PRINTABILITY OF DEFECTS IN OPTICAL LITHOGRAPHY: POLARITY AND CRITICAL LOCATION EFFECTS

by

Vincent Mastromarco

Memorandum No. UCB/ERL M87/40

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Vincent Mastromarco

ABSTRACT -- For optical projection printing, defects in proximity to features show a substantial intensity perturbation due to the nearly coherent interaction of the electric fields from the defect and the feature[1]. The characterization of defect interactions with features is dependent on the positioning and polarities of both defect and features. Using SAMPLE two-dimensional aerial image simulation and resist development simulation along critical cross sections, algebraic models have been established and verified that predict defect-induced linewidth variations.

In investigating the effects of various polarity situations of defects near line edges, the analysis reduces to the case of a clear defect against an opaque background and the case of an opaque defect against a clear background. Both cases gave the same linewidth variation versus defect size, such as $\frac{\Delta L}{L} = 10\%$ for a 0.23 λ/NA defect. Critical location effects were explored using defects between two adjacent features at a minimal spacing. For defects less than 0.12 λ/NA the results follow the algebraic model for single feature interactions. In particular, the resist line edge opening at the substrate follows the 10-15% intensity contour and is independent of defect type. For larger transparent defects, the resist dissolution phenomenon make transparent defects more forgiving up to a catastrophic size of 0.35 λ/NA. However, for opaque defects, a defect size as small as .17 λ/NA can be catastrophic. This enhanced defect printability is due to the impact that the reduced maximum intensity has on the dissolution process' ability to clear the resist between features.

1. Introduction

For optical lithography at the sub-micron level, the tendency for a defect to print is dependent on whether the defect is a pin-hole through which light passes or a particle that blocks the passage of light.

Also, if the defect is near another feature, the contributions from the electric fields from both the feature and defect will effect the composite light intensity on the resist. The result will be a variation in the location of the edge of the resist. We call this variation the "linewidth variation". By convention, a pin-hole that is large enough to print will cause a negative linewidth variation because it will recede the edge of the resist. A particle that is large enough to print will cause a positive linewidth variation because it will laterally increase the resist.

The coherent interaction of electric fields has been investigated and a formula for predicting the composite intensity at a location anywhere along the cross section between the defect and the feature has been derived[1]. This degree of coherence is defined by the dimensionless parameter μ_{eff}. μ_{eff} can assume a value between 0 and 1. Also, an equation for predicting the linewidth variation has been developed. This equation makes use of the coherence parameter μ_{eff} and the intensity contributions of both defect and feature where the intensity contribution is the square of the electric field contribution.

Further investigation of the effects of polarities and positioning of defects is needed to verify these existing equations and to determine critical situations that would arise if a certain size defect of a given polarity is located in a particular location between features. Therefore, in this report, we investigate the validity of the linewidth variation formula[1] developed by Neureuther et al for opaque defects and characterize the resulting effective mutual coherence parameter μ_{eff}. The effect of defects in critical locations is then explored using defects between parallel lines. Finally, SAMPLE resist profile simulations are utilized to examine the degree to which dissolution phenomena result in line edge position deviations from threshold intensity contours.

2. The effects of different polarities on linewidth variation

2.1. Introduction

As depicted in Figure 1, four polarity cases can be described. Upon careful examination, only two distinct cases need be considered: (1) a clear defect against an opaque background near an edge, and (2) an opaque defect against a clear background near an edge. This realization becomes evident when one notices that the two cases describing a clear defect are essentially the same image with a rotation of

180 degrees. This same observation holds for the two cases of the opaque defect.

The intensity plots that have been generated using the 2D simulation program are dependent on the defect size D, the numerical aperture NA, the wavelength, the defocus distance d, the reduction factor M, and the partial coherence factor. All intensities have been normalized so that a clear mask has an intensity level of 1, and all distances and sizes are in units of λ/NA. The magnification is unity and no defocus has been used.

The intensity at the edge of a feature in projection printing is in the range of 25% to 30%. For example, at the edge of a 0.8 transparent feature width, the intensity level is roughly 25.4% for a partial coherence factor of 0.3. At the same edge, increasing the partial coherence factor to 0.7, increases the intensity level to approximately 29.4%. Placing a transparent defect in proximity to this edge will effect the intensity level. The governing equation for the composite intensity is dependent on the intensity contribution of the defect, on the intensity contribution of the feature, and on the effective mutual coherence μ_{eff}.

2.2. Calculating the effective mutual coherence parameter, μ_{eff}

The effective mutual coherence parameter is dependent on the polarity of the defect. For a transparent defect near a transparent feature,

$$\mu_{eff} = \frac{I_c - I_f - I_d}{2\sqrt{I_f}\sqrt{I_d}}$$

which follows from

$$I_c = I_f + 2\mu_{eff}\sqrt{I_f}\sqrt{I_d} + I_d$$

where the subscripts d,f,and c represent defect, feature, and composite, respectively. For an opaque defect near an opaque feature,

$$\mu_{eff} = \frac{I_c - I_f - I_d}{-2\sqrt{I_f}\sqrt{I_d}}$$

which follows from

$$I_c = I_f - 2\mu_{eff}\sqrt{I_f}\sqrt{I_d} + I_d$$

Values for μ_{eff} are dependent on the observation point and, by convention, have been calculated at the intersection of the feature edge and the perpendicular to the feature edge that passes through the center of the defect.

The derivation of the equation for I_c is based on the electric field contributions from the defect and feature. If the defect or feature is opaque, we treat it as a transparent defect or feature, taking the negative of the electric field contribution for a transparent defect or feature. For instance, an opaque defect situated within a transparent feature yields:

$$I_c = (E_f - E_d)^2$$

$$I_c = E_f^2 - 2E_f E_d + E_d^2$$

Recalling that the intensity is the square of the electric field and introducing μ_{eff} to handle the cross term yields:

$$I_c = I_f - 2\mu_{eff}\sqrt{I_f}\sqrt{I_d} + I_d$$

In Figure 2, Neureuther, Flanner, and Shen plot μ_{eff} versus defect center to line edge distance for when the opaque defect lies outside the opaque feature[1]. The alternate situation is when a transparent defect is situated within the opaque feature. For the two cases when sigma=0.3 and when sigma=0.7, the magnitude of μ_{eff} is near unity when the defect is near its edge (Figure 3). For the situation when the defect is transparent, μ_{eff} never gets to a maximum magnitude of 1. Also, the rolloff off μ_{eff} as the defect moves away from the edge of the feature is different for both cases. Nevertheless, both curves appear to follow the mutual coherence function given by the Van Cittert-Zernike theorem[2]:

$$\mu_{12}(x_{12}) = 2\frac{J_1(v)}{v}$$

where

$$v = \frac{2\pi\sigma x_{12}}{|\lambda/NA|}$$

2.3. Calculating linewidth variation

Since the nominal linewidth will be in the vicinity of the feature's edge, we will observe the variation in the intensity contour for the edge of a sole feature. For a sigma of 0.3, the intensity at the edge of a sole feature = 0.25433 (Figure 4). For a sigma of 0.7, the intensity at the line edge is 0.29375 (Figure 5). In both cases, for a defect situated within a feature, as the defect moves away from the line edge the variation drops off (Figures 6 and 7). For large sigma (i.e. sigma = 0.7), the linewidth variation is slightly smaller and rolls off faster with distance, as should be expected from the behavior of μ_{eff}.

In Figure 8, we see that the two points generated for the opaque defect case using the 2D pattern simulation program fit well onto the curves for the case where a transparent defect is touching outside the feature. These results are readily verified by using the following governing equations are:

$$\Delta I = I_c - I_f \approx -2\mu_{eff}\sqrt{I_f}\sqrt{I_d}$$

$$\Delta L \approx \frac{\Delta I}{(\frac{\Delta I}{\Delta X})\,|_{I_t}}$$

$$\Delta L \approx \frac{(-2\mu_{eff}\sqrt{I_t}\sqrt{I_d})}{(\frac{\Delta I}{\Delta x})\,|_{I_t}}$$

$$\Delta l \approx \frac{(-2K_l\sqrt{I_t}\sqrt{I_{dp}})}{(\frac{\Delta I}{\Delta x})\,|_{I_t}}$$

The threshold intensity I_t is the intensity at the feature edge and I_d is the intensity at the edge of an isolated defect. The value of $\sqrt{I_{dp}}$ in this formulation is the magnitude of the peak electric field for an opaque defect which is the equivalent to the magnitude of the electric field for a transparent defect. The intensity slope at the line edge has been characterized previously [1] as $(\frac{\Delta I}{\Delta X})\,|_{0.7} = 2.9 - 1.3\sigma$ and gives 1.99 for $\sigma = 0.7$. Using the third equation to verify out simulated values for ΔL, gives us

$$\Delta L = 2\sqrt{.30}\frac{\sqrt{0.0123}}{1.99} = 0.061$$

This calculated value also falls right on the curve for the 0.2 λ/NA transparent defect, verifying the results of our two dimensional simulation. The fact that the points for the opaque defect case fall right on the curves for the transparent defect case is no surprise and is clearly evident from the way in which the electric field of the defect comes into the formulations.

3. The effects of a defect in a critical location

3.1. Introduction

Two examples of defects in critical locations were used to investigate the anticipated increased tendency of defects to print. The two cases studied were an opaque defect between two opaque features and a transparent defect between two transparent features. Normally, greatest linewidth variation occurs when the defect is touching the feature. However, a defect positioned at the midpoint between two features can potentially effect the image near both features, as well as in the gap between, thus producing enhanced effects.

3.2. The transparent defect touching inside one of two transparent features

For a transparent defect touching inside one of two transparent features, intensity plots reveal that as the defect gets larger, the shift in intensity contours near the line edge increases. However, the maximum intensity remains close to 100% and the minimum intensity remains below 15% (Figure 9). Similar results were observed for the case where a transparent defect is touching a sole transparent feature where a 17% intensity perturbation is observed, producing a significant linewidth variation (Figure 10). The substantial intensity perturbation is due to the coherence interaction. The coherence interaction is indeed dramatic when we compare this intensity perturbation of 17% to the intensity perturbation of 3% for an isolated defect (Figure 11).

3.3. The transparent defect exactly between two transparent features

For a transparent defect exactly between two transparent features, the intensity plots of Figure 12 reveal that as the defect gets larger, the minimum intensity level increases, attaining a level as high as 25% for a .4 λ/NA defect. This increase in I_{min} will be another factor effecting the development of the resist, as we shall soon see. No substantial shift in intensity contours was observed near the line edge for defects less than .25 λ/NA in width, revealing that the intensity curve does not roll off as fast as when the defect is touching due to the lower μ_{eff}.

3.4. The opaque defect touching inside one of two opaque features

Considering the opposite polarity, we found that an opaque sole defect of 0.2 λ/NA produced an intensity minimum of approximately 70%, corresponding to a perturbation of approximately 30% (Figure 13). This result is not at all surprising because our equations for I_c predict such behavior. Taking the background as an intensity level of 1, and treating the electric field of an opaque defect as the negative of the electric field of a transparent defect yields:

$$I_{d(opaque)} = (1 - \sqrt{I_{d(transparent)}})^2$$

$$I_{d(opaque)} = (1 - \sqrt{0.03})^2$$

Giving us an intensity $I_{d(opaque)} = 0.68$ which is a 32% perturbation from the background intensity of 1. We might anticipate that the large intensity perturbation will in some way lead to greater difficulty with opaque defects in critical locations.

For the case where an opaque defect was touching inside one of two opaque features, the intensity plots of Figure 14 reveal that as the defect gets larger, the shift in intensity contours near the line edge increases. Also, as the defect gets larger, the maximum intensity decreases, attaining a level as low as 75% for a .3 λ/NA defect. Here, we note that besides a shift in the intensity near the line edge, a dampening of the maximum intensity is observed, a condition that will contribute to the resist development.

3.5. The opaque defect exactly between two opaque features

For the case where an opaque defect is positioned exactly between two opaque features, the intensity plots of Figure 15 reveal that as the defect gets larger, the shift in intensity contours near the line edge increases. Also, as the defect gets larger, the maximum intensity decreases, attaining a level as low as 80% for a .2 λ/NA defect. Here, we note that the shift in intensity level at the line edge and the dampening of I_{max} are more pronounced than in the previous case. This reduction of I_{max} will have important consequences in resist dissolutions, which will be considered in the next section.

4. Resist profiles

4.1. Introduction

The resist development simulator SAMPLE was used to observe the effects of defects in the development of the photoresist. Typical parameter values used in the profile simulations are: $\lambda = 0.5$, $NA = 0.5$, and $\sigma = 0.7$. The resist thickness was 0.818 microns and typically the develop would break through the resist within 30 to 40 secs of the total development time. Figure 16 is the input file for all parameters used in the simulation. An example of the resultant output profile is shown in Figure 17A. From these resist profiles, we then plotted the variation in linewidth of the 60sec contour against various intensity contours to see if the intensity profile would be sufficient for predicting the effects of defects.

4.2. The transparent defect touching inside one of two transparent features

An example of the resist profile for a transparent defect touching one of two transparent features is shown in Figure 17B. When the location of the line edge versus intensity contours is plotted as in Figure 18, the line edge location follows the 10% contour, meaning that for this particular case, the resist development was solely dependent on intensity threshold. Simulations reveal that resist does remain on the wafer for defects as large as .4 λ/NA (Figure 17C).

4.3. The transparent defect exactly between two transparent features

An example of the resist profile for a transparent defect exactly between two transparent features is shown in Figure 19A. For this case, the line edge location follows the 10% contour for defects as large as .2 λ/NA before deviating, as shown in Figure 20. Clearly, for defects as large as .2 λ/NA, the line edge location is solely dependent on the threshold intensity. However, as the defect becomes greater than .2 λ/NA, the threshold resist dissolution is more forgiving than the 10% contour. Substantial toploss does not occur until the defect becomes large than .33 λ/NA, as is clearly depicted in Figure 19A through Figure 19F.

4.4. The opaque defect touching inside one of two opaque features

For the case where an opaque defect is touching one of two opaque features, our concern is whether the defect will interfere with the develop breaking through the resist. For small defects, the develop did break through the resist. However, for defects greater than .25 λ/NA, the 60sec contour could no longer break through to the substrate as is clearly shown in Figure 21. Plotting the line edge location versus various intensity contours reveals that the line edge location follows the 15% contour for defects as large as .2 λ/NA before deviating upward, as is shown in Figure 22. Recall that for the transparent case, the line edge location deviate downwards from the intensity contour, reflecting the fact that transparent defects are more forgiving. Here, the deviation upwards reveals that opaque defects are more damaging than would be indicated by merely tracking an intensity contour. The reason for the deviation stems from the fact that the maximum intensity I_{max} has been dampened substantially.

4.5. The opaque defect exactly between two opaque features

For the case where an opaque defect is exactly between two opaque features, we found that the develop would break through for only very small defects. When the defect became larger than approximately 0.17 λ/NA, the 60sec contour no longer could reach the substrate as is illustrated in Figure 23. In other words, a defect as small as 21% of the feature width will print, causing the develop not to break through the resist. Plotting the line edge location versus various intensity contours reveals that the line edge location follows the 15% contour for defects as large as .12 λ/NA before deviating upward, as is shown in Figure 24. The deviation from the intensity contour begins at a smaller defect size because the damaging effect from the dampening of I_{max} is even more pronounced than in the previous case, since the opaque defect is now positioned exactly in the center. Clearly, the opaque defect exactly between two opaque features is the worst of the four cases because this case will begin to print defects at a smaller defect size than in the previous cases.

