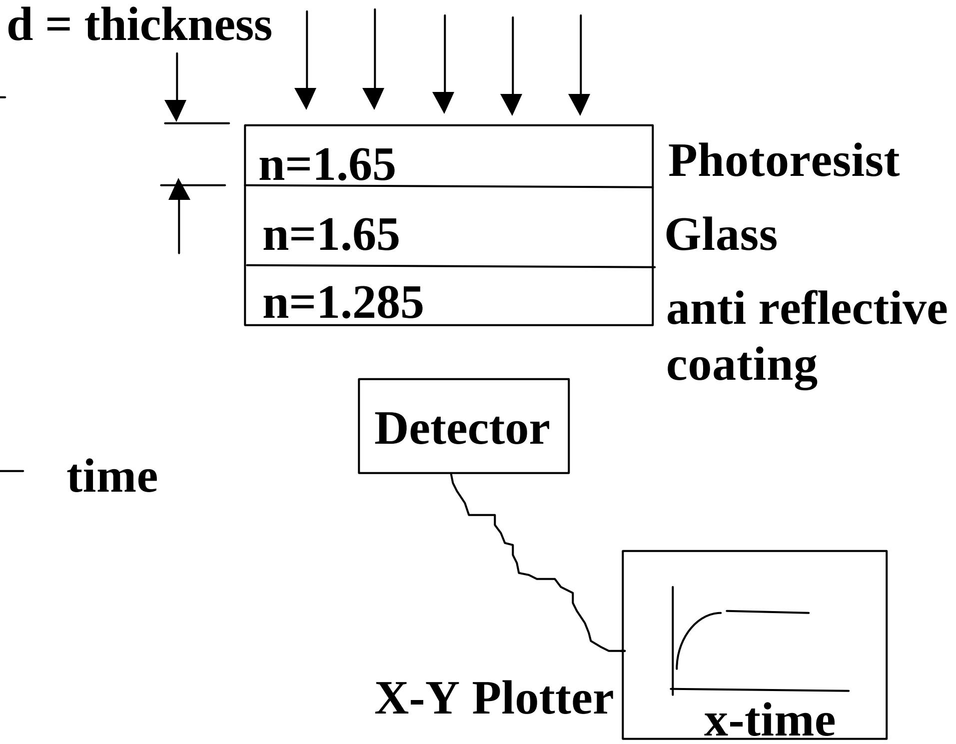
A,B,C PARAMETERS FOR EXPOSURE

A,B,C Exposure Parameters for AZ 1350J

l	A	B	C	n
	(µm^{-1})	(µm^{-1})	(cm^2/mj)	
436nm	0.54	0.06	0.014	1.68
405nm	0.86	0.07	0.018	1.70
365nm	0.74	0.20	0.012	1.72

MEASUREMENT OF A,B,C, PARAMETERS





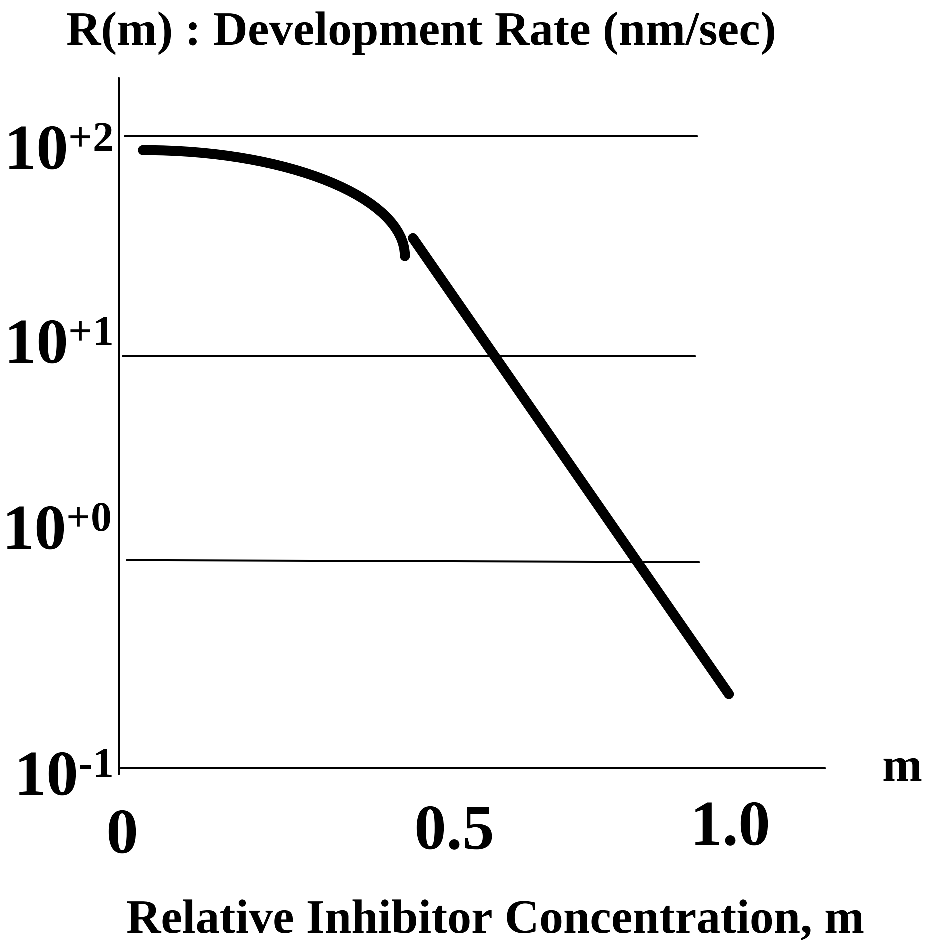
$$A = 1/d \ \ln [T(\infty)/T(0)]$$
$$B = -1/d \ \ln T(\infty)$$
$$C = \ \{A+B/AI_0 \ T(0) \ (1-T(0))\} \ dT(0)/dt$$

MODELING OF DEVELOPMENT IN POSITIVE RESIST

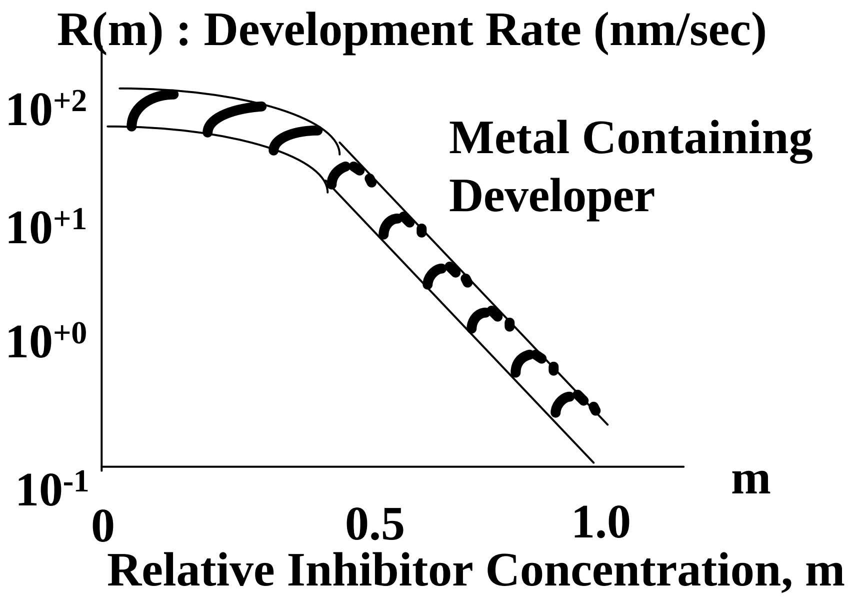
Kim's Model:

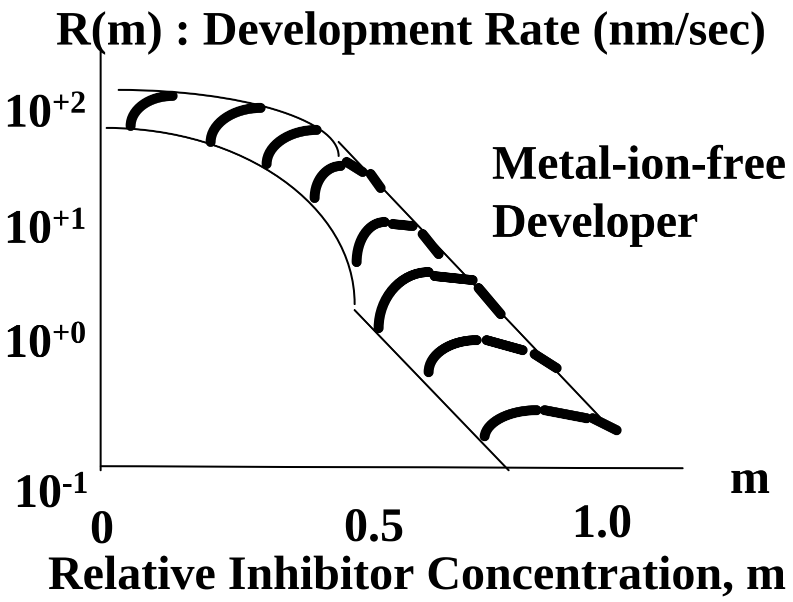
$$R(m) = \frac{1}{\dfrac{1 - m e^{Rs\,(1-m)}}{R1} + \dfrac{m e^{-Rs(1-m)}}{R2}}$$

where R1 is rate of fully exposed resist
R2 is rate of unexposed resist
Rs is sensitivity of development rate to changes in m



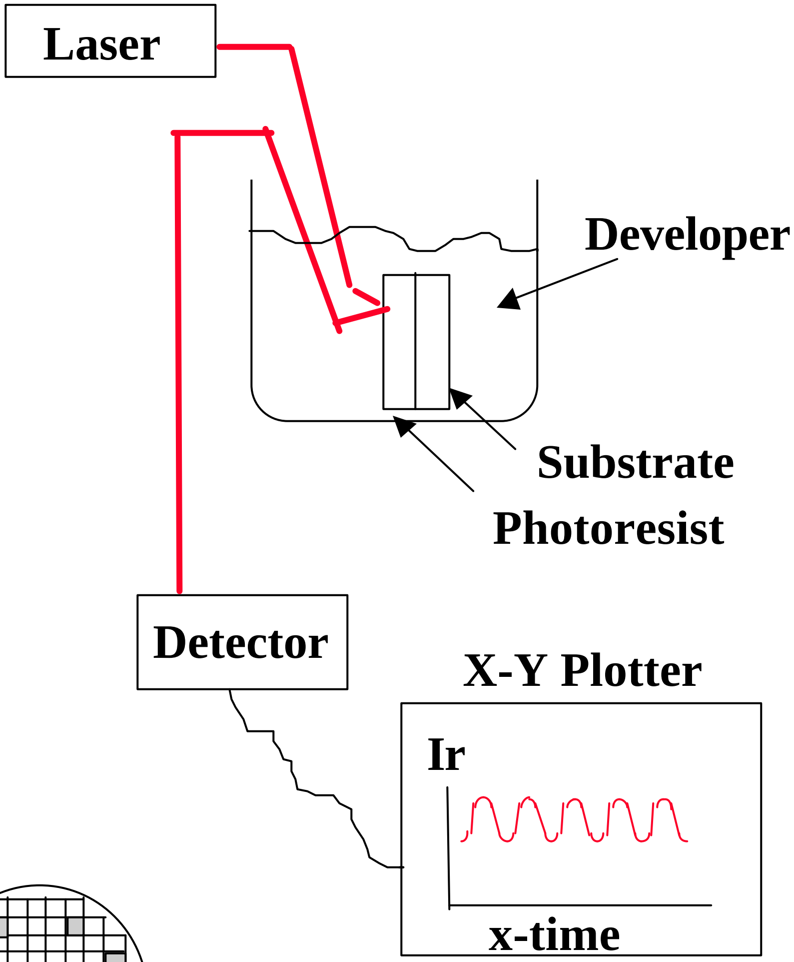
SURFACE RATE RETARDATION EFFECT



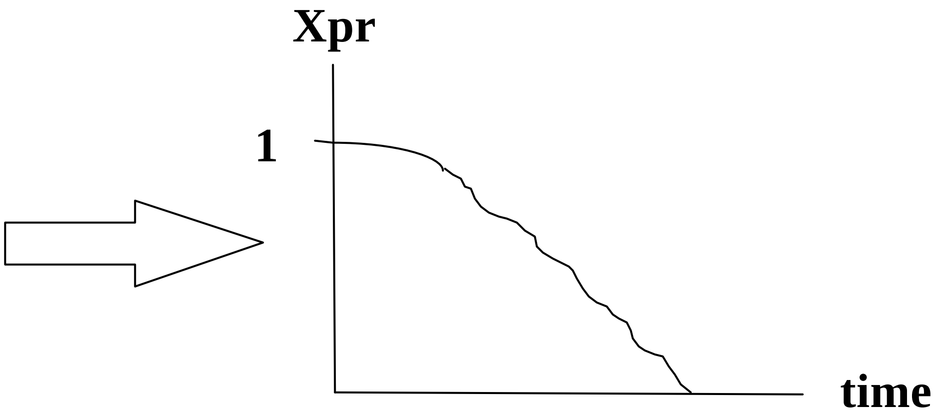


This retardation may be described by a multiplicative factor which varies linearly with exposure parameter m. The value of the factor with m=0 is called R5 and with m=1 is called R6. The depth dependence factor is exponential with characteristic delay distance R4. Metal-ion-free developer uses additional parameters R7, R8, R, R10.

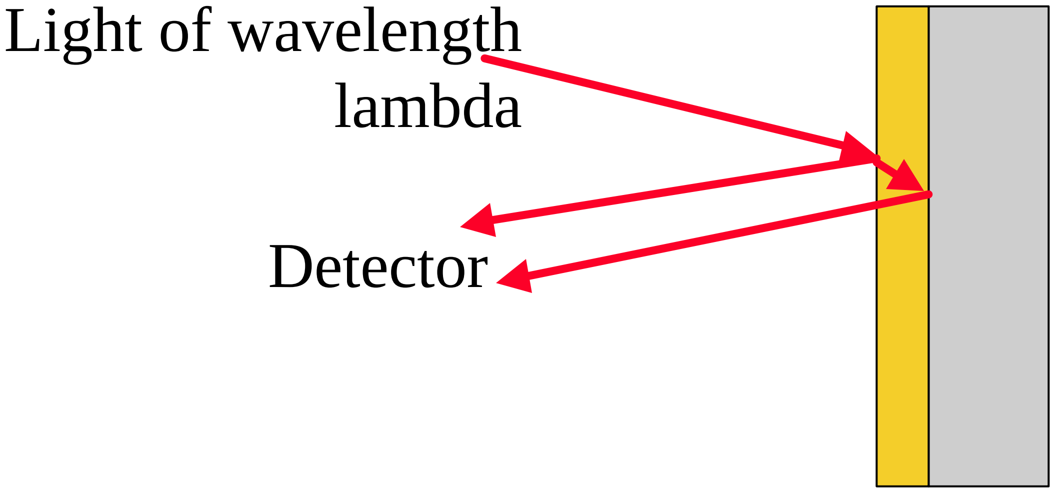
MEASUREMENT OF DEVELOPMENT RATE



Convert the data Ir vs t into Xpr vs t
The slope dXpr/dt
is the development rate.

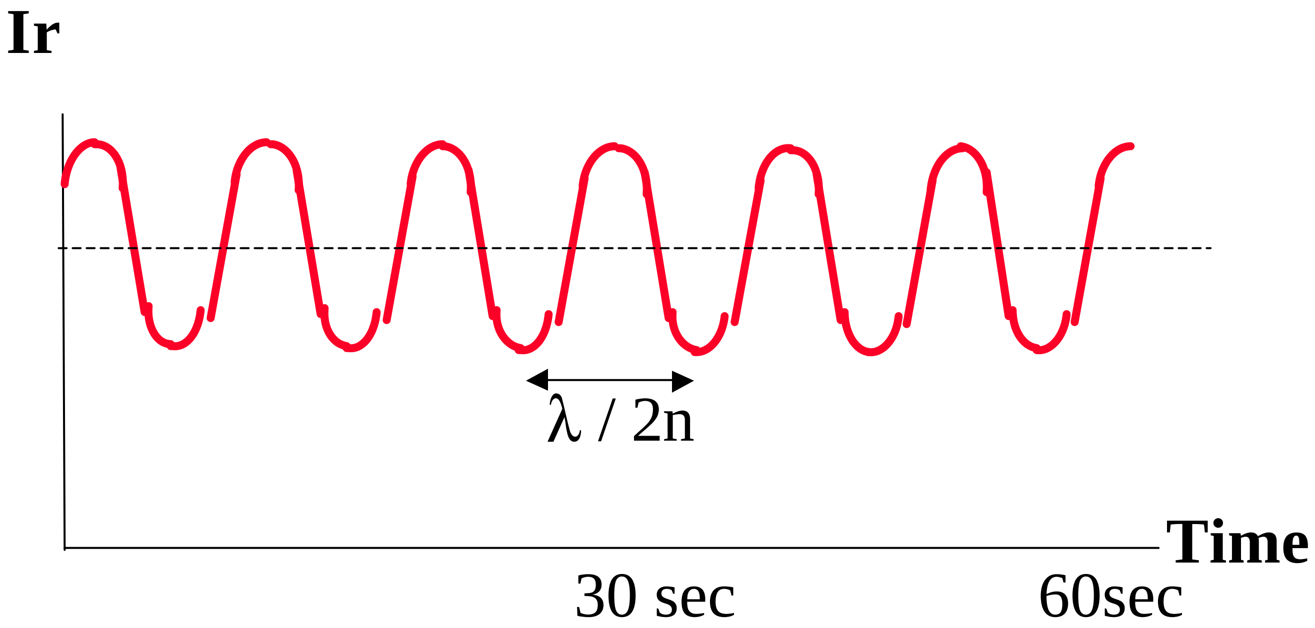


ORIGIN OF THE SIGNAL



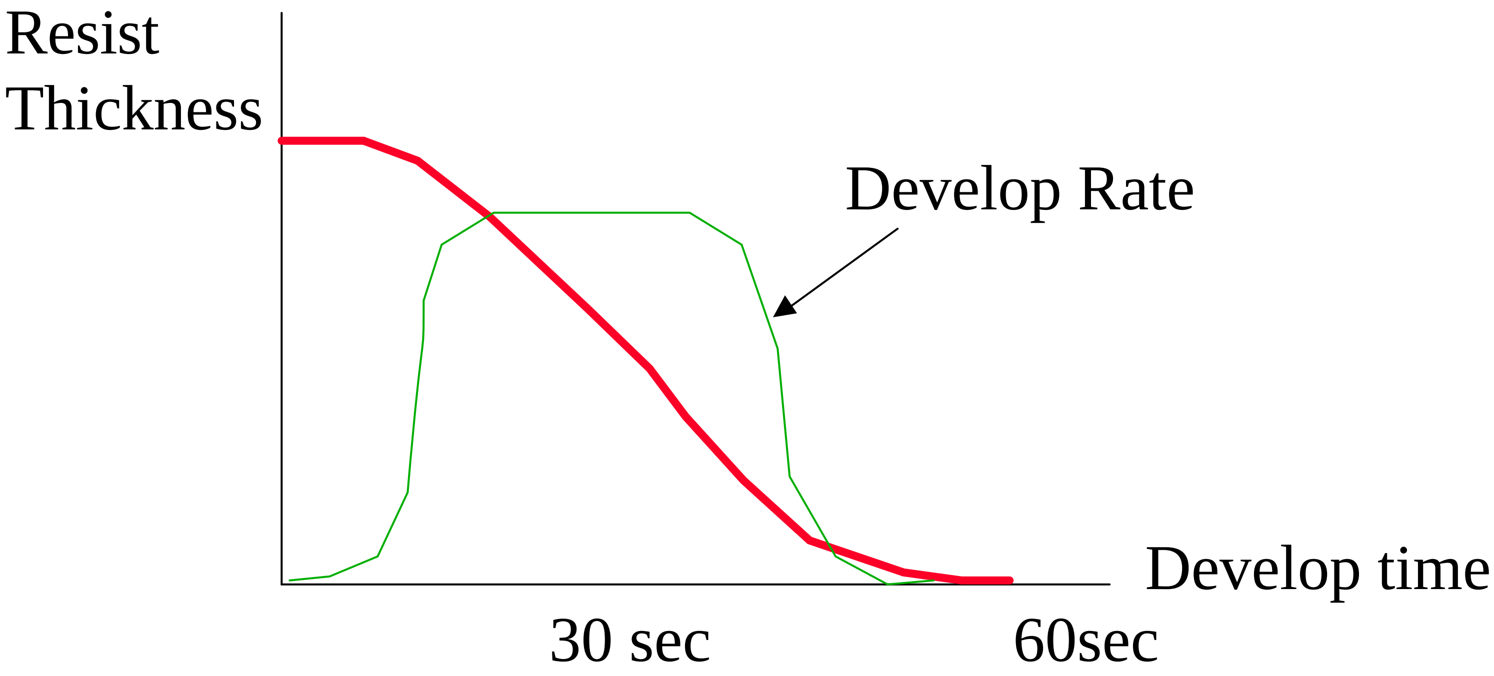
The reflected light intensity is the combination of the light reflected from the surface of the resist and from the surface of the substrate. If the resist thickness is a multiple of lambda/2n then the light reflected from the substrate will be in phase with the light reflected from the surface of the resist. The combination will be a signal maximum. As the resist is developed it becomes thinner giving signal minima and maxima until the resist is gone.