5. Conclusion

For optical projection printing, the polarity and proximity of defects to features produce coherence effects that would cause defects to print that we would normally not expect to print. The polarities issue reduces to two cases: (1) a transparent defect against an opaque background near a line edge and (2) an opaque defect against a transparent background near a line edge. We have determined that the effective mutual coherence parameter μ_{eff} is near unity about the line edge, confirming that the coherence effect is most prevalent at the line edge. We have also determined that the linewidth variation is independent of polarity for defect sizes less than .12 λ/NA in width.

In examining the issue of a defect in a critical location, namely between two features, we must remember that there are two contributions in determining the printability of defects. The first contribution comes from the shift in the intensity threshold near the line edge. The second contribution comes from the perturbation of the intensity extremum for each given case. These intensity extrema then play a role in line edge positions caused by the dissolution phenomena. For transparent defects, the dissolution process is a forgiving effect, allowing larger defects not to print than would be expected from intensity contours, and resulting in little top loss. For opaque defects, the dampening of the maximum intensity is a damaging effect, causing smaller defect to print than would be expected from intensity behavior at the line edge. As a result, we find that for the transparent case, defects as large as .33 λ/NA are tolerated, yet for the opaque case, defects as small as .17 λ/NA will print.

References

[1]A.R. Neureuther and P.Flanner III, "Coherence of Defect Interactions with Features in Optical Imaging," Electron, Ion and Photon Beams Symposium, May 27-30, 1986, Boston.

[2]M.Born and E.Wolf, "Principles of Optics," Chapter 10, Pergamon Press, New York, 1972.

DEFECT/FEATURE POLARITY COMBINATIONS

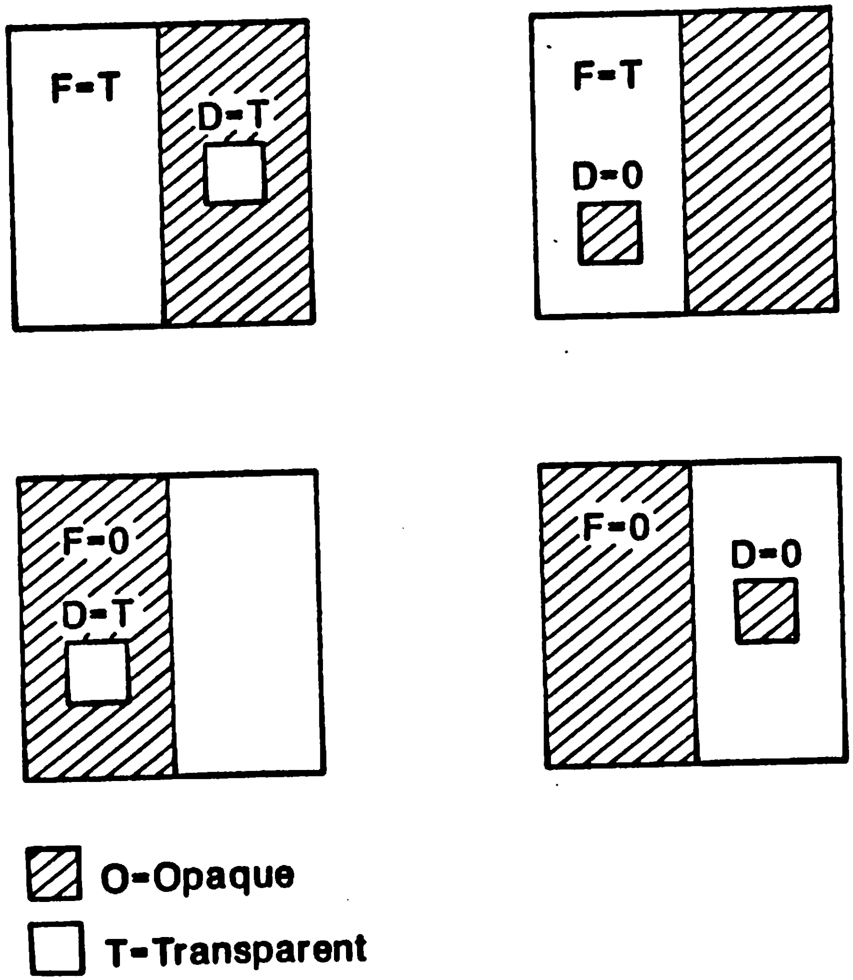
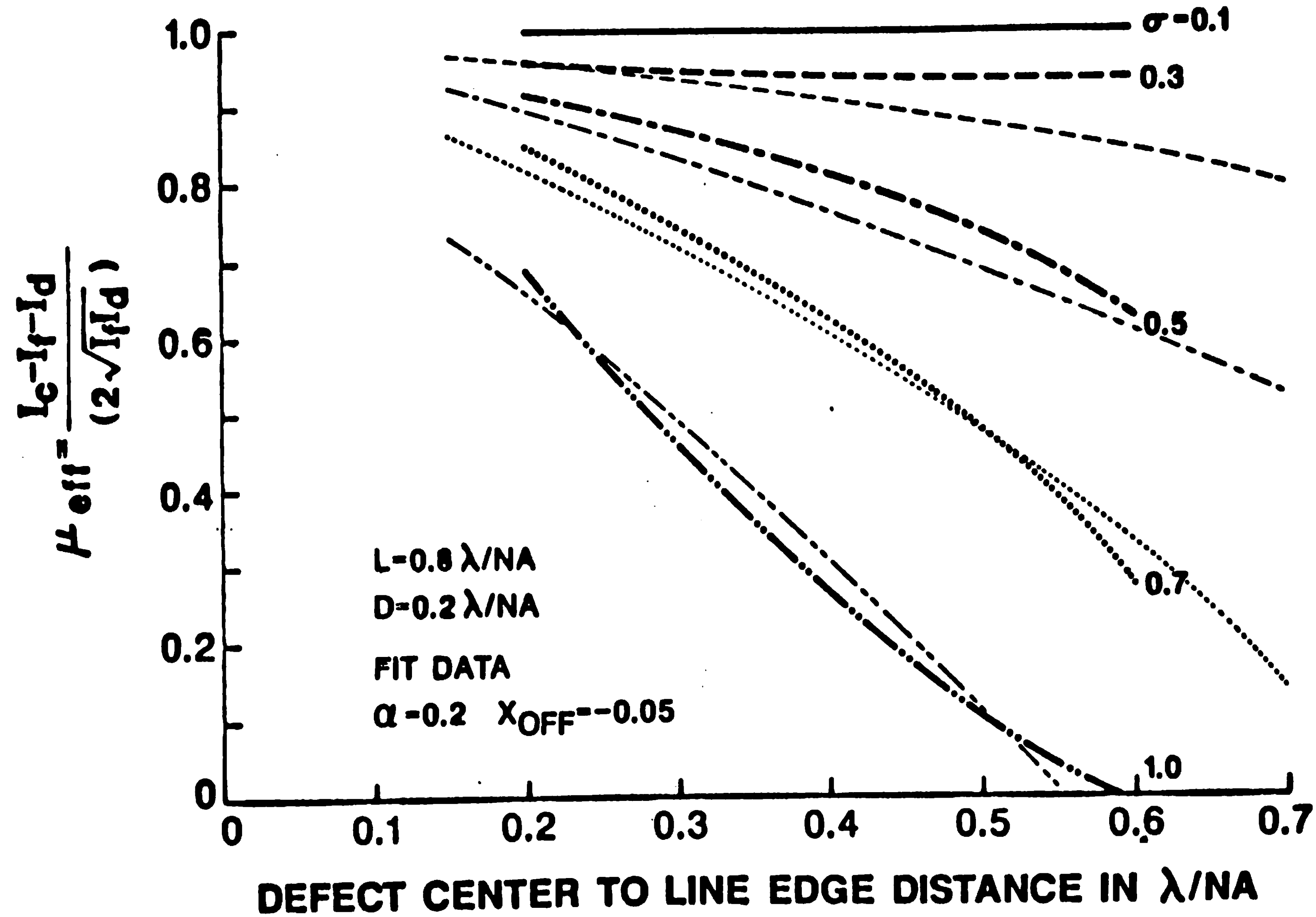
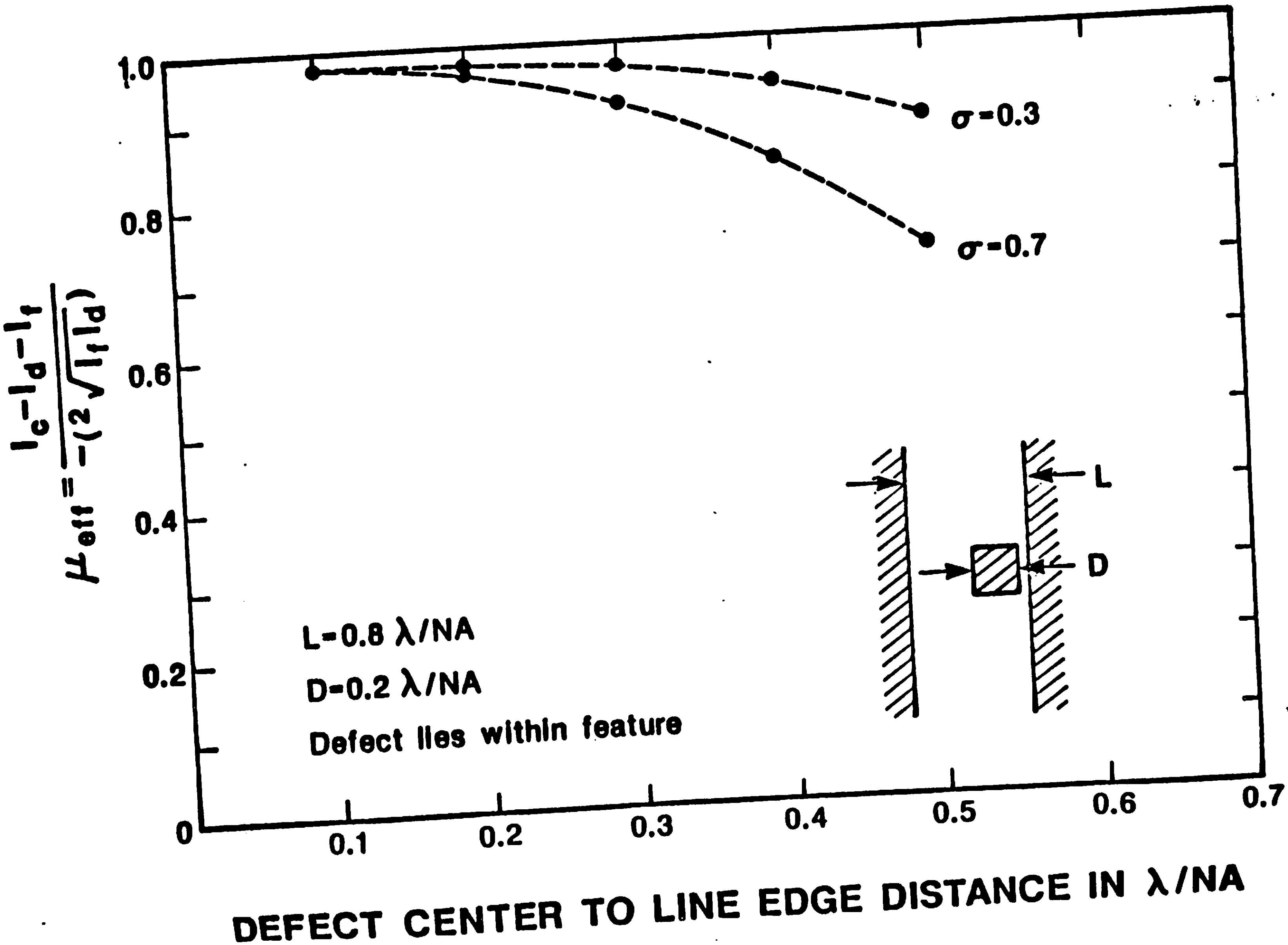


Fig. 1



1.0
0.8
0.6
0.4
0.2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
$\mu_{eff} = \frac{I_c - I_f - I_d}{(2\sqrt{I_f I_d})}$
DEFECT CENTER TO LINE EDGE DISTANCE IN λ/NA
σ=0.1
0.3
0.5
0.7
1.0
L=0.8 λ/NA
D=0.2 λ/NA
FIT DATA
α=0.2 X_{OFF}=-0.05

Fig. 2



1.0
0.8
0.6
0.4
0.2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
σ=0.3
σ=0.7
L
D
L=0.8 λ/NA
D=0.2 λ/NA
Defect lies within feature
$\mu_{eff} = \frac{I_c - I_d - I_f}{-(2\sqrt{I_f I_d})}$
DEFECT CENTER TO LINE EDGE DISTANCE IN λ/NA

Fig. 3

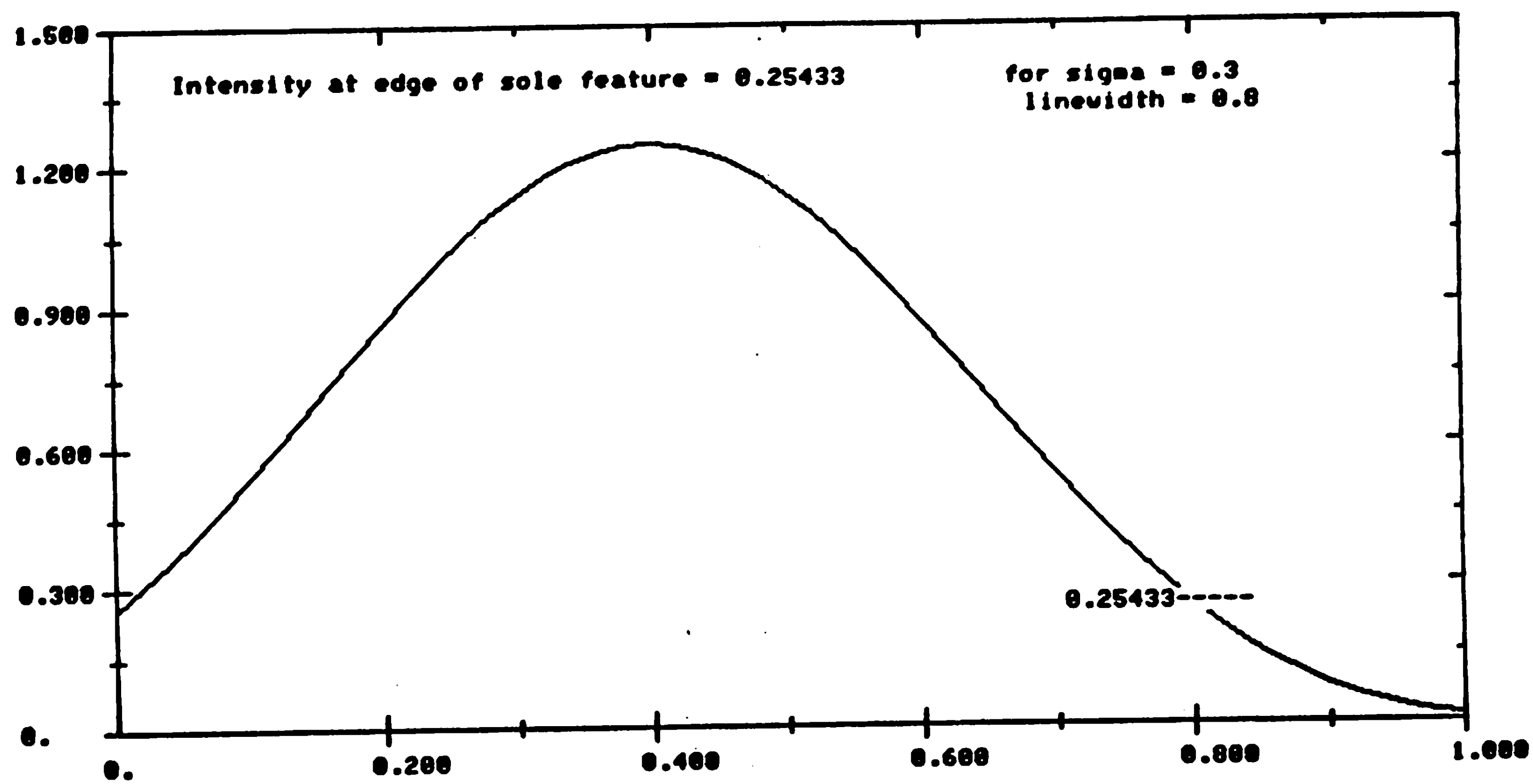

Intensity at edge of sole feature = 0.25433
for sigma = 0.3
linewidth = 0.8
0.25433
1.500
1.200
0.900
0.600
0.300
0.
0.
0.200
0.400
0.600
0.800
1.000

Fig. 4

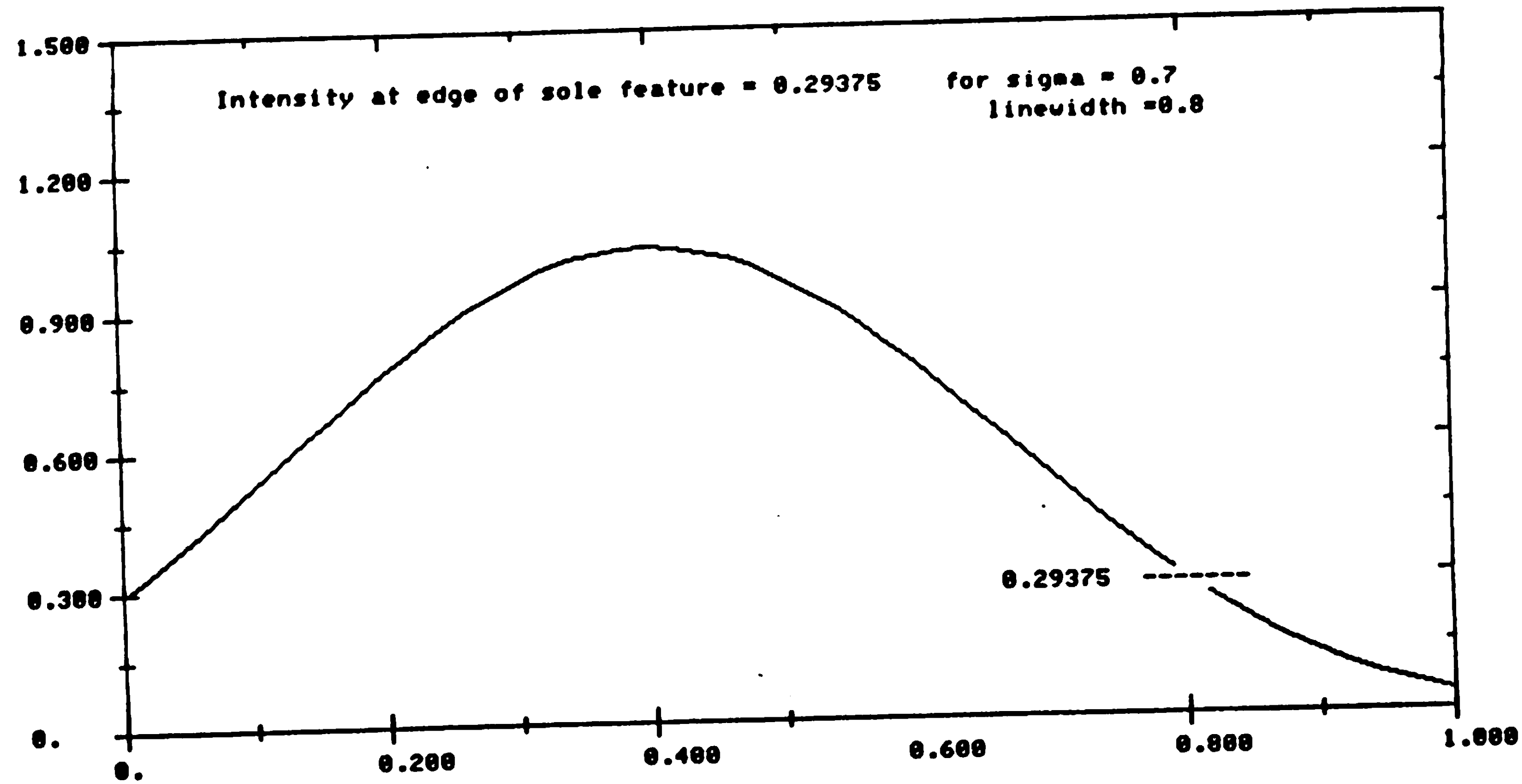
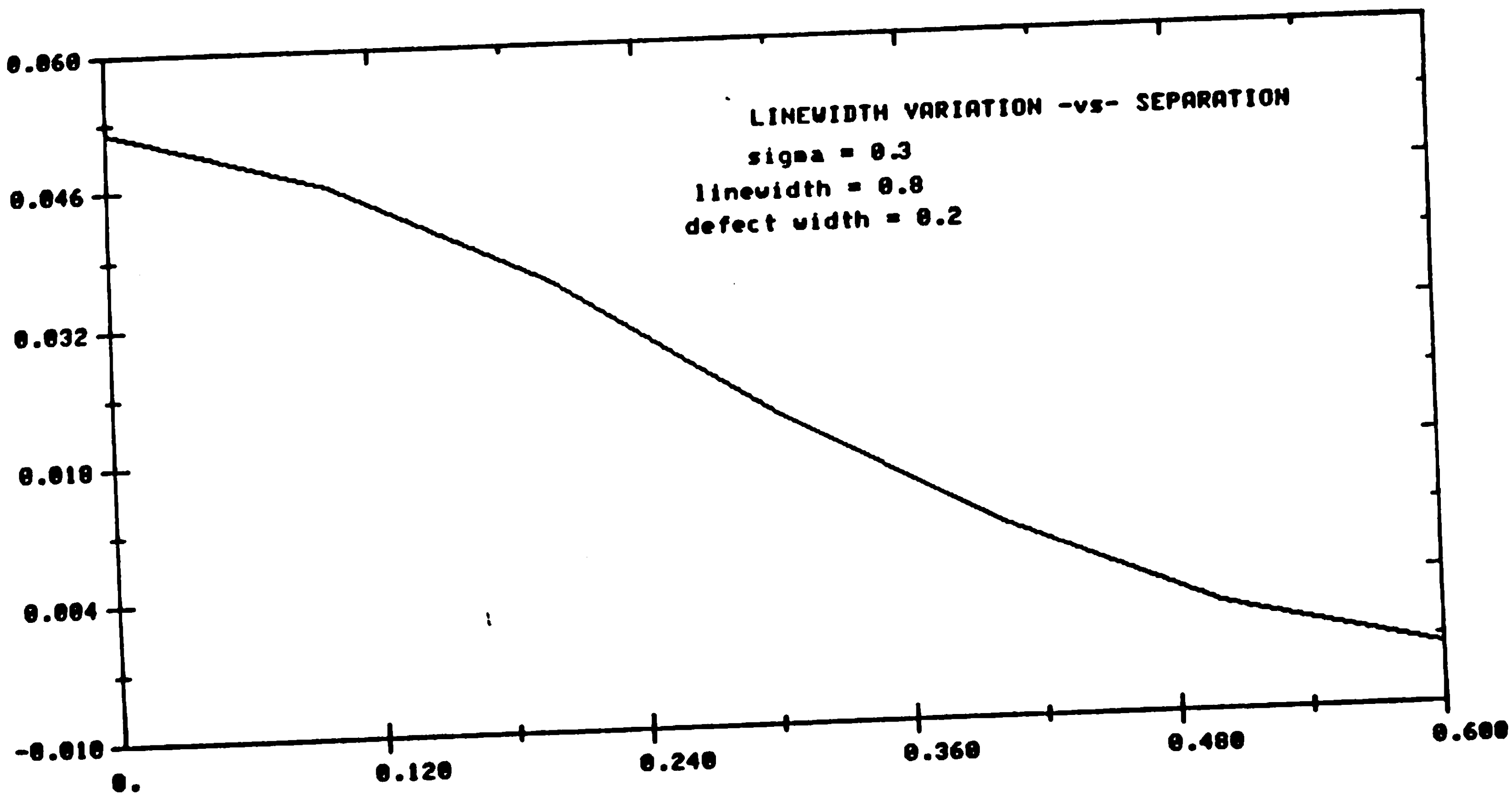
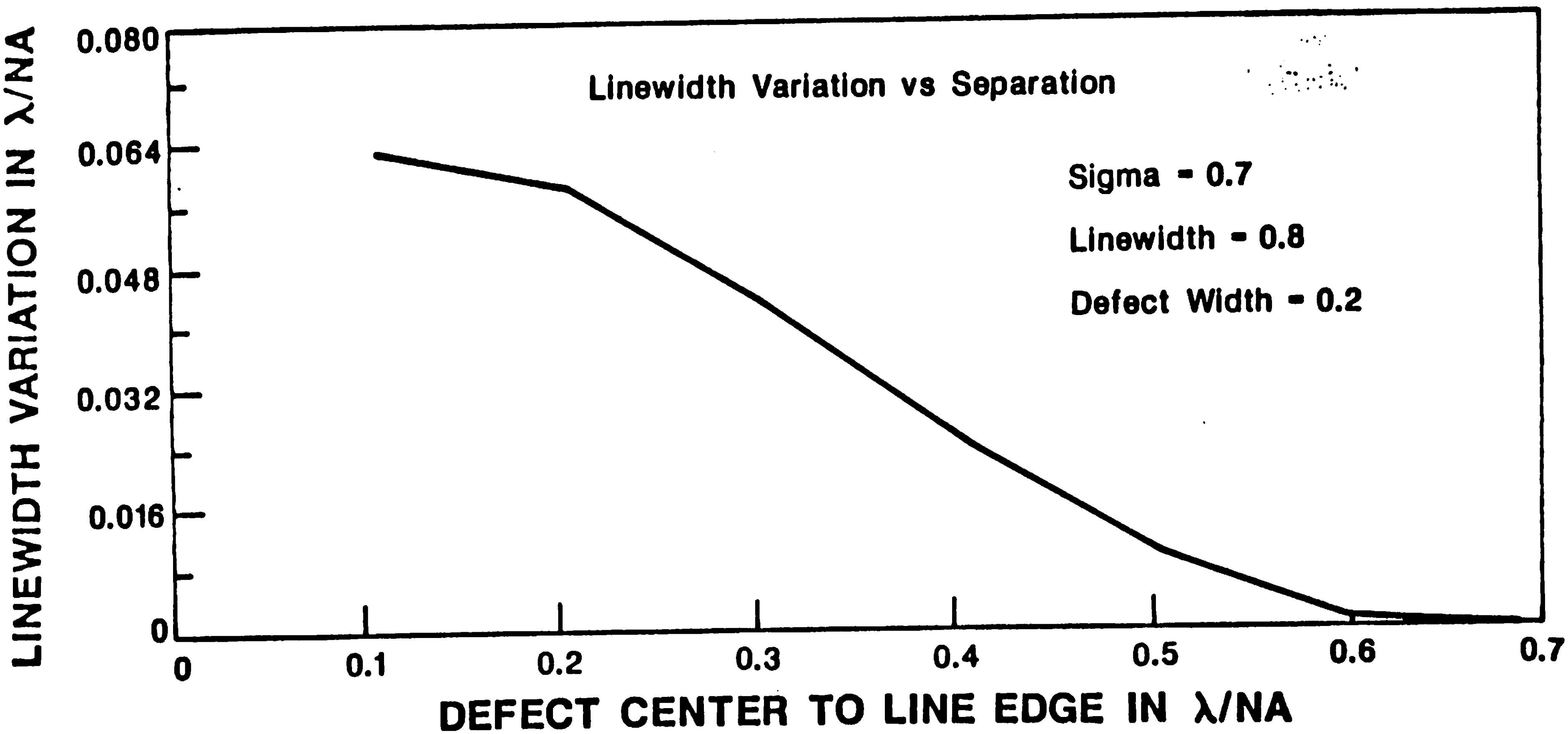

Intensity at edge of sole feature = 0.29375
for sigma = 0.7
linewidth =0.8
1.500
1.200
0.900
0.600
0.300
0.
0.29375
0.
0.200
0.400
0.600
0.800
1.000

Fig. 5



LINEWIDTH VARIATION -vs- SEPARATION
sigma = 0.3
linewidth = 0.8
defect width = 0.2
0.060
0.046
0.032
0.018
0.004
-0.010
0.
0.120
0.240
0.360
0.480
0.600

Fig. 6



Linewidth Variation vs Separation
Sigma = 0.7
Linewidth = 0.8
Defect Width = 0.2
LINEWIDTH VARIATION IN λ/NA
0.080
0.064
0.048
0.032
0.016
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
DEFECT CENTER TO LINE EDGE IN λ/NA