SIGNAL VERSUS TIME

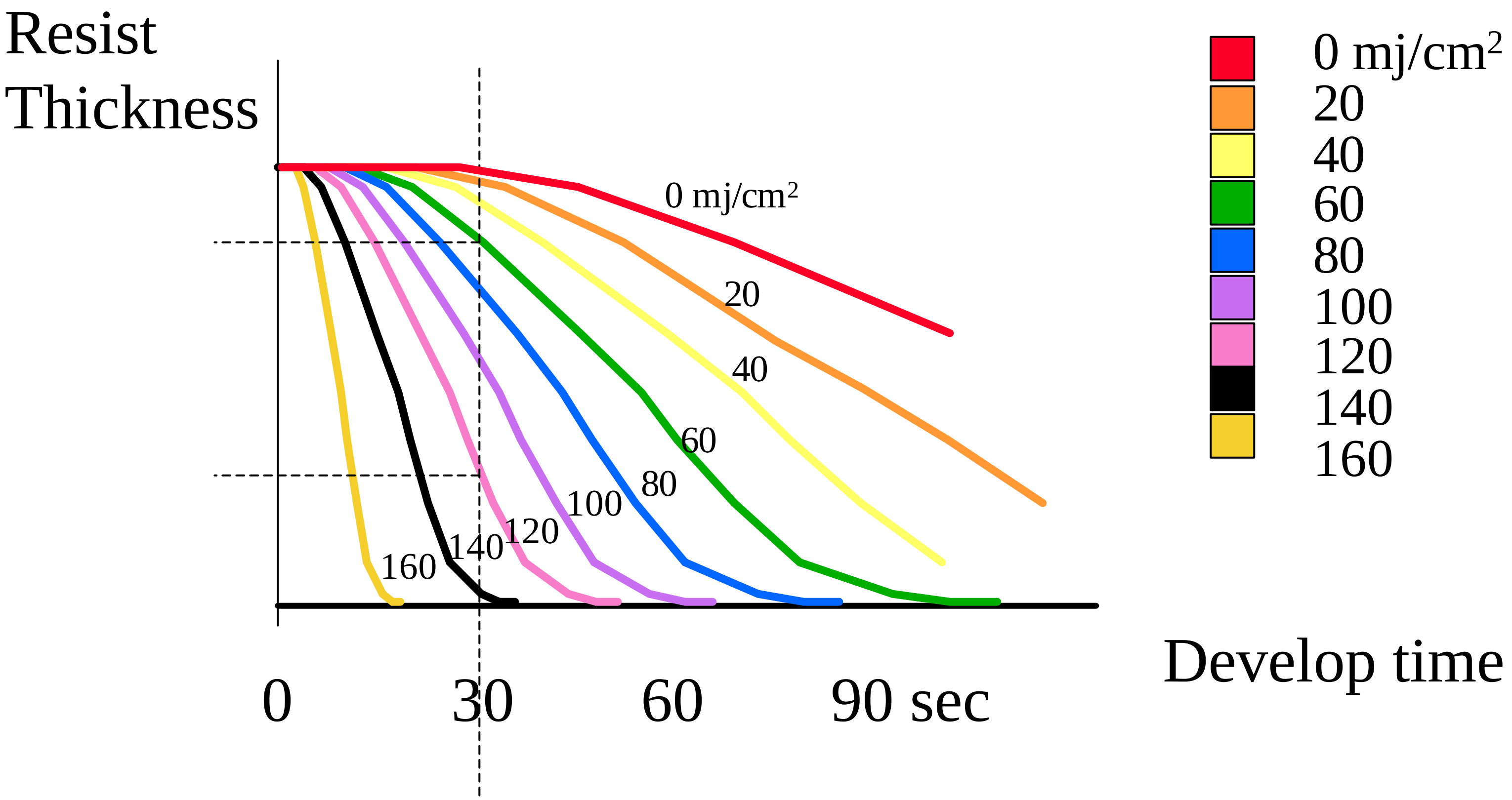


Example: λ = 6328Å and total of ~6 cycles each representing λ/2n and n = 1.68 so starting resist thickness = 1.13 µm

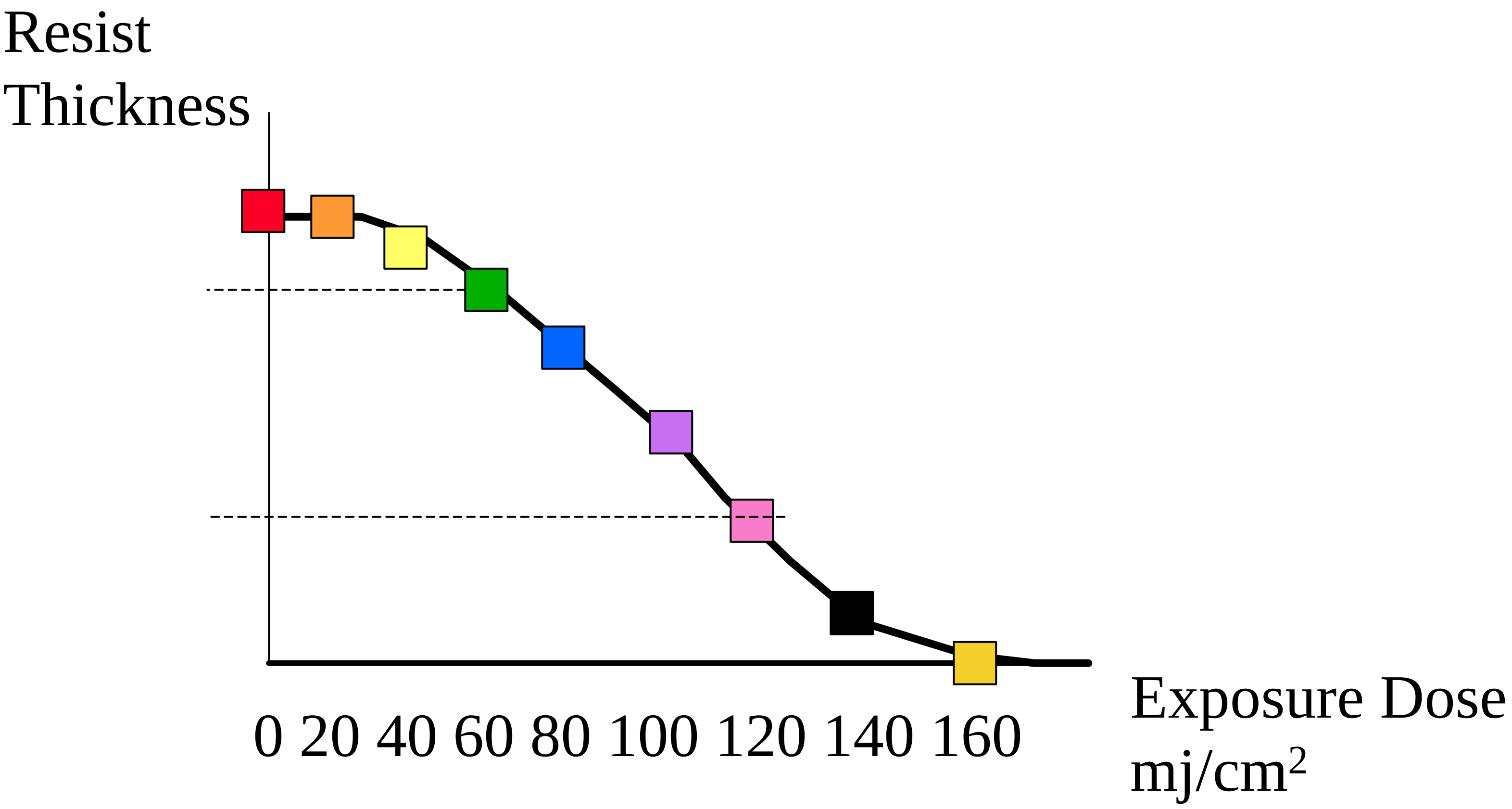
THICKNESS AND RATE VERSUS TIME



THICKNESS VERSUS TIME FOR DIFFERENT EXPOSURE

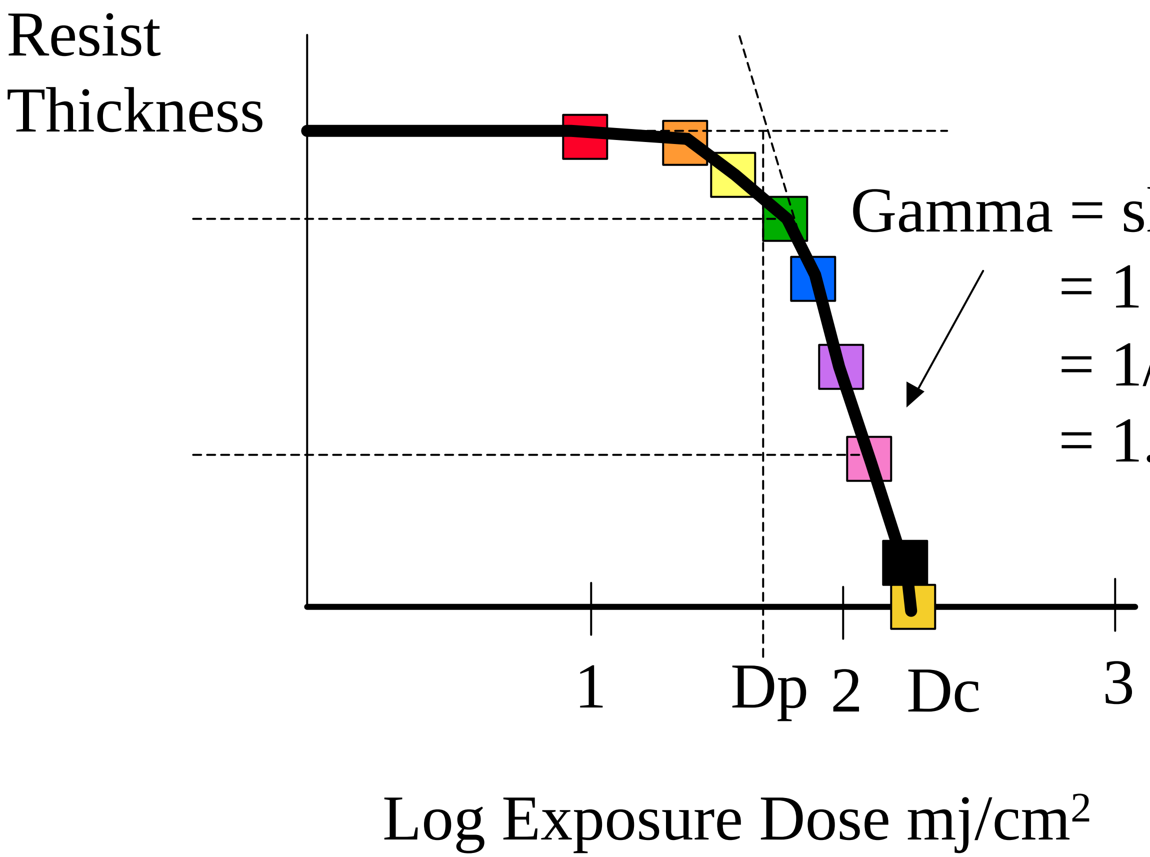


THICKNESS VERSUS EXPOSURE



THICKNESS VERSUS LOG EXPOSURE - GAMMA

0
1.3
1.6
1.78
1.90
2
2.08
2.15
2.20

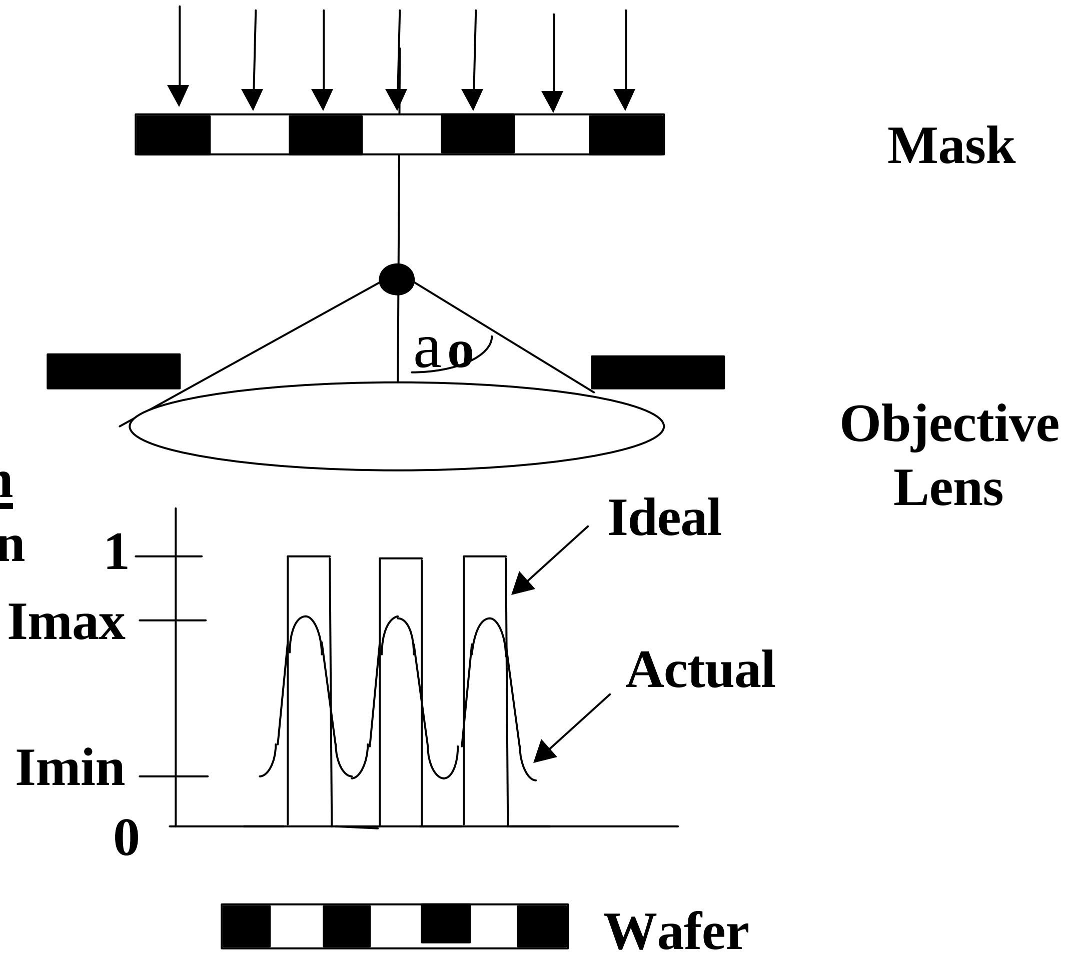


Gamma = slope
$= 1 / (\log Dp - \log Dc)$
$= 1/ (2.2-1.6)$
$= 1.67$

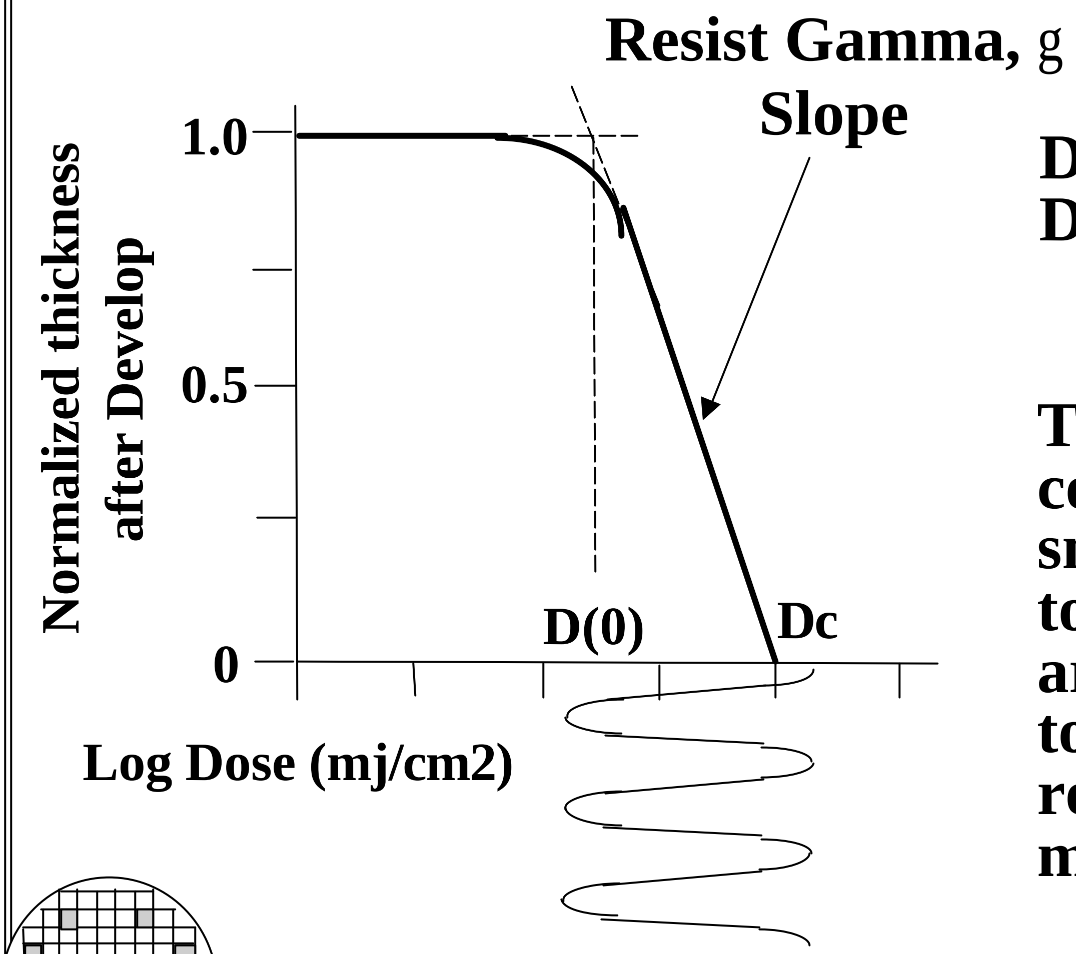
MODULATION

Modulation:

$$M = \frac{Imax - Imin}{Imax + Imin}$$



RELATIONSHIP BETWEEN MODULATION AND GAMMA

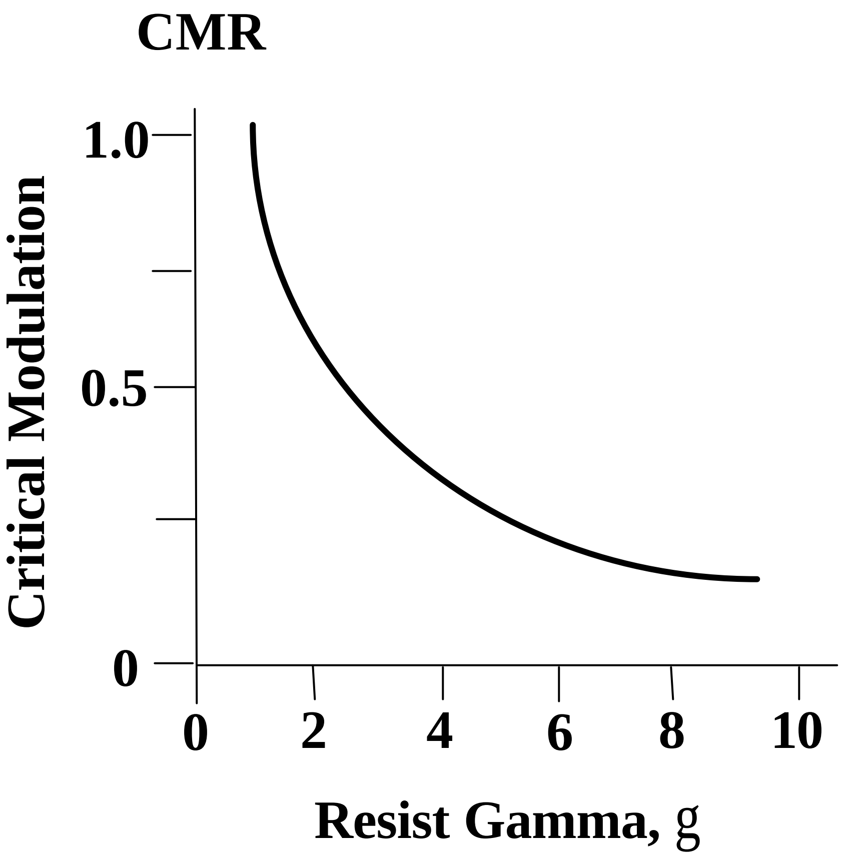


Dc is the dose to clear
D(0) is the max dose for unexposed areas

The higher the slope or contrast, gamma, then the smaller the difference needs to be between exposure in areas to be cleared and areas to leave resist. That is the required aerial image modulation is smaller.

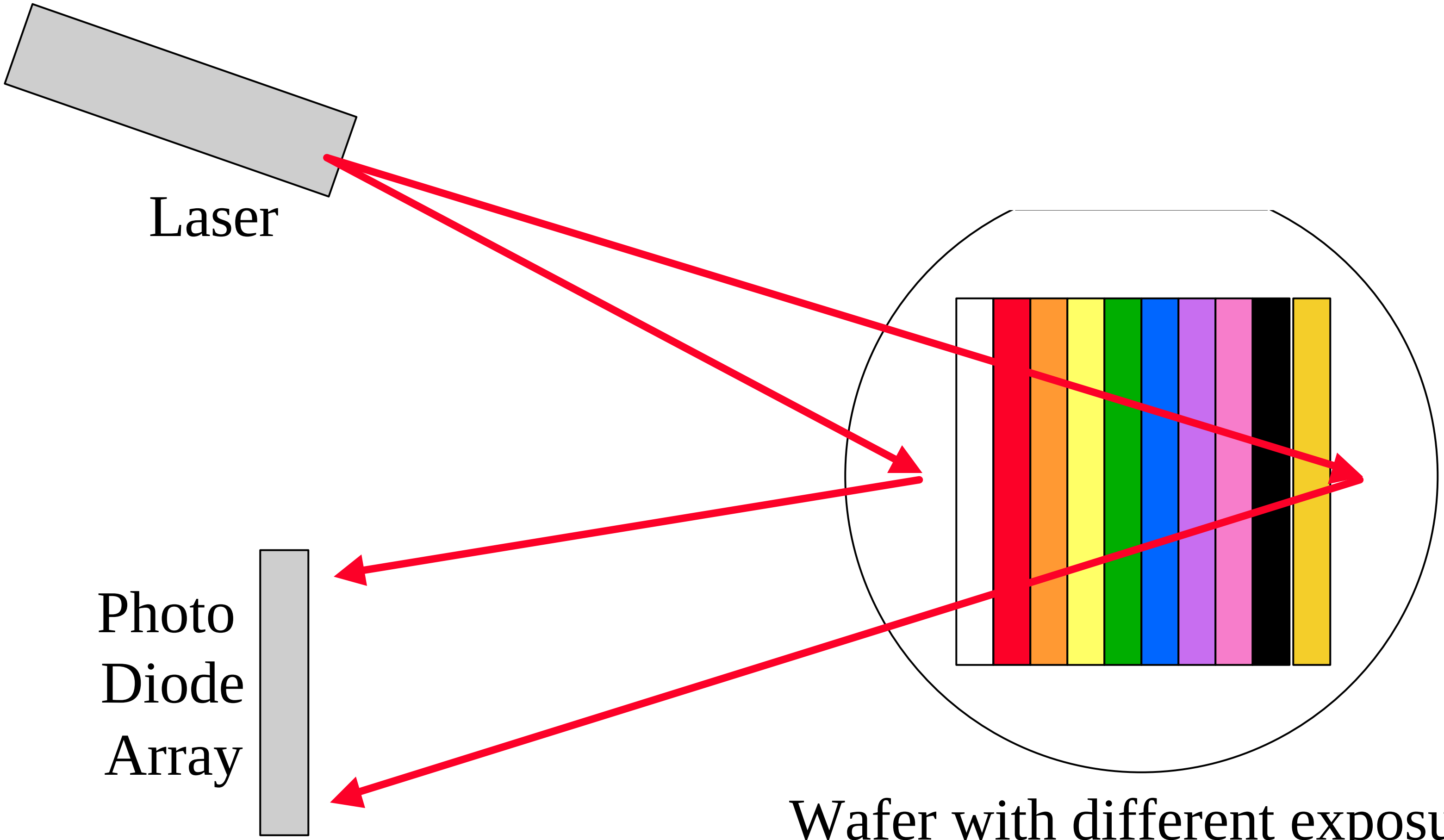
CRITICAL MODULATION FOR RESIST

The higher the contrast, gamma, the smaller the required aerial image modulation.