Fig. 7

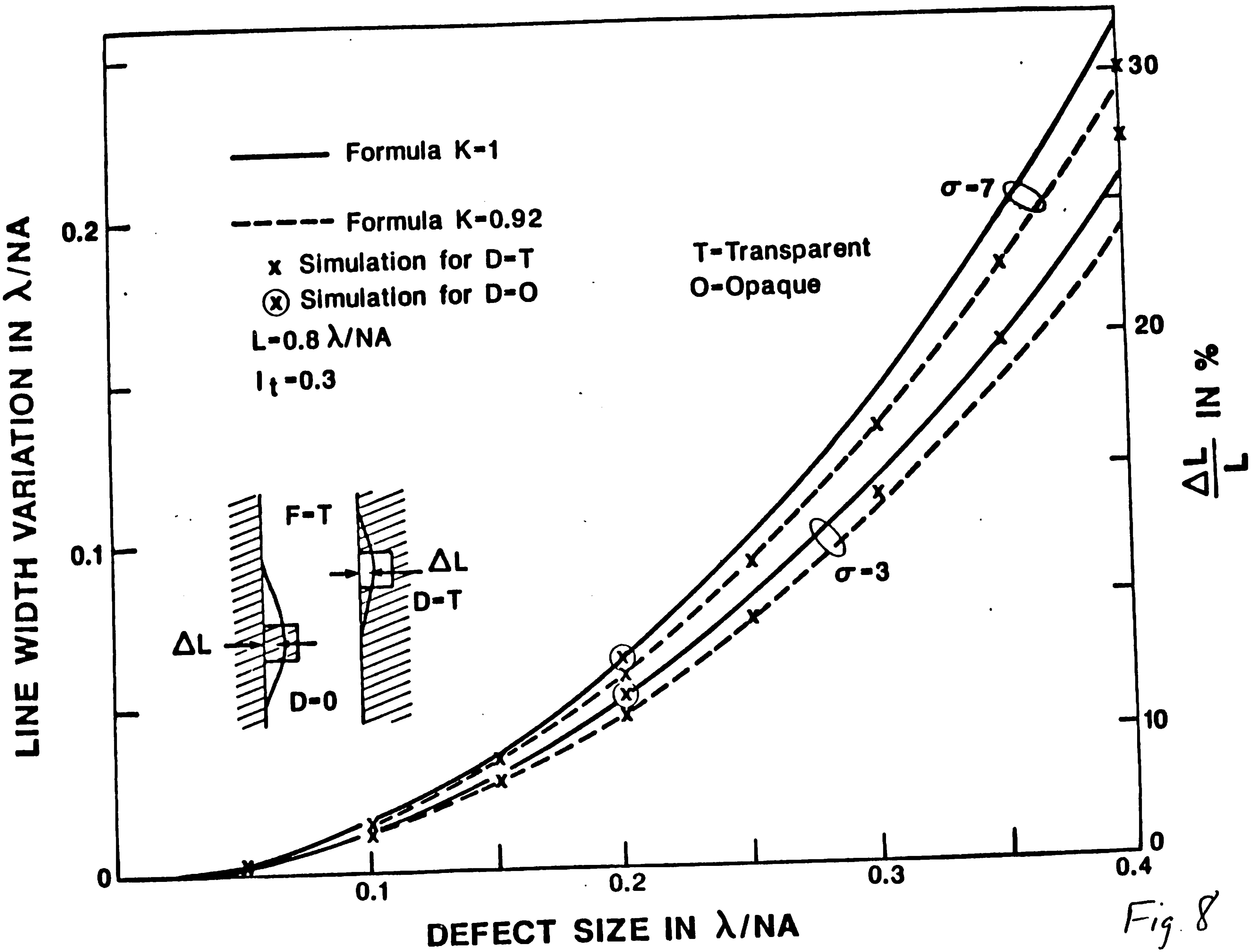
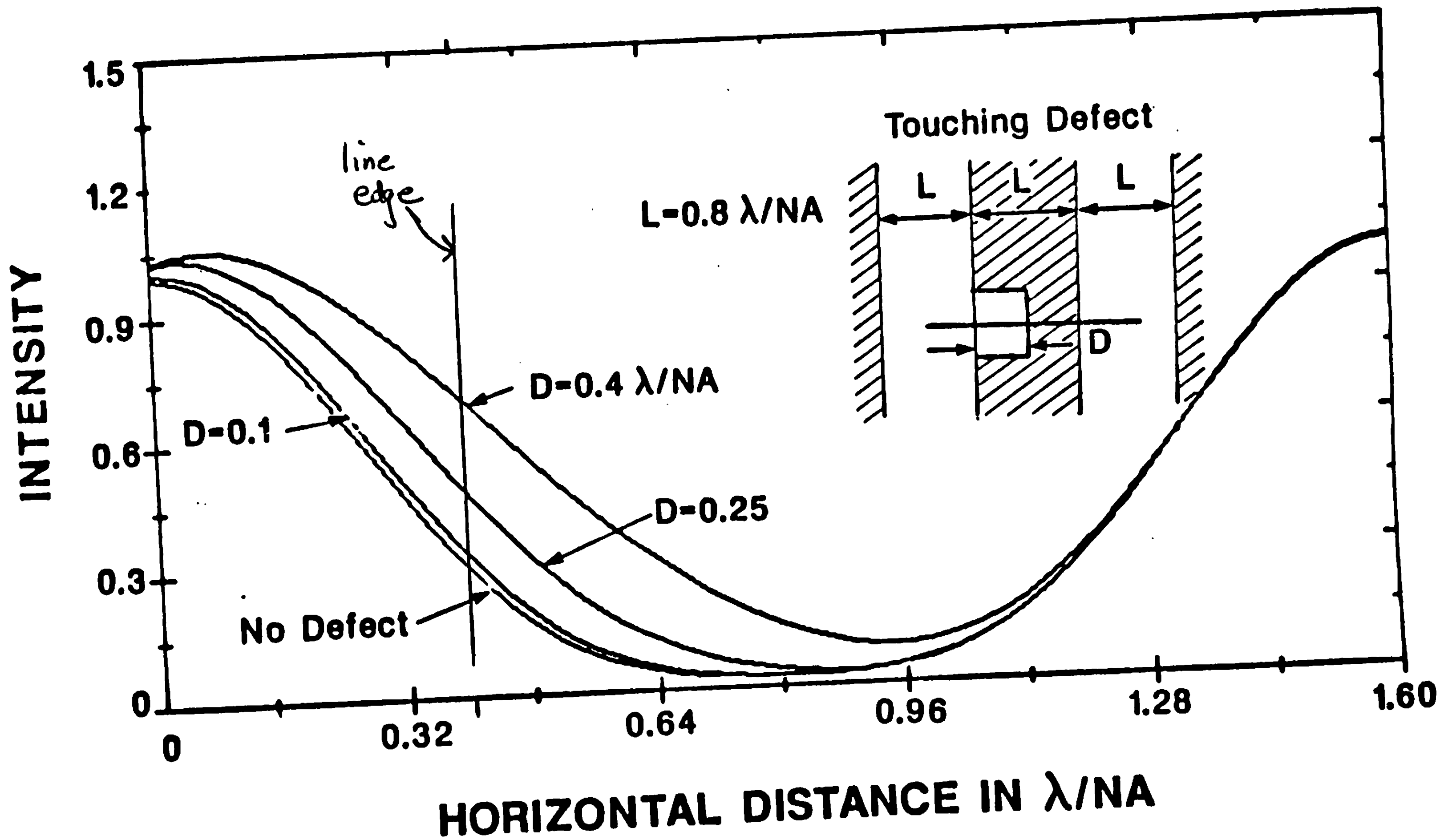
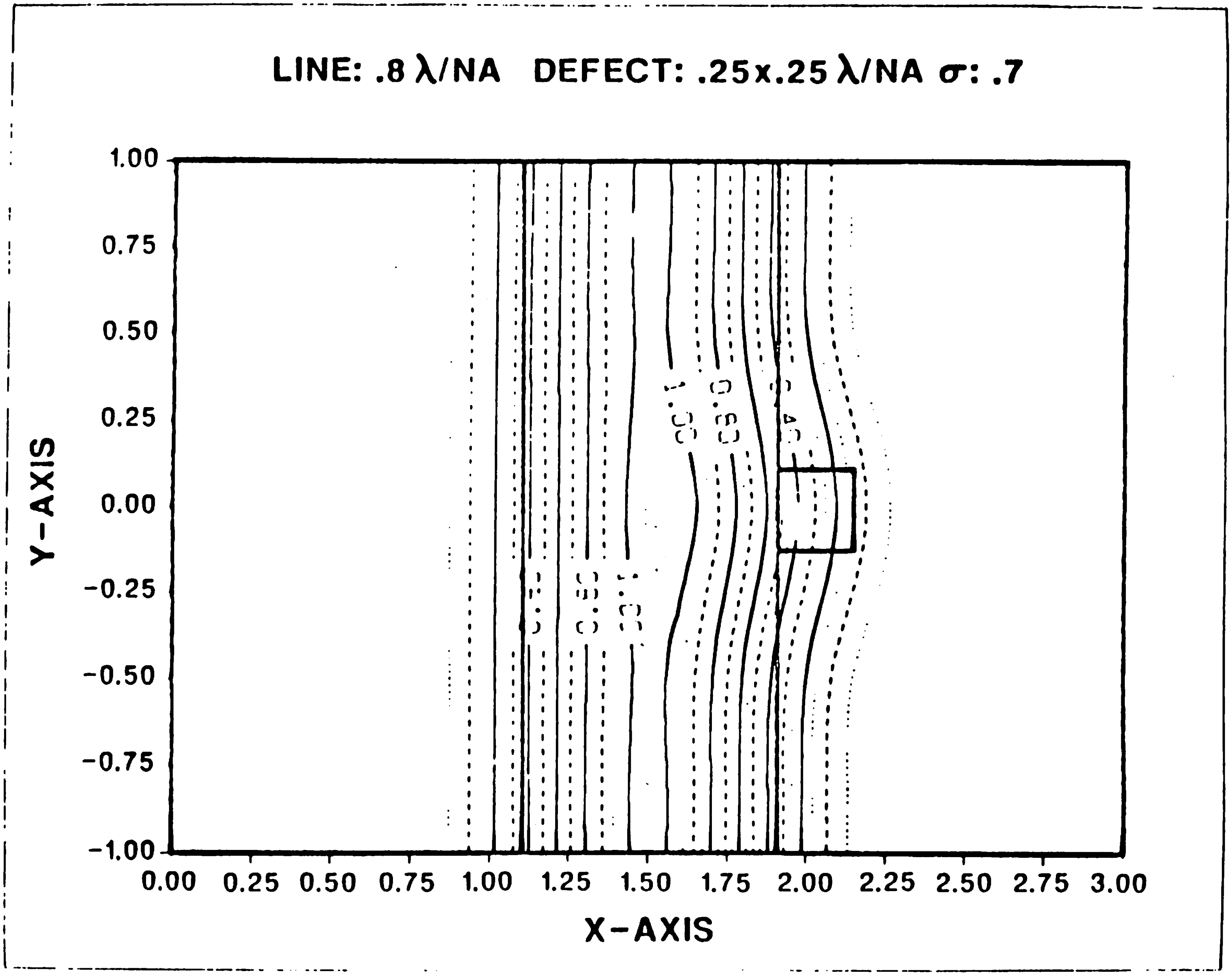

Formula K=1
Formula K=0.92
x Simulation for D=T
Simulation for D=O
L=0.8 λ/NA
I_t=0.3
T=Transparent
O=Opaque
σ=7
σ=3
F=T
ΔL
D=T
ΔL
D=0
LINE WIDTH VARIATION IN λ/NA
ΔL/L IN %
DEFECT SIZE IN λ/NA
0
0.1
0.2
0.3
0.4
10
20
30

Fig. 8



Touching Defect
L=0.8 λ/NA
L
L
L
D
line edge
D=0.4 λ/NA
D=0.1
D=0.25
No Defect
INTENSITY
1.5
1.2
0.9
0.6
0.3
0
0
0.32
0.64
0.96
1.28
1.60
HORIZONTAL DISTANCE IN λ/NA

Fig. 9



LINE: .8 λ/NA DEFECT: .25x.25 λ/NA σ: .7
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
Y−AXIS
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00
X−AXIS

FIG 2

Fig. 10

ISOLATED CLEAR 0.2 λ/NA DEFECT

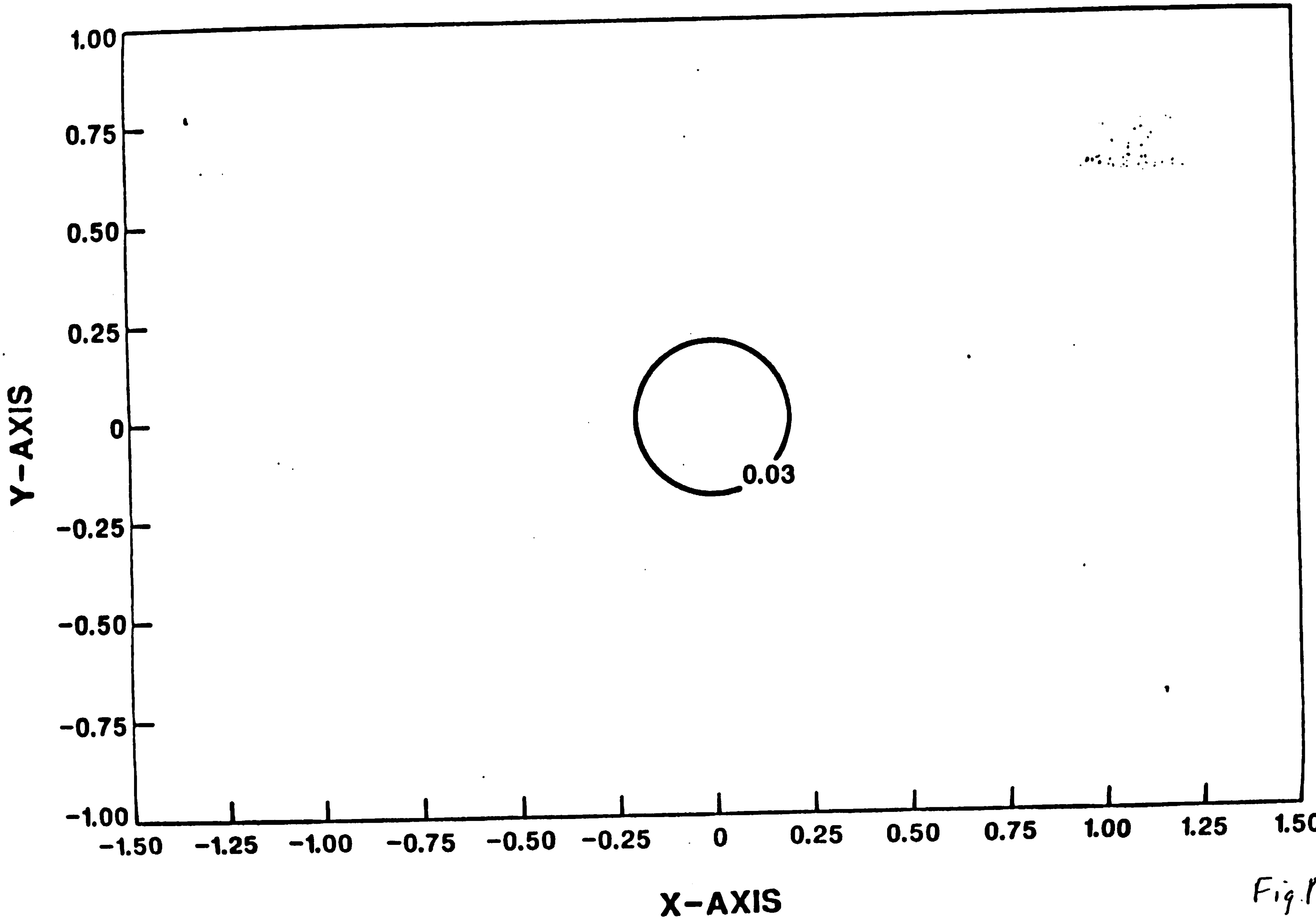


Fig. 18.

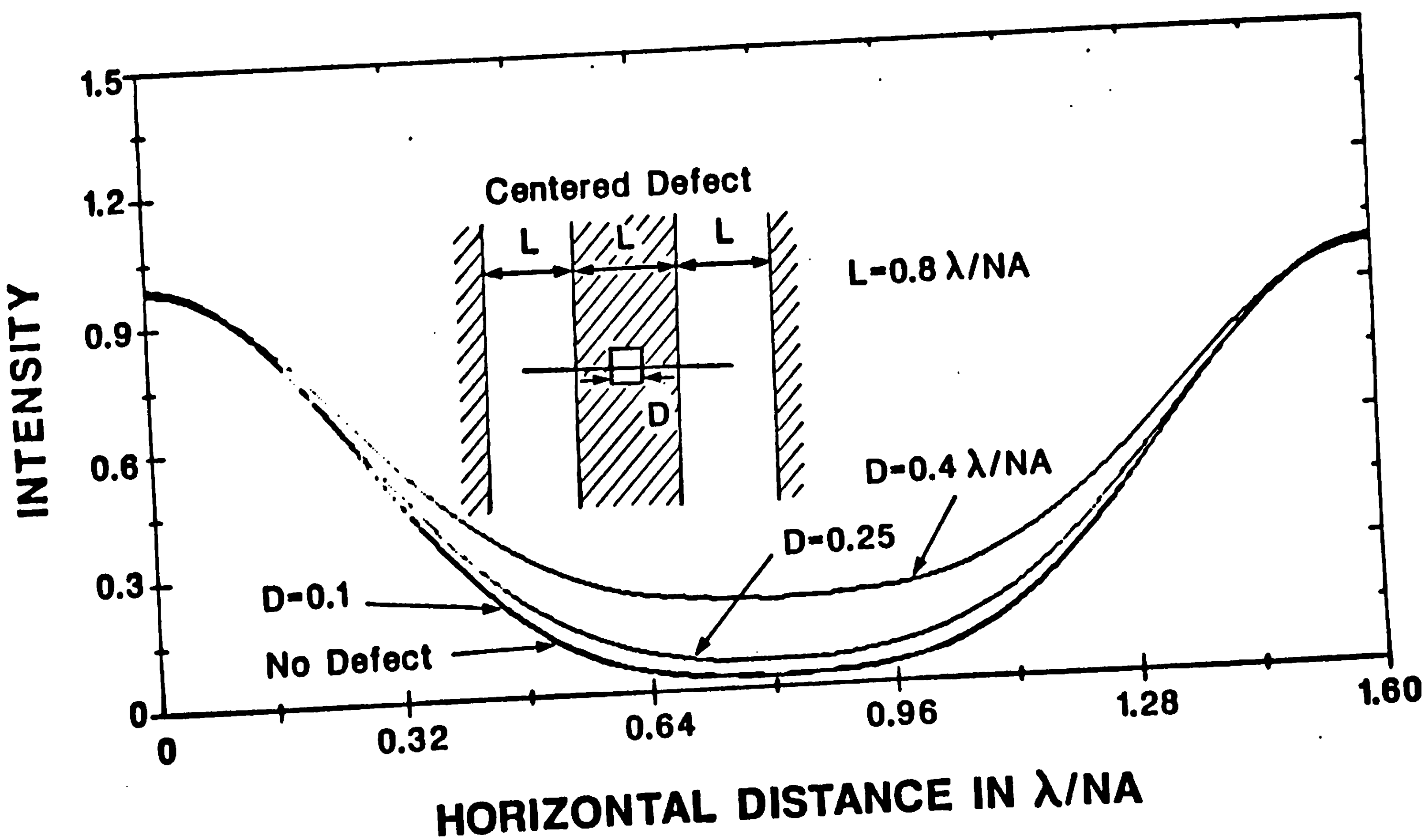

Centered Defect
L
L
L
D
L=0.8 λ/NA
D=0.4 λ/NA
D=0.25
D=0.1
No Defect
INTENSITY
1.5
1.2
0.9
0.6
0.3
0
0
0.32
0.64
0.96
1.28
1.60
HORIZONTAL DISTANCE IN λ/NA

Fig 12

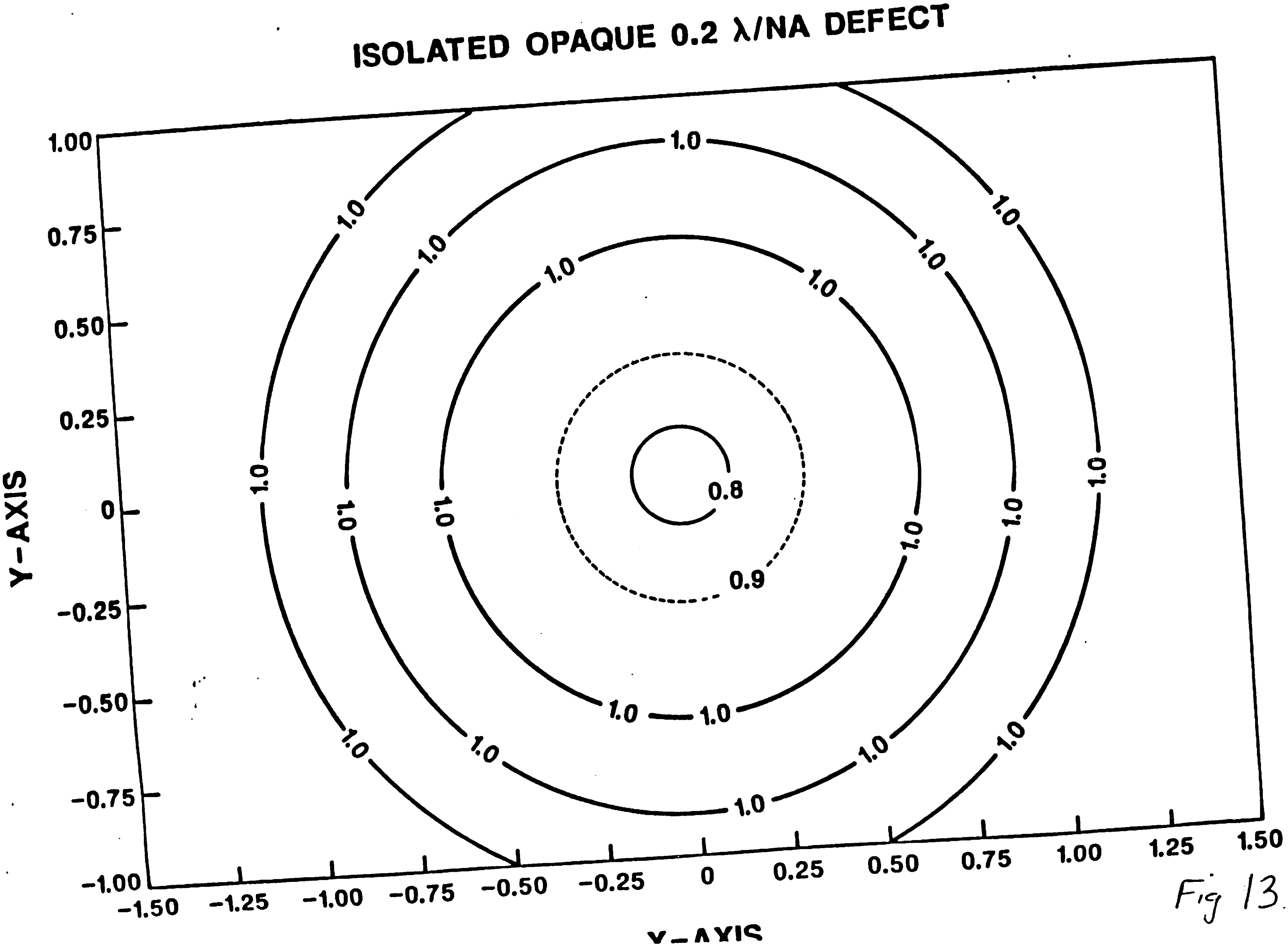
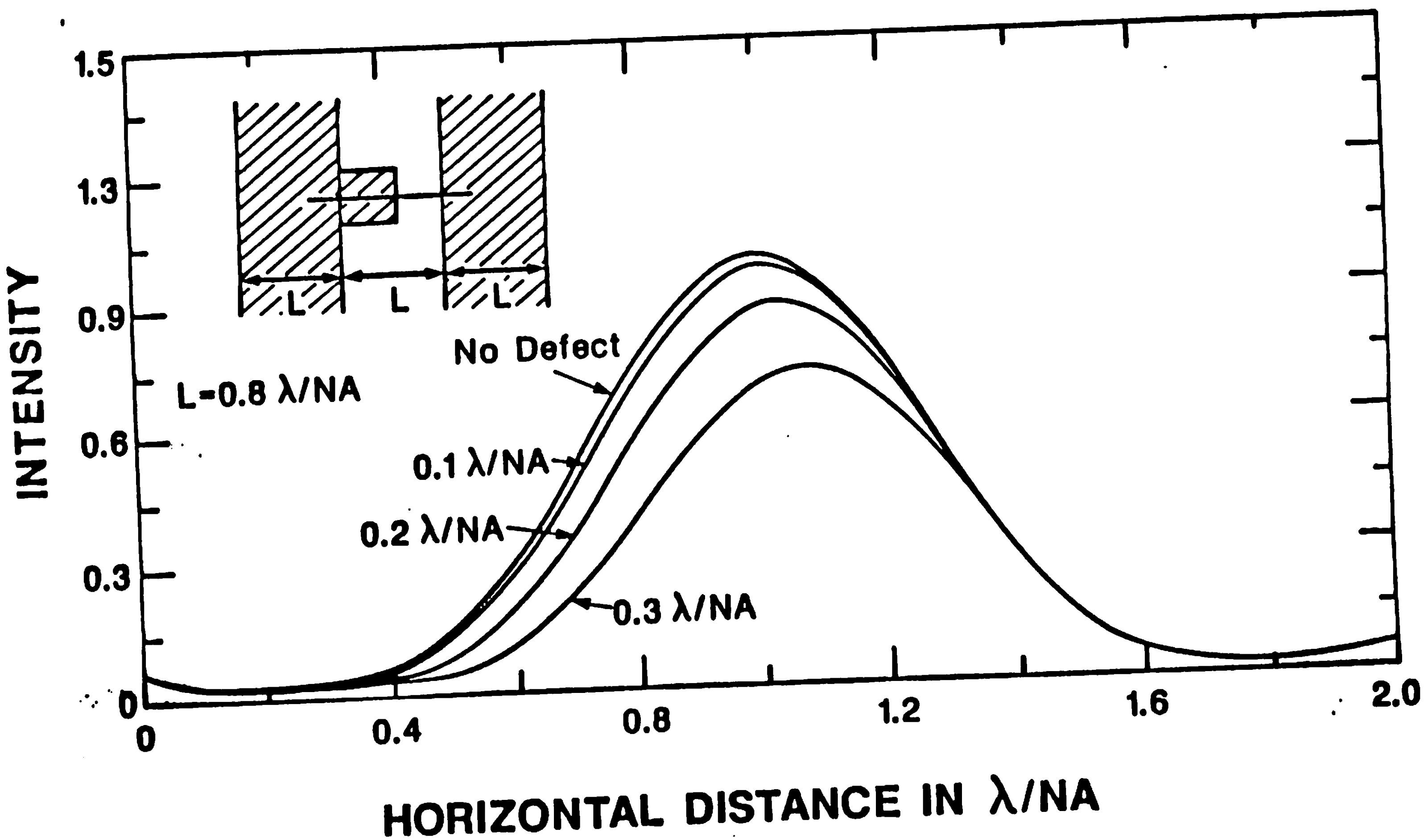

ISOLATED OPAQUE 0.2 λ/NA DEFECT
Y-AXIS
X-AXIS
1.00
0.75
0.50
0.25
0
-0.25
-0.50
-0.75
-1.00
-1.50
-1.25
-1.00
-0.75
-0.50
-0.25
0
0.25
0.50
0.75
1.00
1.25
1.50
1.0
0.9
0.8

Fig 13



1.5
1.3
0.9
0.6
0.3
0
INTENSITY
L
L
L
L=0.8 λ/NA
No Defect
0.1 λ/NA
0.2 λ/NA
0.3 λ/NA
0
0.4
0.8
1.2
1.6
2.0
HORIZONTAL DISTANCE IN λ/NA

Fig 14

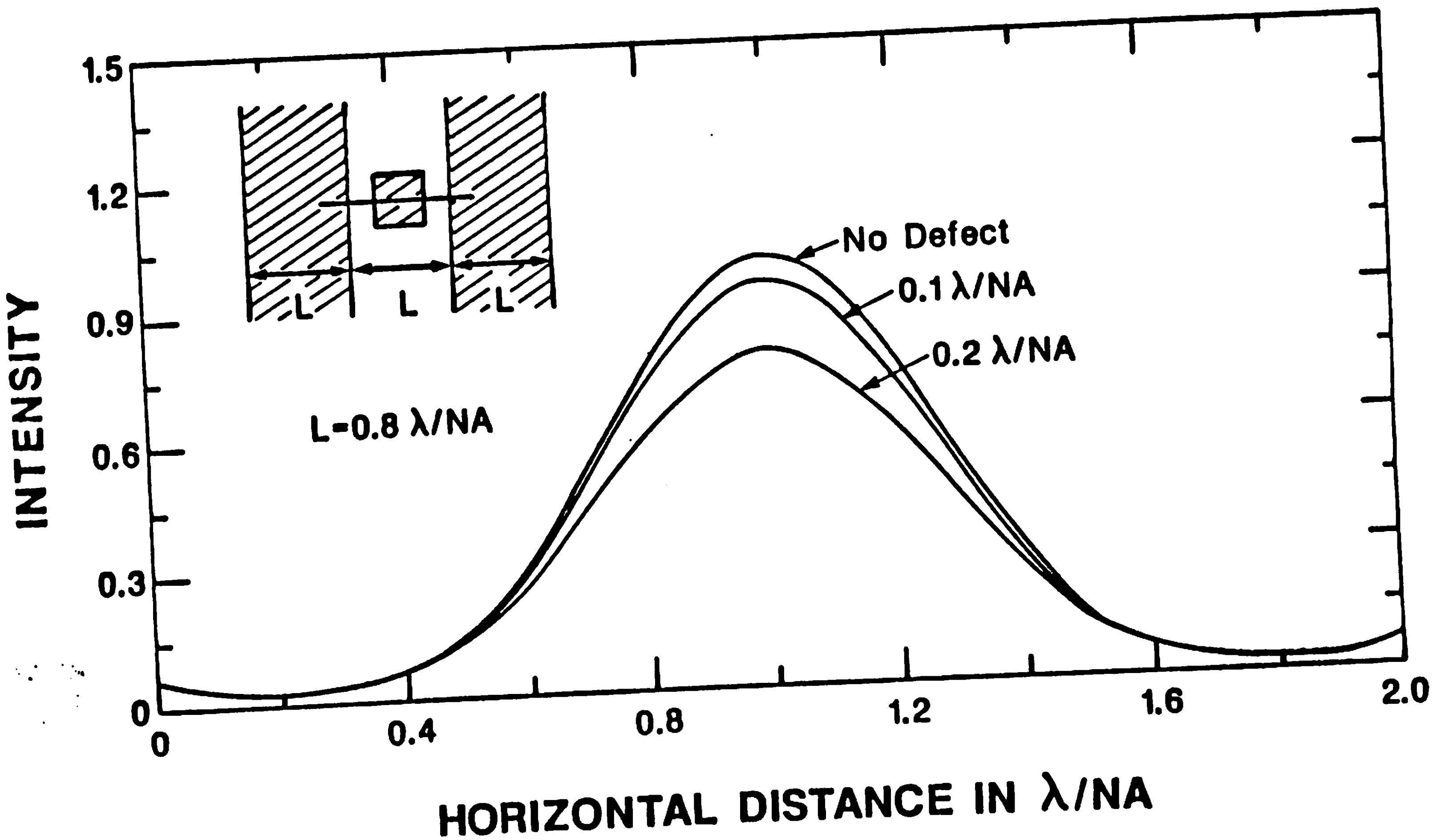

1.5
1.2
0.9
0.6
0.3
0
INTENSITY
L
L
L
L=0.8 λ/NA
No Defect
0.1 λ/NA
0.2 λ/NA
0
0.4
0.8
1.2
1.6
2.0
HORIZONTAL DISTANCE IN λ/NA