$$\mathrm{CMR} = (10^{1/g} - 1)/(10^{1/g} + 1)$$

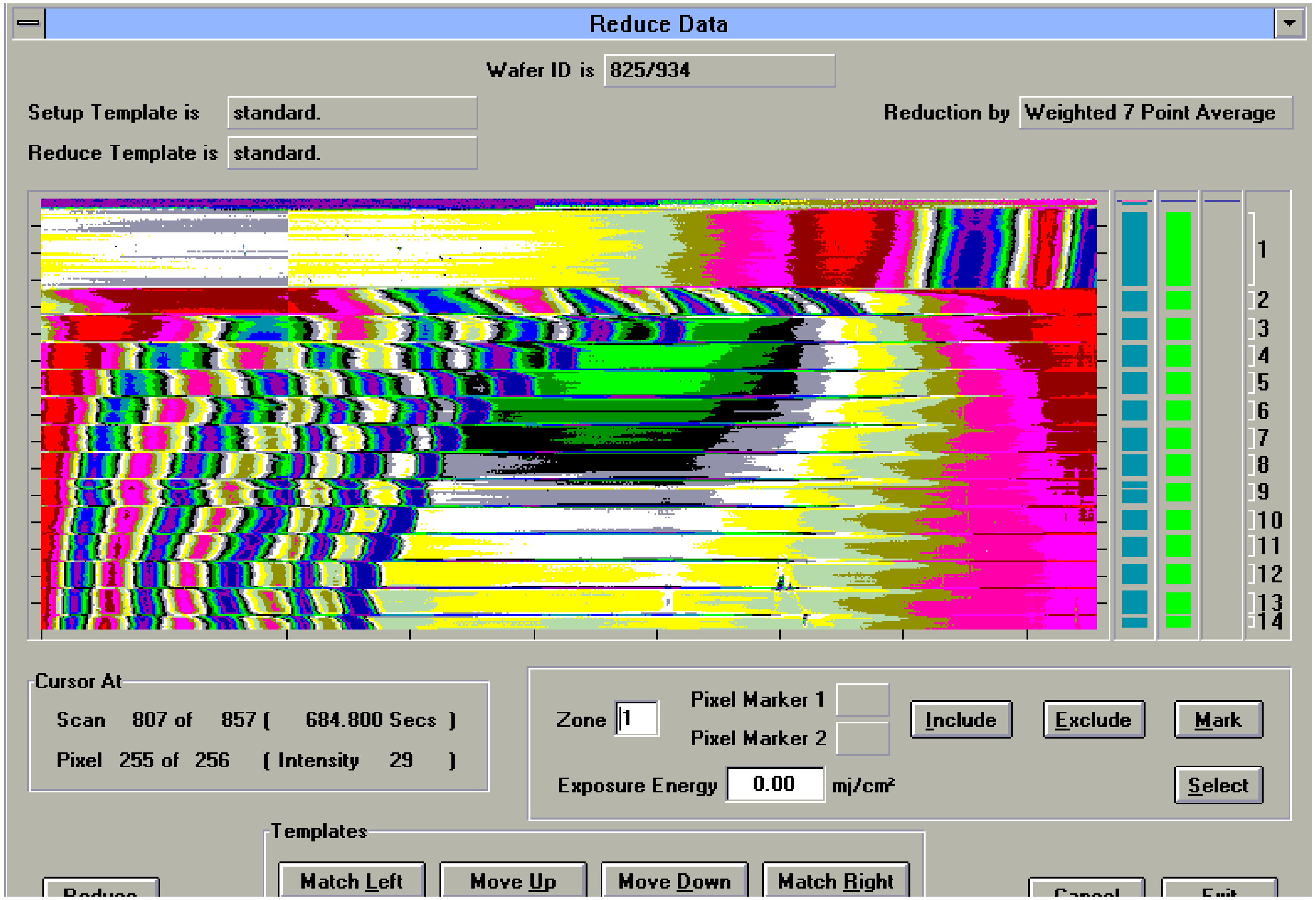
DEVELOPMENT RATE MONITOR (DRM)



Wafer with different exposures
(special stepper job)

PERKIN ELMER DRM

RAW DATA FROM 256 PHOTO DIODES



Reduce Data

Wafer ID is 825/934

Setup Template is standard.

Reduce Template is standard.

Reduction by Weighted 7 Point Average

Cursor At

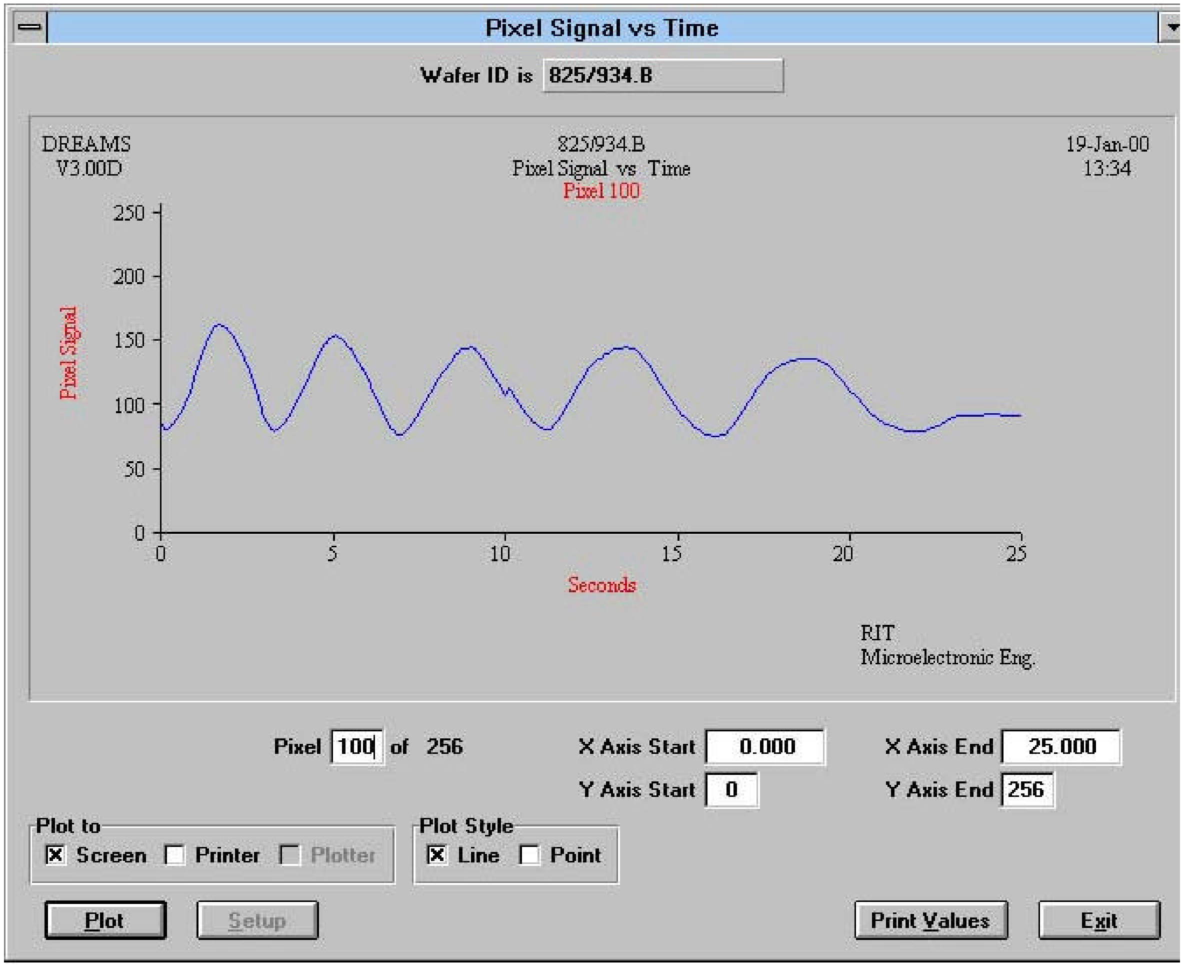
Scan 807 of 857 (684.800 Secs)

Pixel 255 of 256 (Intensity 29)