Fig 1:

```
# Single wavelength projection lithography with descum  -- twodsamopl
lambda 0.5000                              ; # lambda parameter
proj 0.50                                  ; # numerical aperture
#linespace 0.8  2.40                       ; # linespace parameters
parcohdef 0 0.7 0.0                        ; # sigma and defocus
optimgexp 1 0 1 0 0                        ; # profile coordinates for plot
readimage
resmodel ((0.5000))
         (0.551, 0.058, 0.010)
         (1.68, ((-0.02))) (0.8180)        ; # resist exposure parameters
layers (4.73,-0.14)
       (1.47,0.0,0.0850)                   ; # layer parameters
dose 150                                   ; # dose for exposure
vertrespts 120
#devscalpar 0.7 0.7 0.7
run 3                                      ; # run exposure machine
optdevelop 0 1 0                           ; # profile coordinates for plot
devrate 1 (5.63, 7.43, -12.6)              ; # resist development parameters
devtime 15 75, 5                           ; # development times
run 4                                      ; # run development machine
#descumspec  0.02, 0.04, 3                  ; # run descum
```

Fig. 16

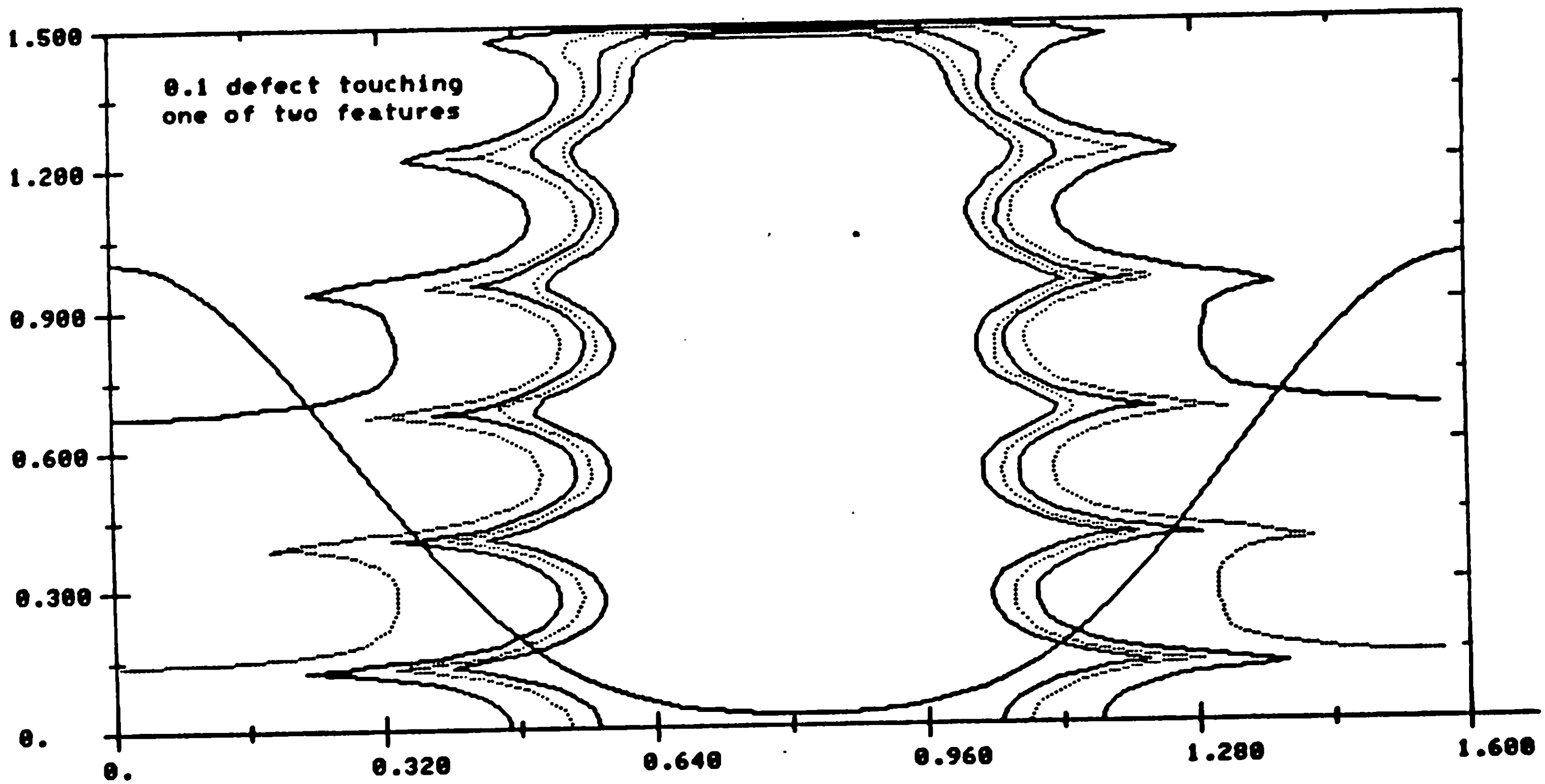

1.500
1.200
0.900
0.600
0.300
0.
0.1 defect touching
one of two features
0.
0.320
0.640
0.960
1.280
1.600

Fig 17A

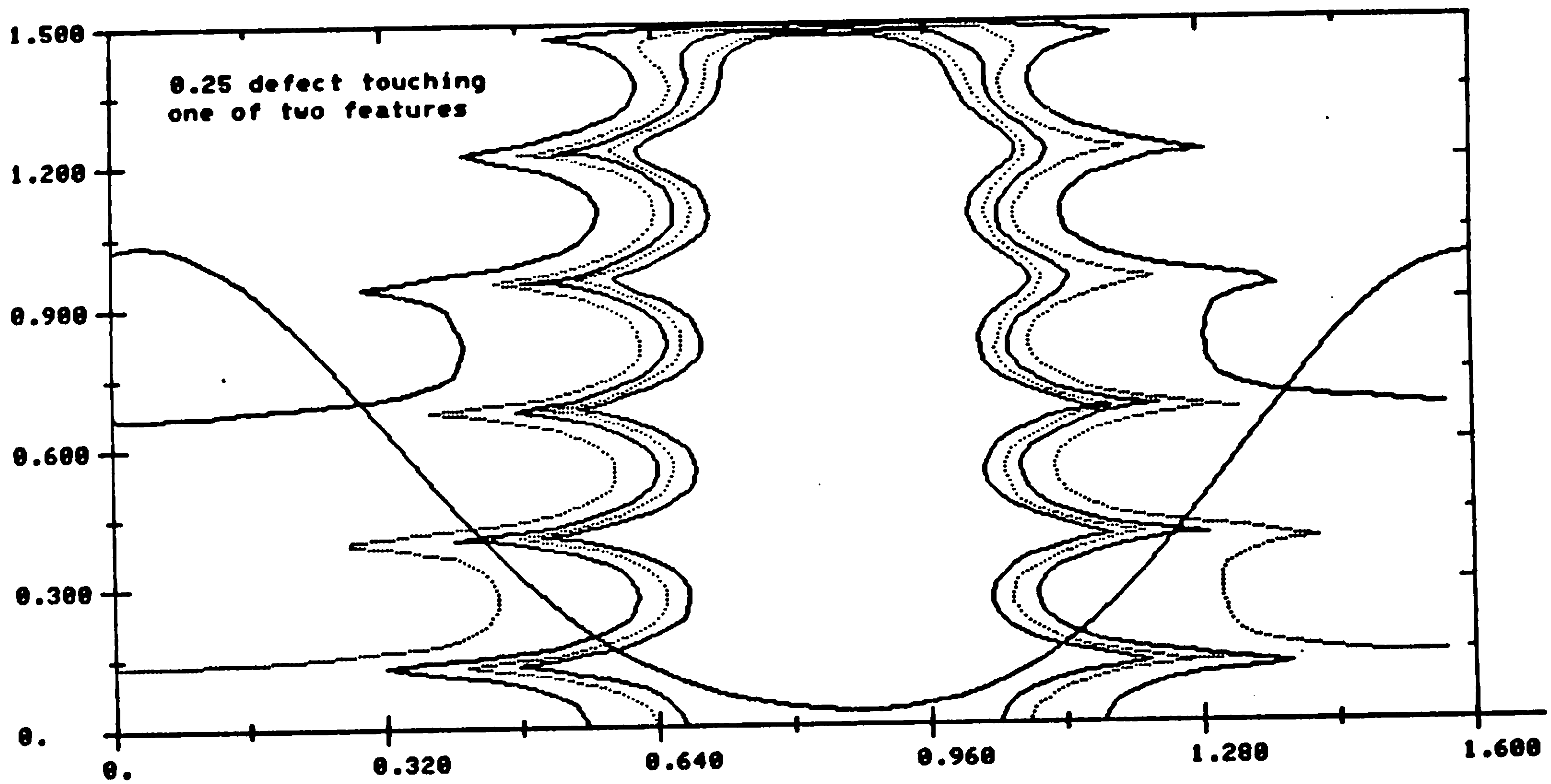

0.25 defect touching
one of two features
1.500
1.200
0.900
0.600
0.300
0.
0.
0.320
0.640
0.960
1.280
1.600

Fig 17B

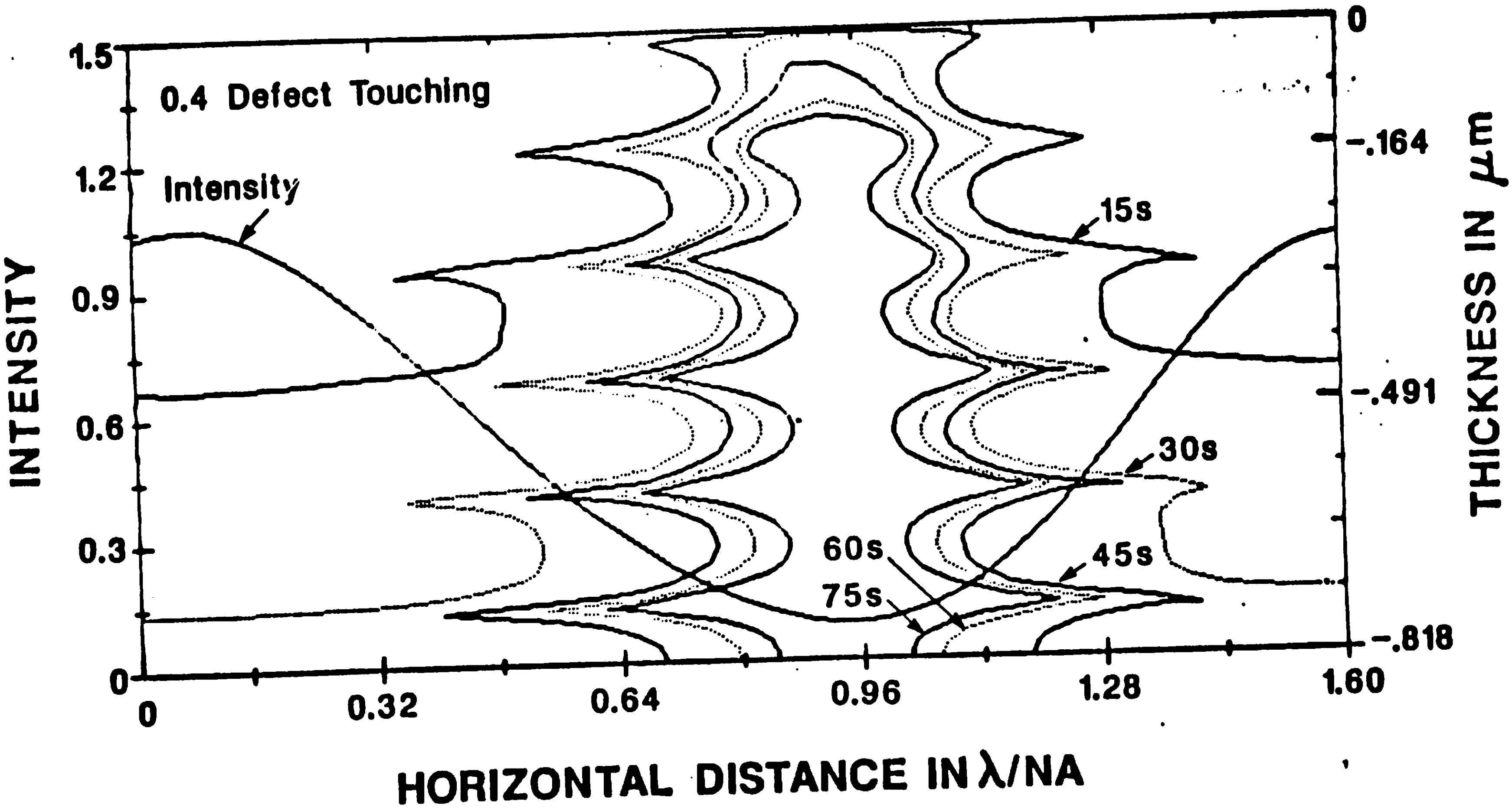
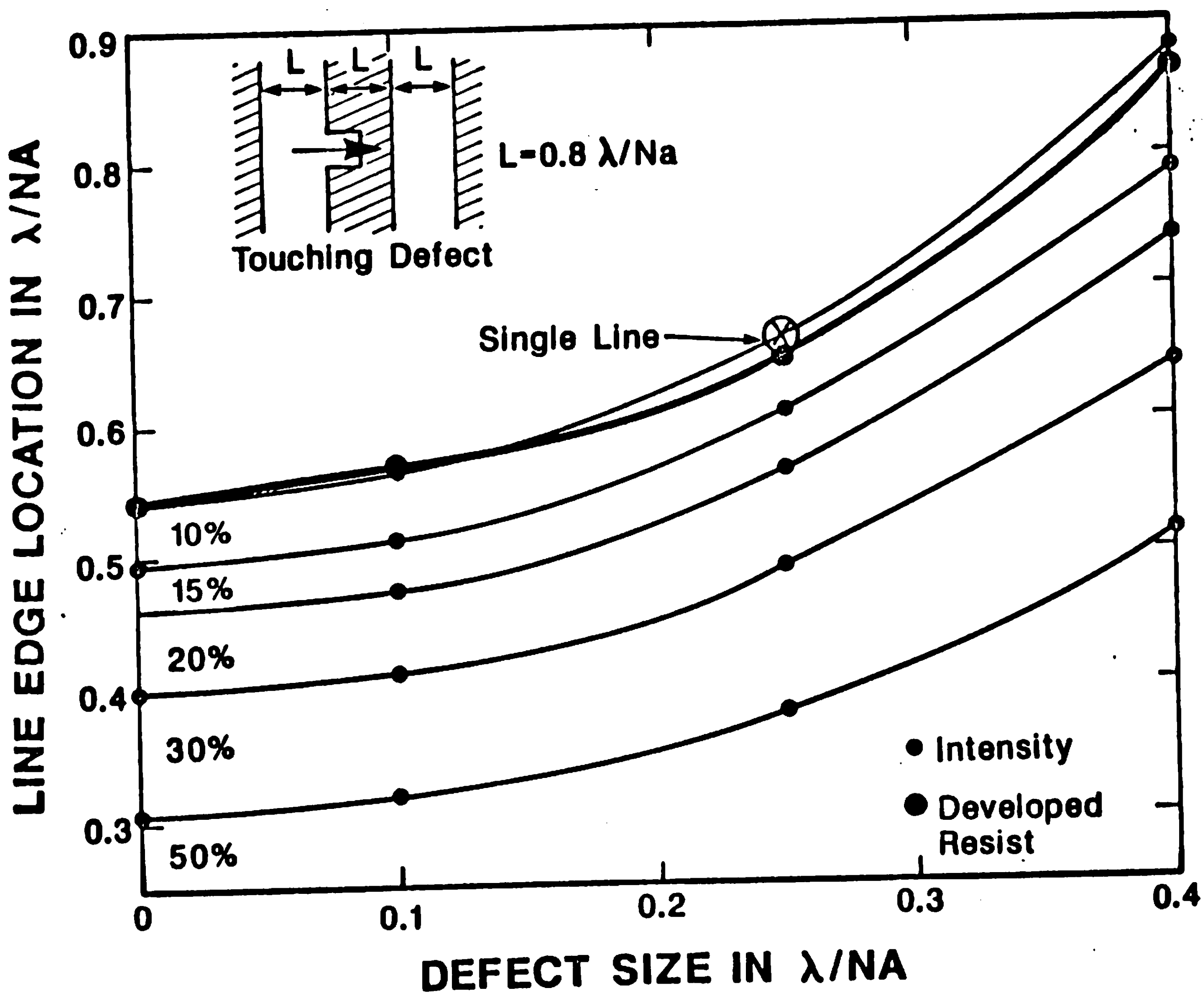