Zone 1

Exposure Energy 0.00 mj/cm²

PIXEL #100 SIGNAL VERSUS TIME



Wafer ID is 825/934.B

Pixel 100 of 256

X Axis Start 0.000

X Axis End 25.000

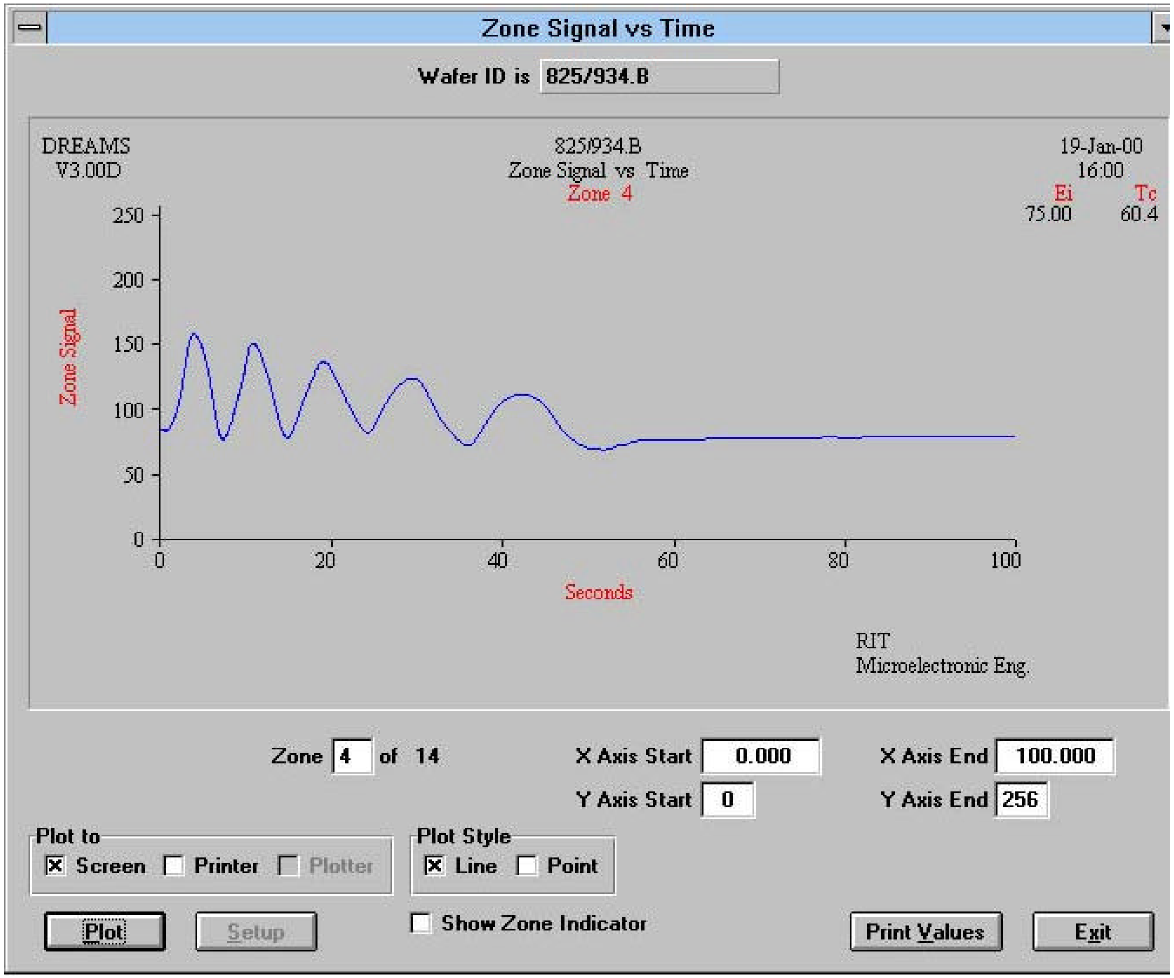
Y Axis Start 0

Y Axis End 256

Plot to: ☒ Screen ☐ Printer ☐ Plotter

Plot Style: ☒ Line ☐ Point

ZONE THICKNESS VERSUS TIME



Wafer ID is 825/934.B

Zone 4 of 14

X Axis Start 0.000

X Axis End 100.000

Y Axis Start 0

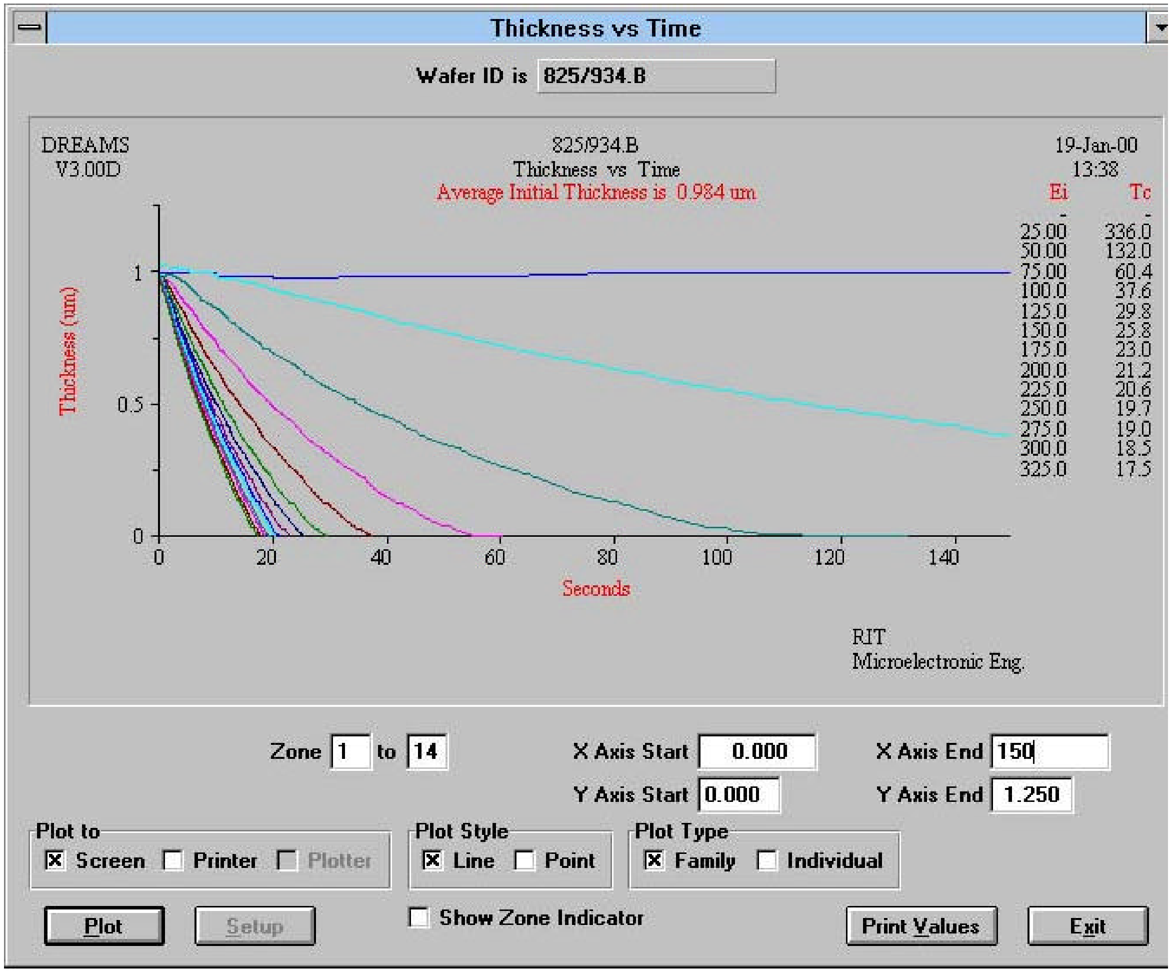
Y Axis End 256

Plot to: ☒ Screen ☐ Printer ☐ Plotter

Plot Style: ☒ Line ☐ Point

☐ Show Zone Indicator

THICKNESS VERSUS TIME FAMILY



Wafer ID is 825/934.B

Average Initial Thickness is 0.984 um

Ei	Tc
-	-
25.00	336.0
50.00	132.0
75.00	60.4
100.0	37.6
125.0	29.8
150.0	25.8
175.0	23.0
200.0	21.2
225.0	20.6
250.0	19.7
275.0	19.0
300.0	18.5
325.0	17.5

Zone 1 to 14

X Axis Start 0.000

X Axis End 150

Y Axis Start 0.000

Y Axis End 1.250

Plot to: ☒ Screen ☐ Printer ☐ Plotter

Plot Style: ☒ Line ☐ Point

Plot Type: ☒ Family ☐ Individual

☐ Show Zone Indicator

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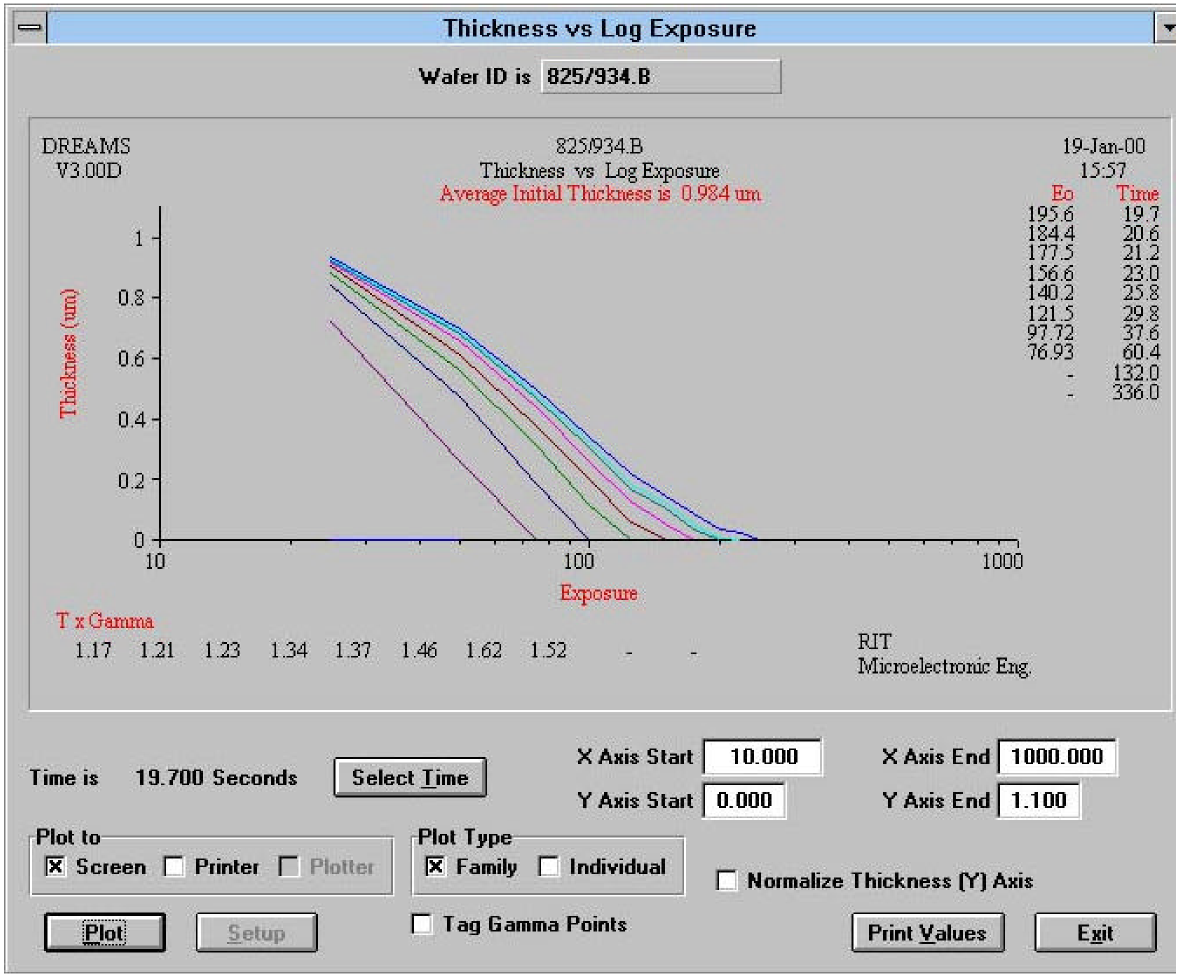
THICKNESS VERSUS LOG DOSE



Wafer ID is 825/934.B

DREAMS
V3.00D

825/934.B
Thickness vs Log Exposure
Average Initial Thickness is 0.984 um

19-Jan-00
15:57

Eo	Time
195.6	19.7
184.4	20.6
177.5	21.2
156.6	23.0
140.2	25.8
121.5	29.8
97.72	37.6
76.93	60.4
-	132.0
-	336.0