0.4 Defect Touching
Intensity
15s
30s
45s
60s
75s
INTENSITY
THICKNESS IN μm
HORIZONTAL DISTANCE IN λ/NA
1.5
1.2
0.9
0.6
0.3
0
0.32
0.64
0.96
1.28
1.60
-.164
-.491
-.818

Fig. 17c



L
L
L
L=0.8 λ/Na
Touching Defect
Single Line
10%
15%
20%
30%
50%
Intensity
Developed Resist
0.9
0.8
0.7
0.6
0.5
0.4
0.3
LINE EDGE LOCATION IN λ/NA
0
0.1
0.2
0.3
0.4
DEFECT SIZE IN λ/NA

Fig 18

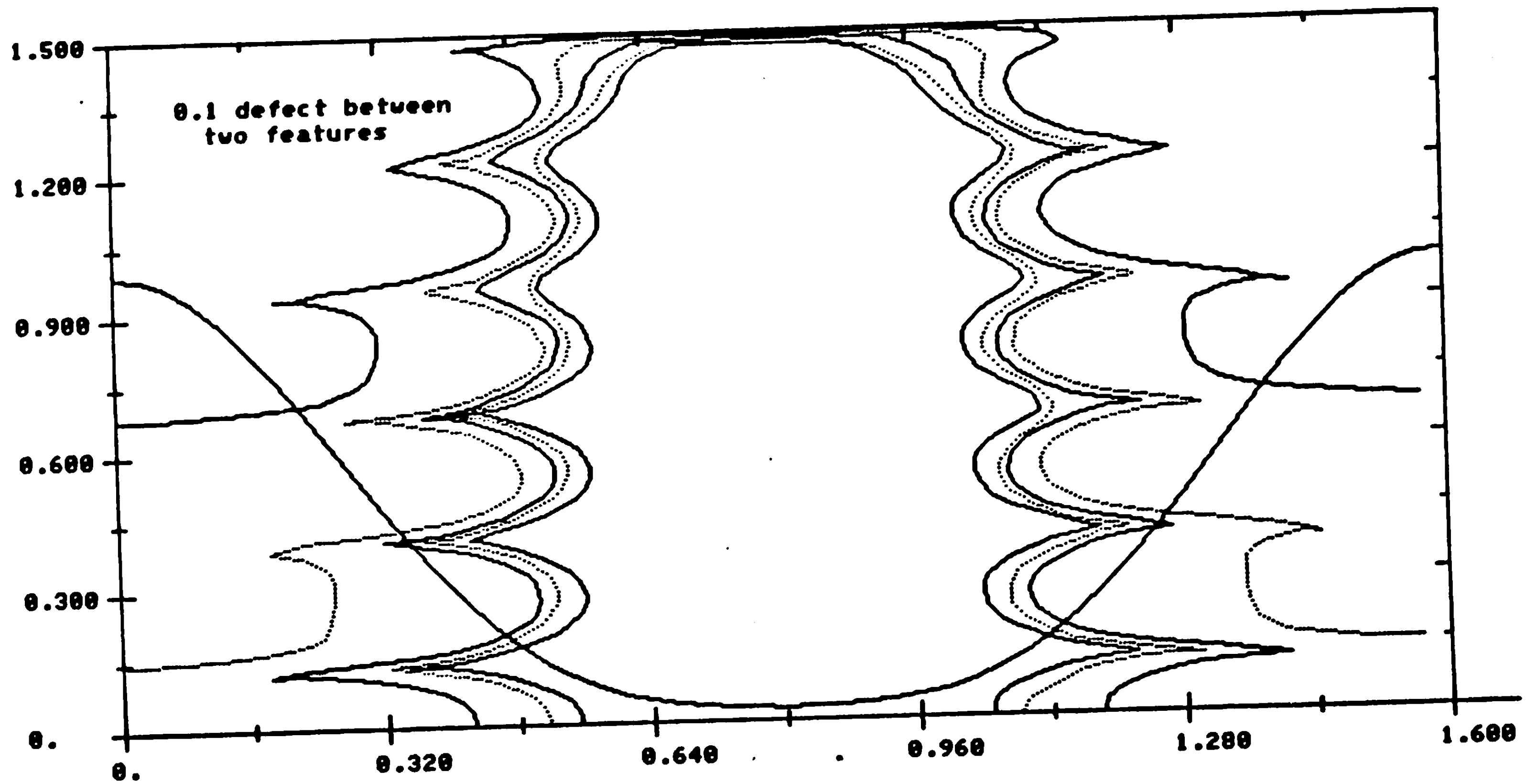

0.1 defect between
two features
1.500
1.200
0.900
0.600
0.300
0.
0.
0.320
0.640
0.960
1.280
1.600

Fig. 19A

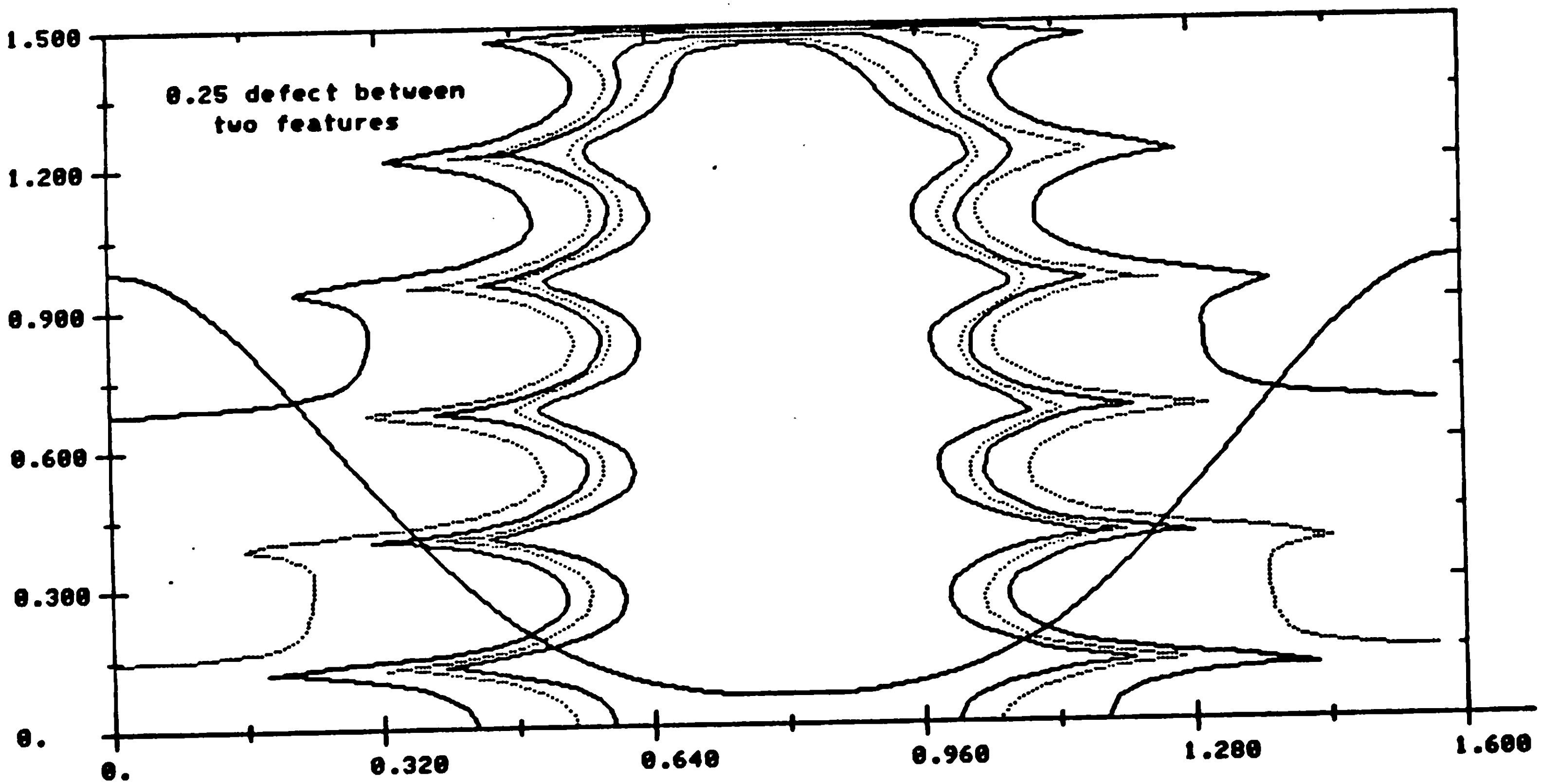

0.25 defect between
two features
1.500
1.200
0.900
0.600
0.300
0.
0.
0.320
0.640
0.960
1.280
1.600

Fig. 19B

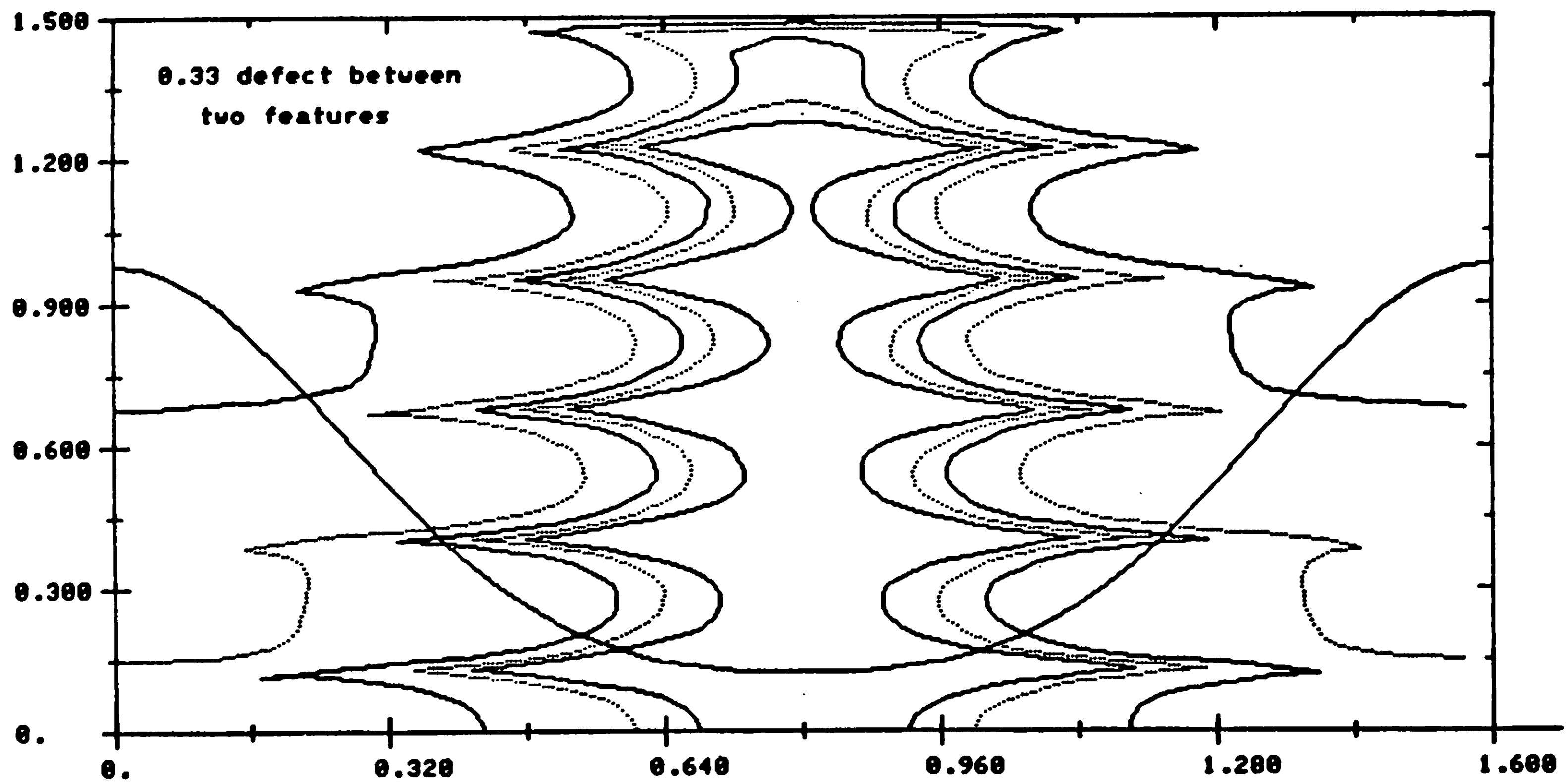
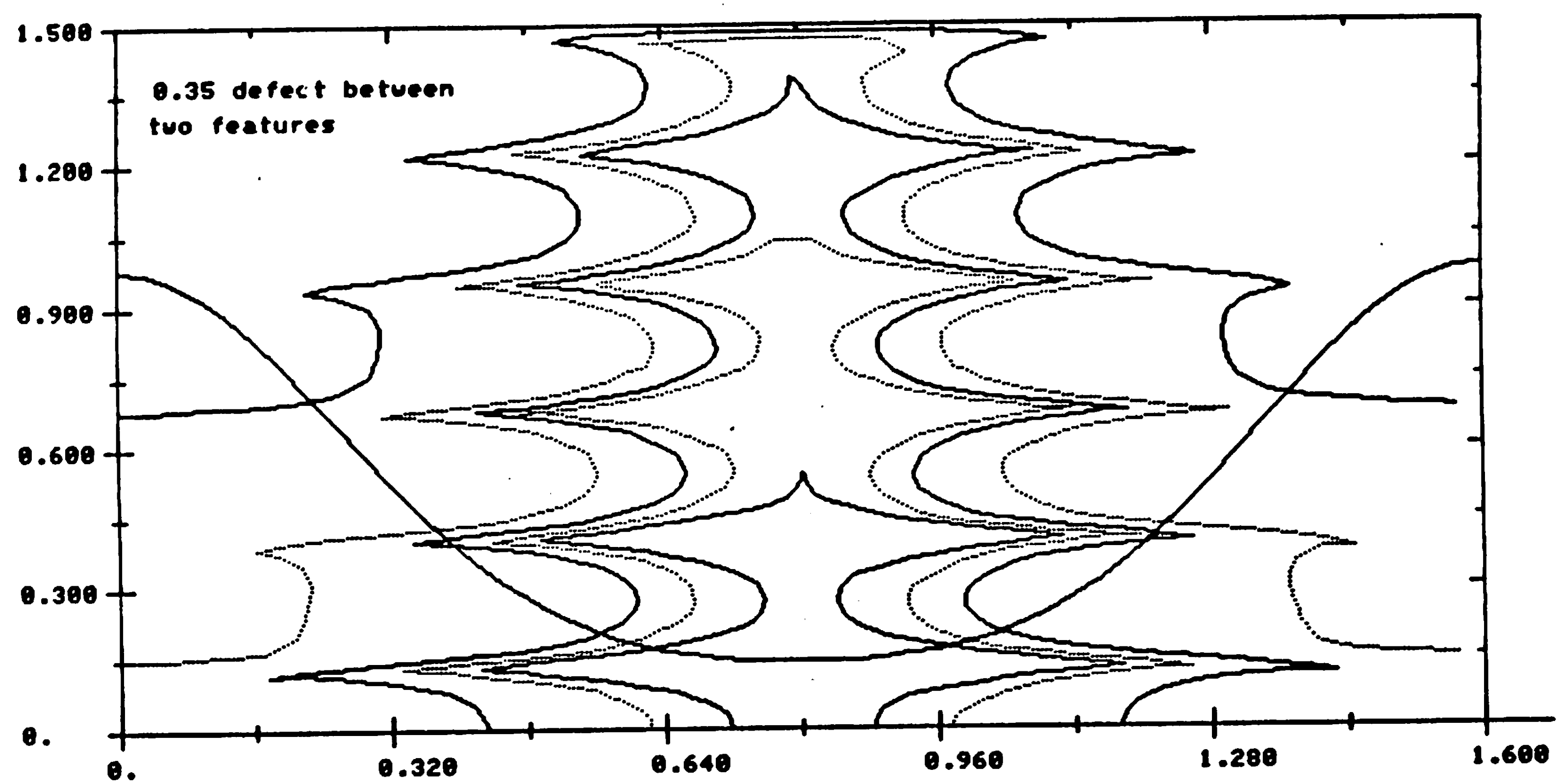