T x Gamma
1.17 1.21 1.23 1.34 1.37 1.46 1.62 1.52 - -

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Time is 19.700 Seconds

X Axis Start 10.000

X Axis End 1000.000

Y Axis Start 0.000

Y Axis End 1.100

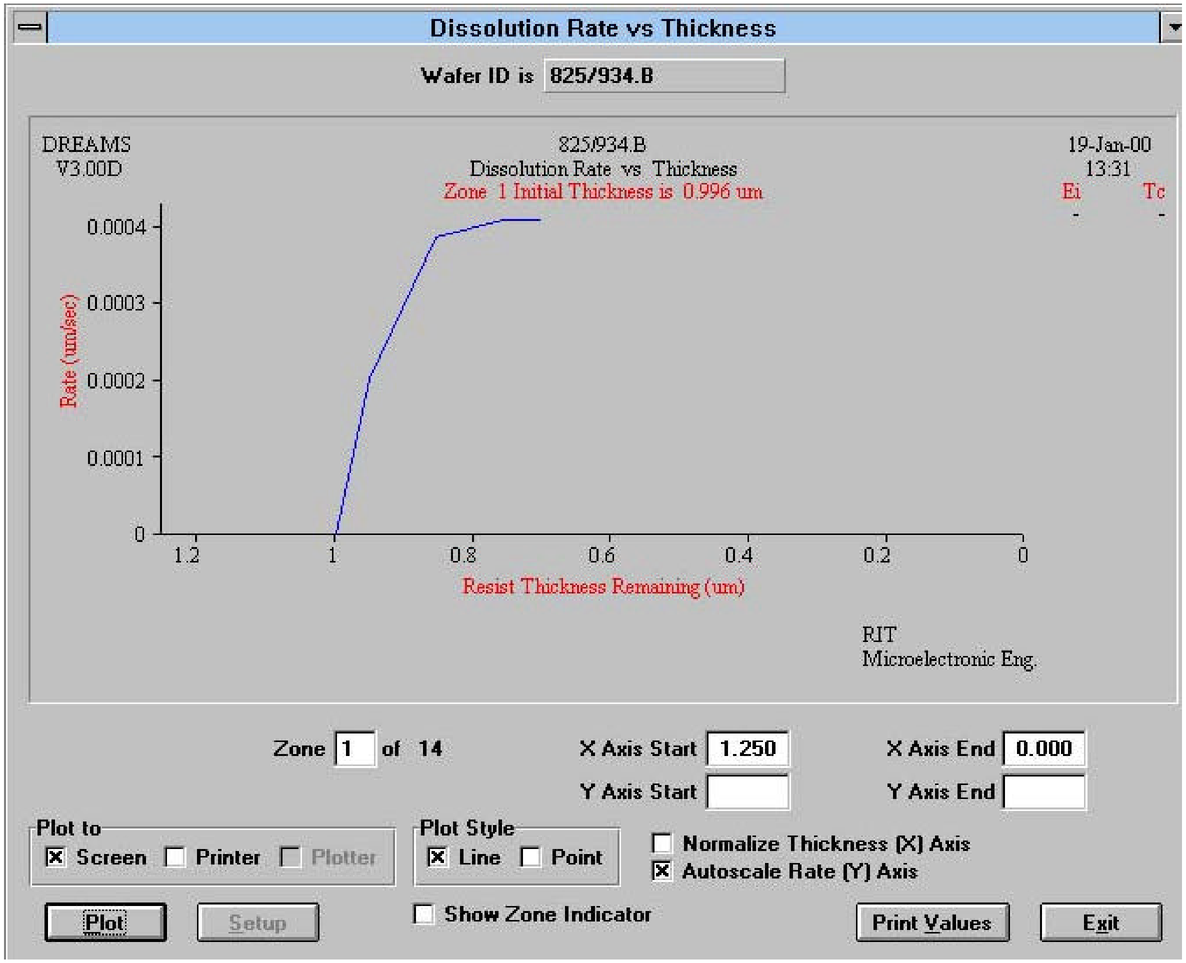
Plot to: ☒ Screen ☐ Printer ☐ Plotter

Plot Type: ☒ Family ☐ Individual

☐ Normalize Thickness (Y) Axis

☐ Tag Gamma Points

DISSOLUTION RATE VERSUS THICKNESS



Wafer ID is 825/934.B

Zone 1 of 14

X Axis Start 1.250

X Axis End 0.000

Y Axis Start

Y Axis End

Plot to

☒ Screen ☐ Printer ☐ Plotter

Plot Style

☒ Line ☐ Point

☐ Normalize Thickness (X) Axis

☒ Autoscale Rate (Y) Axis

☐ Show Zone Indicator

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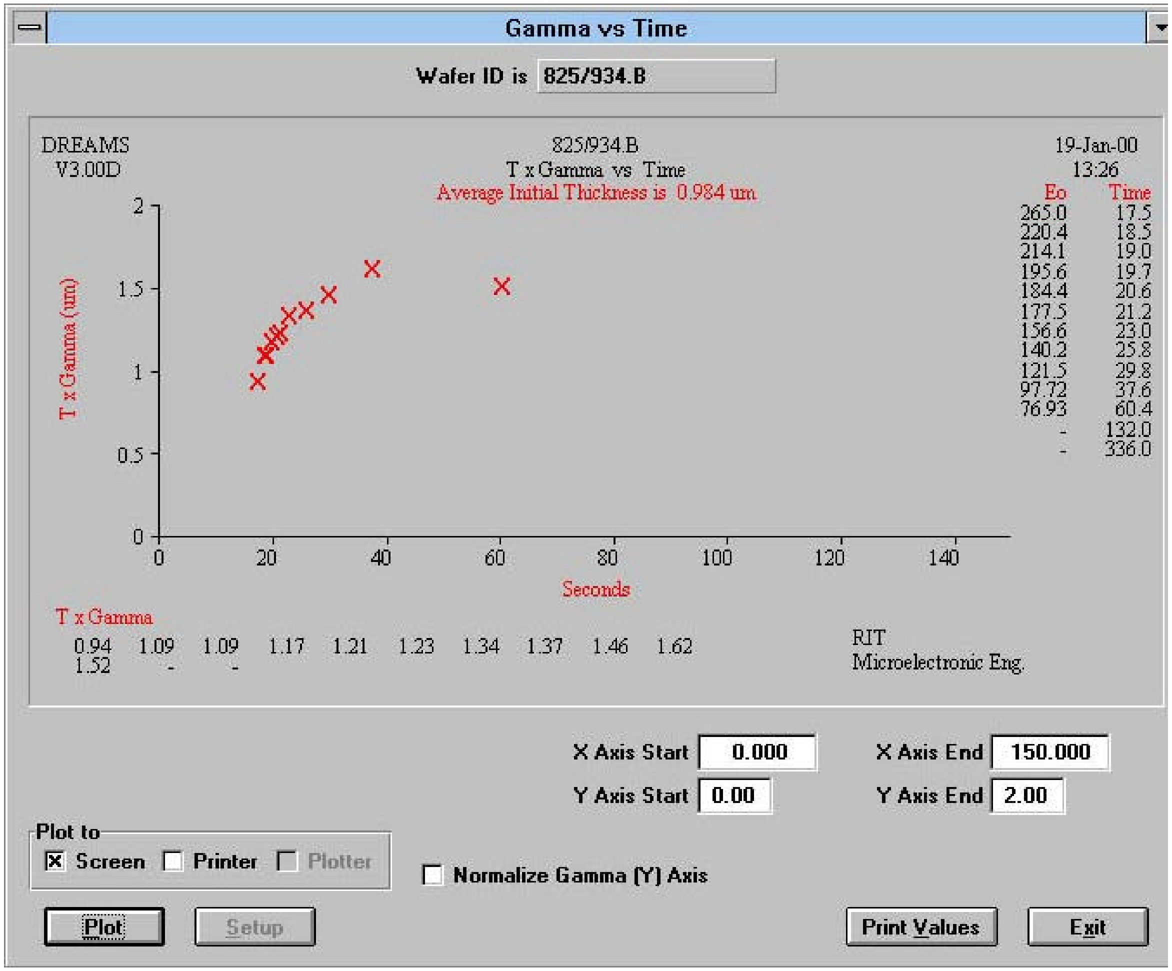
THICKNESS TIMES GAMMA VERSUS TIME



Wafer ID is 825/934.B

Average Initial Thickness is 0.984 um

19-Jan-00
13:26

Eo	Time
265.0	17.5
220.4	18.5
214.1	19.0
195.6	19.7
184.4	20.6
177.5	21.2
156.6	23.0
140.2	25.8
121.5	29.8
97.72	37.6
76.93	60.4
-	132.0
-	336.0

T x Gamma

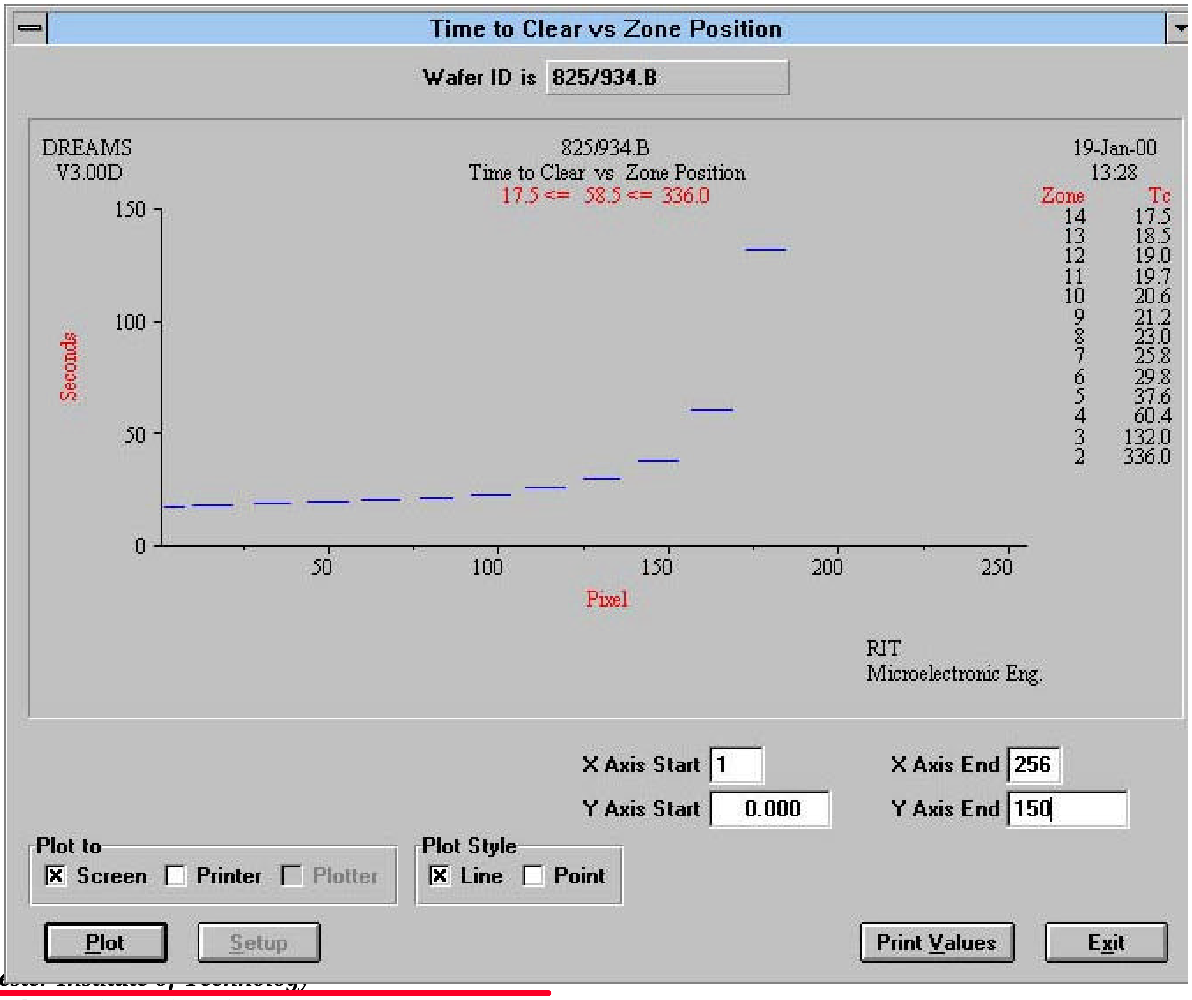
```
0.94   1.09   1.09   1.17   1.21   1.23   1.34   1.37   1.46   1.62
1.52    -      -
```

X Axis Start 0.000
X Axis End 150.000
Y Axis Start 0.00
Y Axis End 2.00

Plot to
☒ Screen ☐ Printer ☐ Plotter

☐ Normalize Gamma (Y) Axis

TIME TO CLEAR VERSUS ZONE POSITION



Time to Clear vs Zone Position

Wafer ID is 825/934.B

DREAMS
V3.00D

825/934.B
Time to Clear vs Zone Position
17.5 <= 58.5 <= 336.0

19-Jan-00
13:28

Zone	Tc
14	17.5
13	18.5
12	19.0
11	19.7
10	20.6
9	21.2
8	23.0
7	25.8
6	29.8
5	37.6
4	60.4
3	132.0
2	336.0

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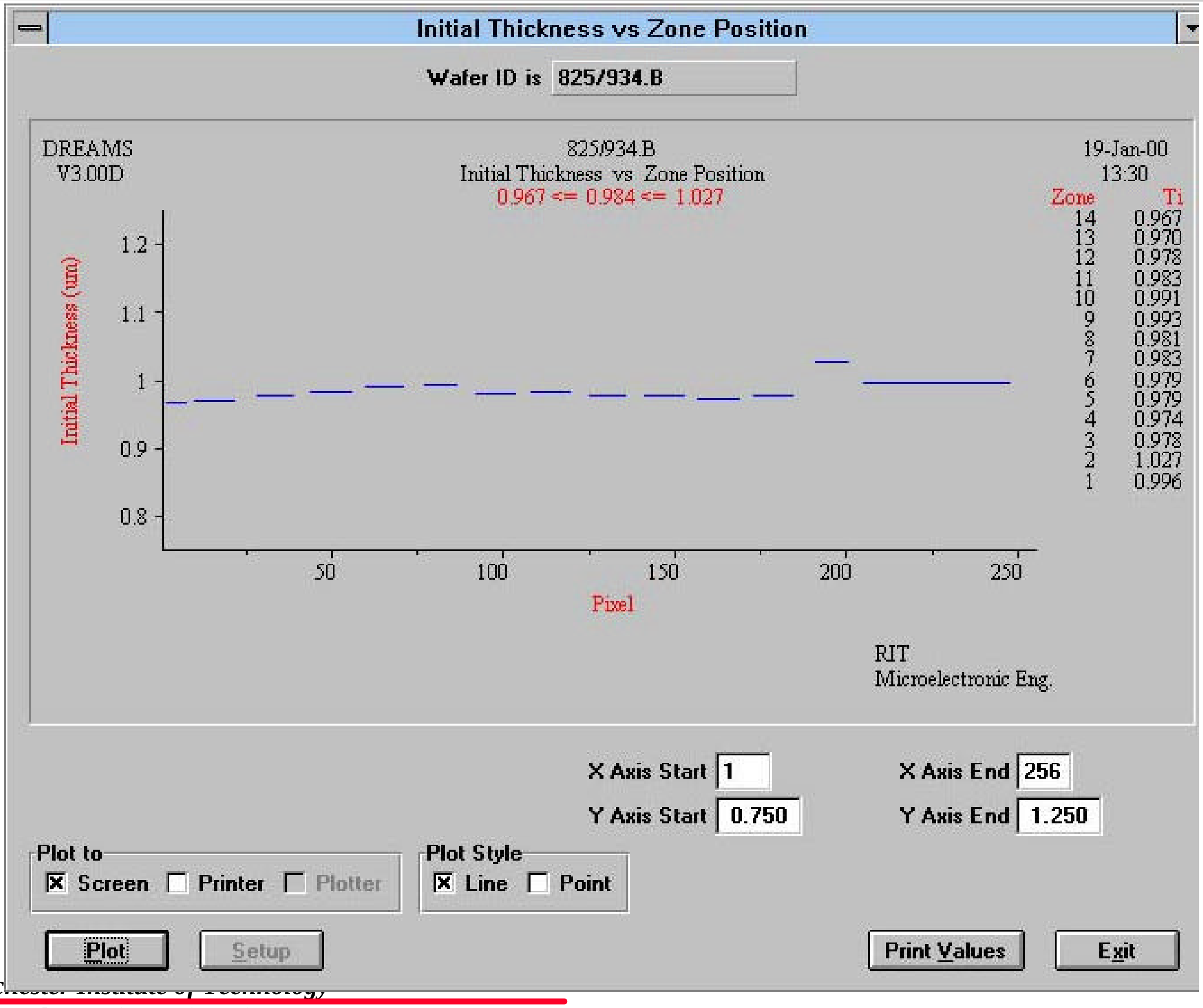
X Axis Start: 1
X Axis End: 256
Y Axis Start: 0.000
Y Axis End: 150

Plot to: ☒ Screen ☐ Printer ☐ Plotter

Plot Style: ☒ Line ☐ Point

INITIAL THICKNESS VERSUS ZONE POSITION



Wafer ID is 825/934.B

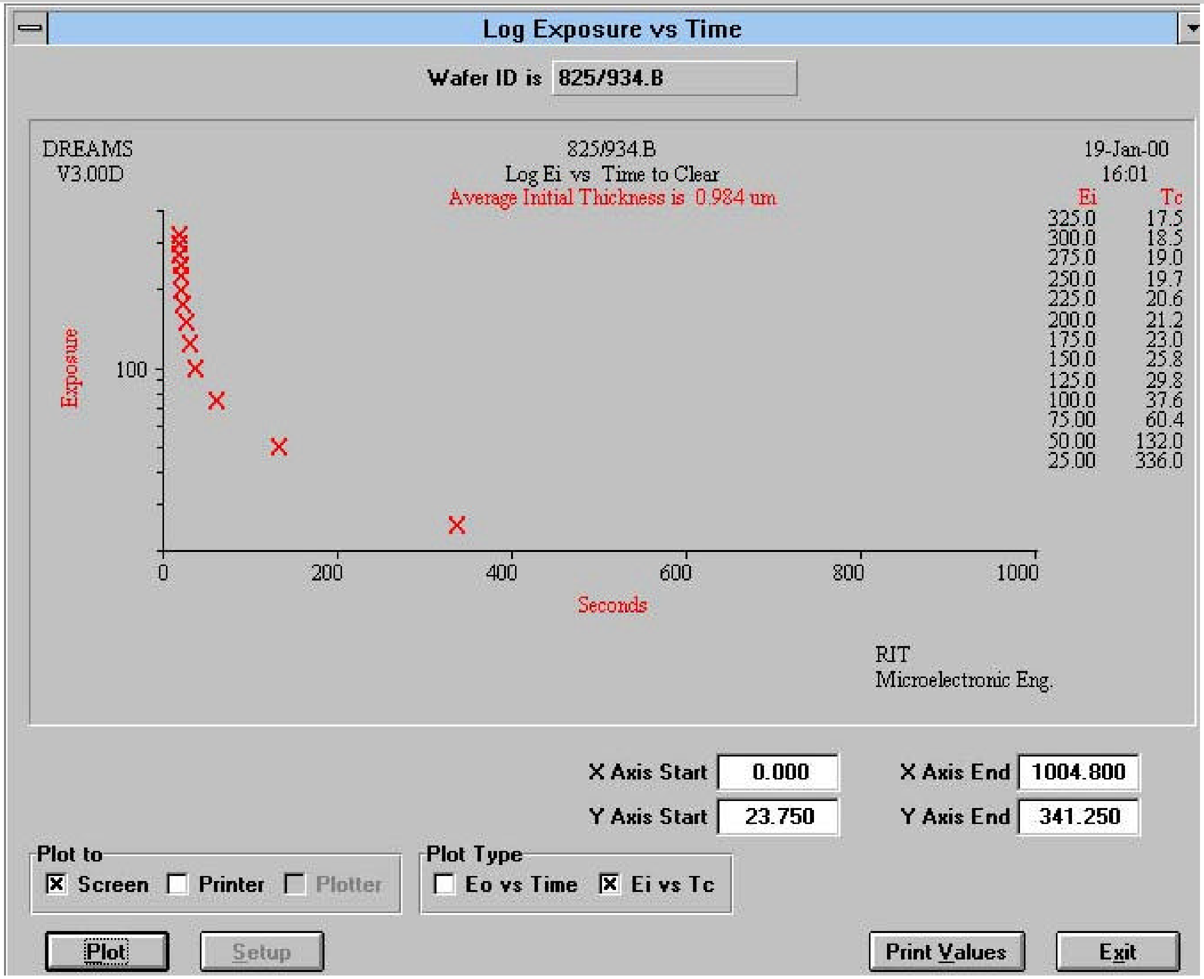
Zone	Ti
14	0.967
13	0.970
12	0.978
11	0.983
10	0.991
9	0.993
8	0.981
7	0.983
6	0.979
5	0.979
4	0.974
3	0.978
2	1.027
1	0.996

X Axis Start 1
X Axis End 256
Y Axis Start 0.750
Y Axis End 1.250

Plot to
☒ Screen ☐ Printer ☐ Plotter

Plot Style
☒ Line ☐ Point

LOG EXPOSURE VERSUS TIME



Wafer ID is 825/934.B

Average Initial Thickness is 0.984 um

Ei	Tc
325.0	17.5
300.0	18.5
275.0	19.0
250.0	19.7
225.0	20.6
200.0	21.2
175.0	23.0
150.0	25.8
125.0	29.8
100.0	37.6
75.00	60.4
50.00	132.0
25.00	336.0

X Axis Start 0.000

X Axis End 1004.800

Y Axis Start 23.750

Y Axis End 341.250

Plot to: ☒ Screen ☐ Printer ☐ Plotter

Plot Type: ☐ Eo vs Time ☒ Ei vs Tc

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REFERENCES

1. Introduction to Microlithography, Second Edition, Edited by Larry F. Thompson, C.Grant Willson and Murrae J. Bowden, ACS Professional Reference Book, American Chemical Society, Washington, DC 1994.
2. “Resist Modeling and Profile Simulation”, A.R.Neureuther, W.G.Oldham, Solid State Technology, May 1985.
3. “A General Simulator for VLSI Lithography and Etching Processes: Part I - Application to Projection Lithography”, W. G. Oldham, S.N. Nandgaokar, A.R.Neureuther, M.O’Toole, IEEE Transactions on Electron Devices, Vol. ED-26, No.4, April 1979.
4. “A General Simulator for VLSI Lithography and Etching Processes: Part II - Application to Deposition and Etching”, W. G. Oldham, A.R.Neureuther, C. Sung, John L. Reynolds, S.N. Nandgaonkar, IEEE Transactions on Electron Devices, Vol. ED-27, No.8, August 1980.
5. “Optical Lithography”, Frederick H. Dill, IEEE Transactions on Electron Devices, Vol. ED-32, No.7. July 1975.
6. Microlithography, Sheats and Smith

HOMEWORK - DRM

- What would the signal versus time plot look like for a situation in which there is significant standing wave effect?
- What would the development rate plot look like for a situation in which there is significant standing wave effect?