0.33 defect between
two features
1.500
1.200
0.900
0.600
0.300
0.
0.
0.320
0.640
0.960
1.280
1.600

Fig 19C



0.35 defect between
two features
1.500
1.200
0.900
0.600
0.300
0.
0.
0.320
0.640
0.960
1.280
1.600

Fig. 19D

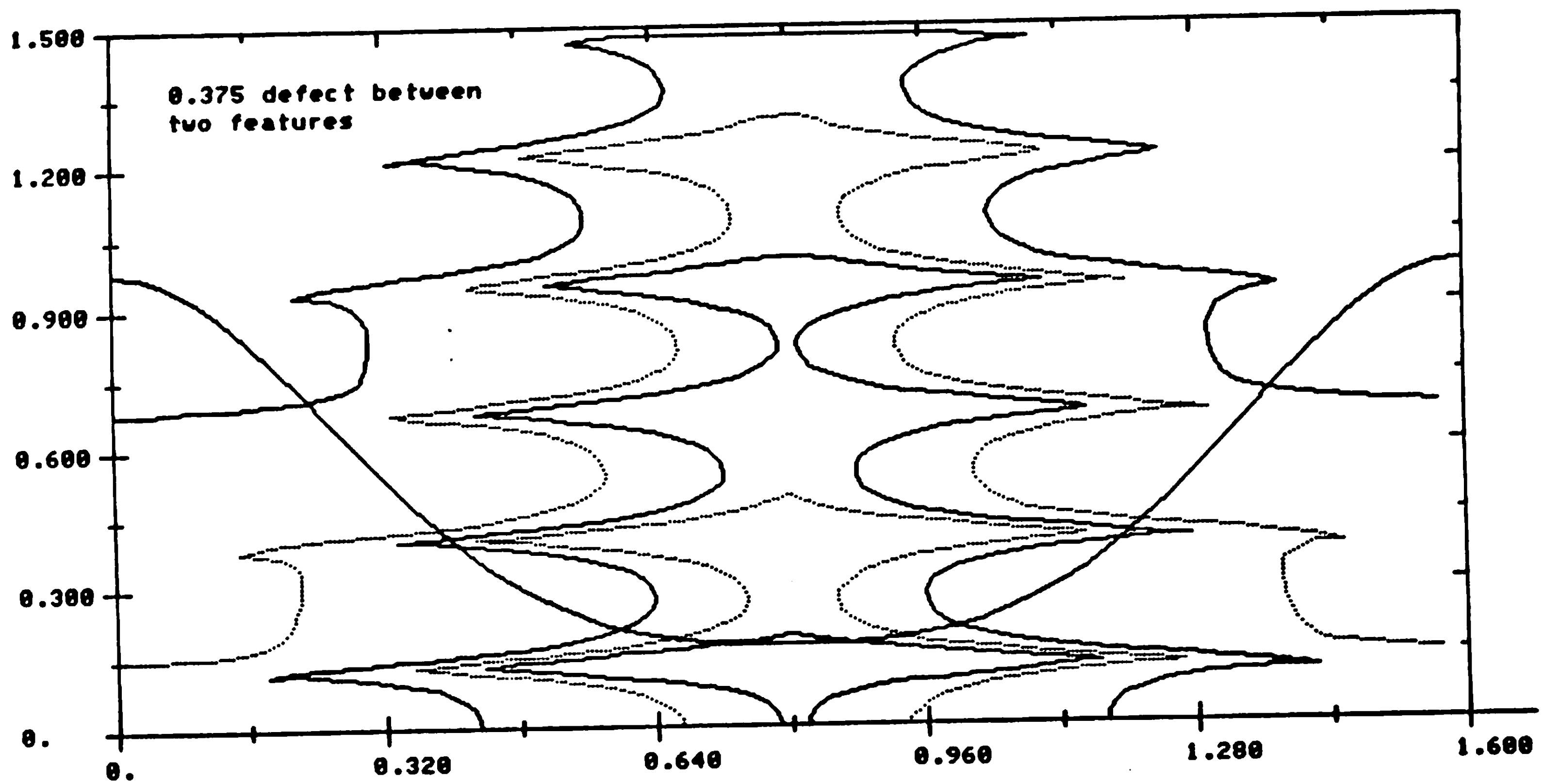
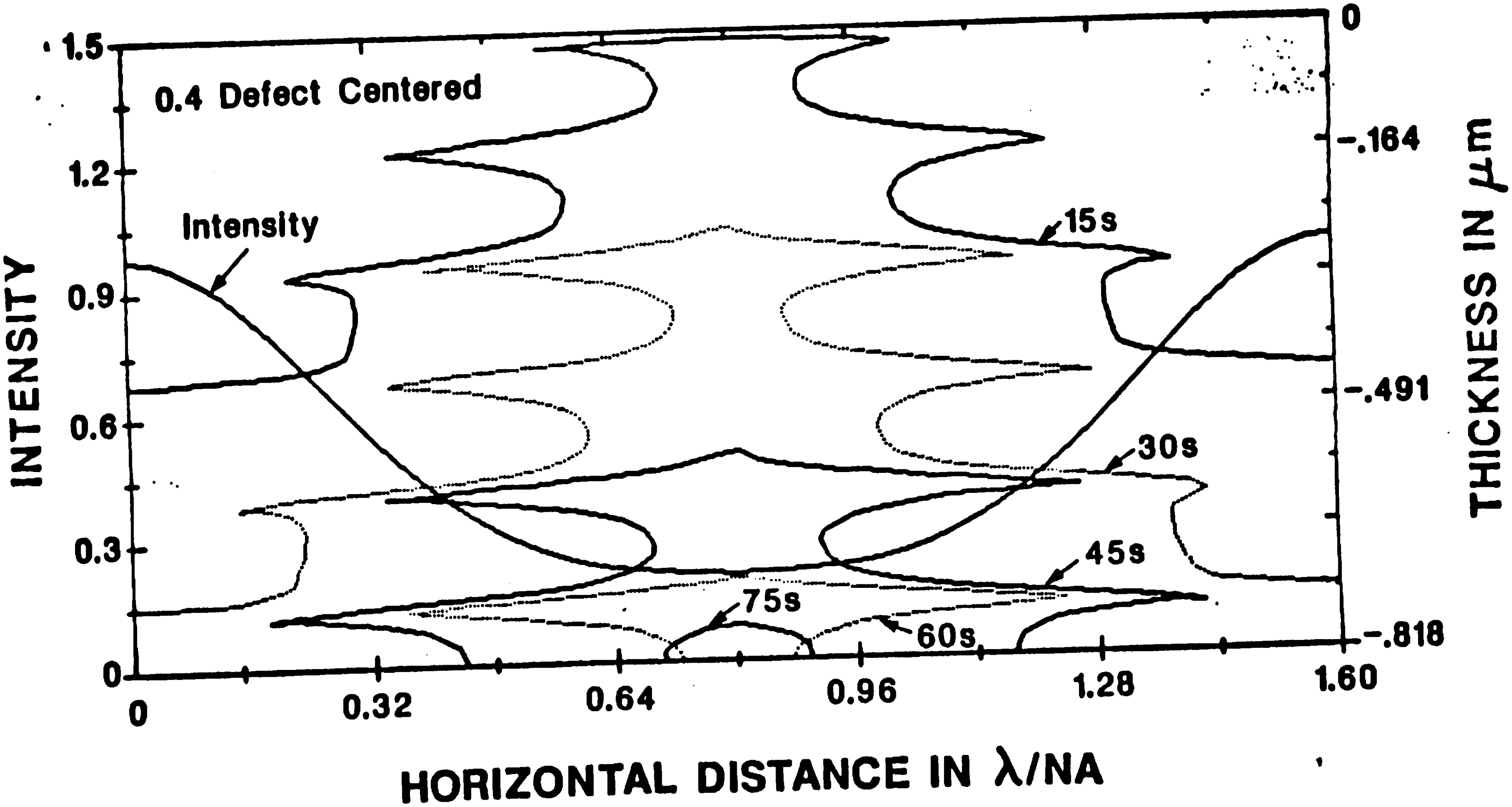

0.375 defect between
two features
1.500
1.200
0.900
0.600
0.300
0.
0.
0.320
0.640
0.960
1.280
1.600

Fig 19E



0.4 Defect Centered
Intensity
15s
30s
45s
60s
75s
INTENSITY
THICKNESS IN μm
HORIZONTAL DISTANCE IN λ/NA
1.5
1.2
0.9
0.6
0.3
0
0
0.32
0.64
0.96
1.28
1.60
0
-.164
-.491
-.818

Fig. 19F

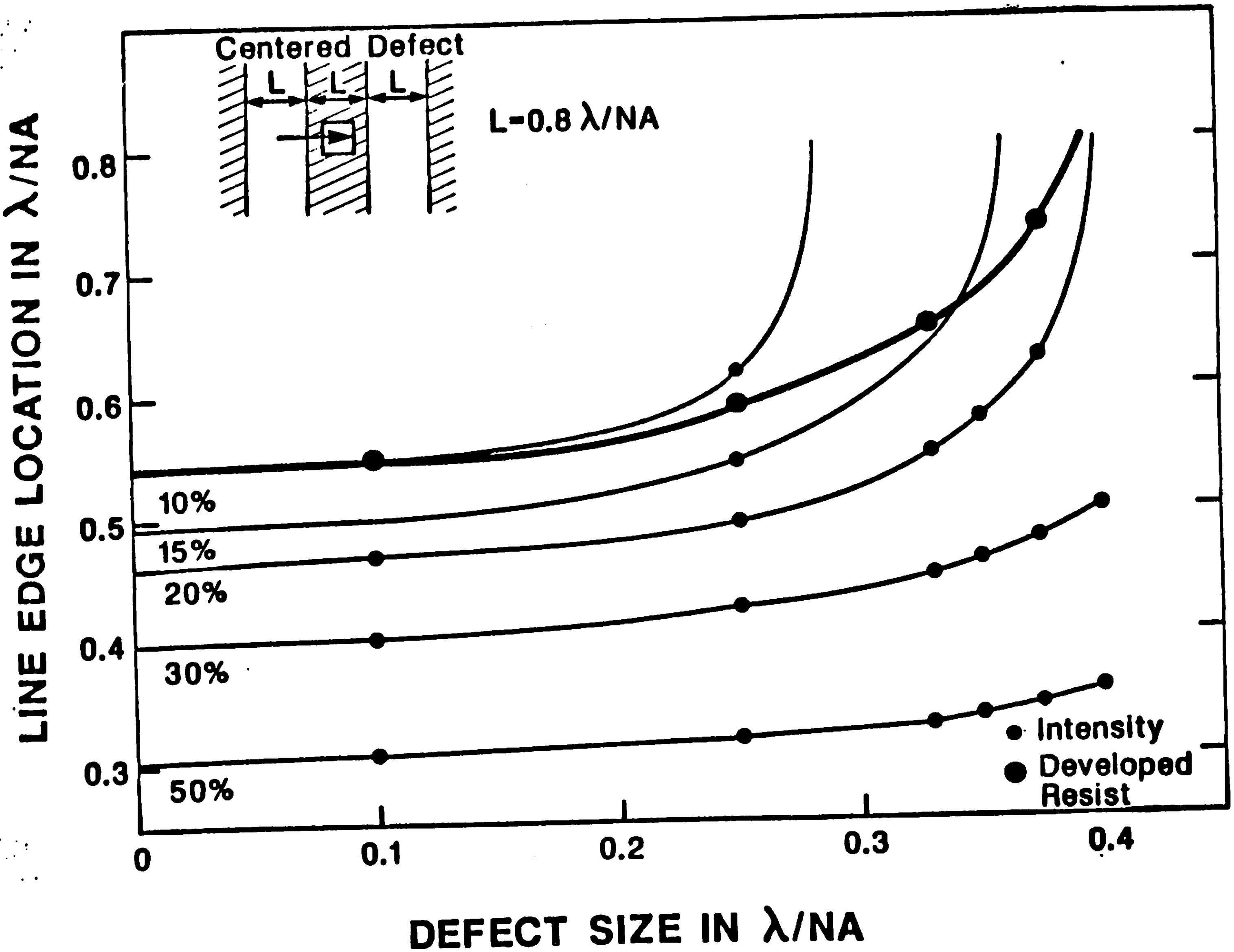
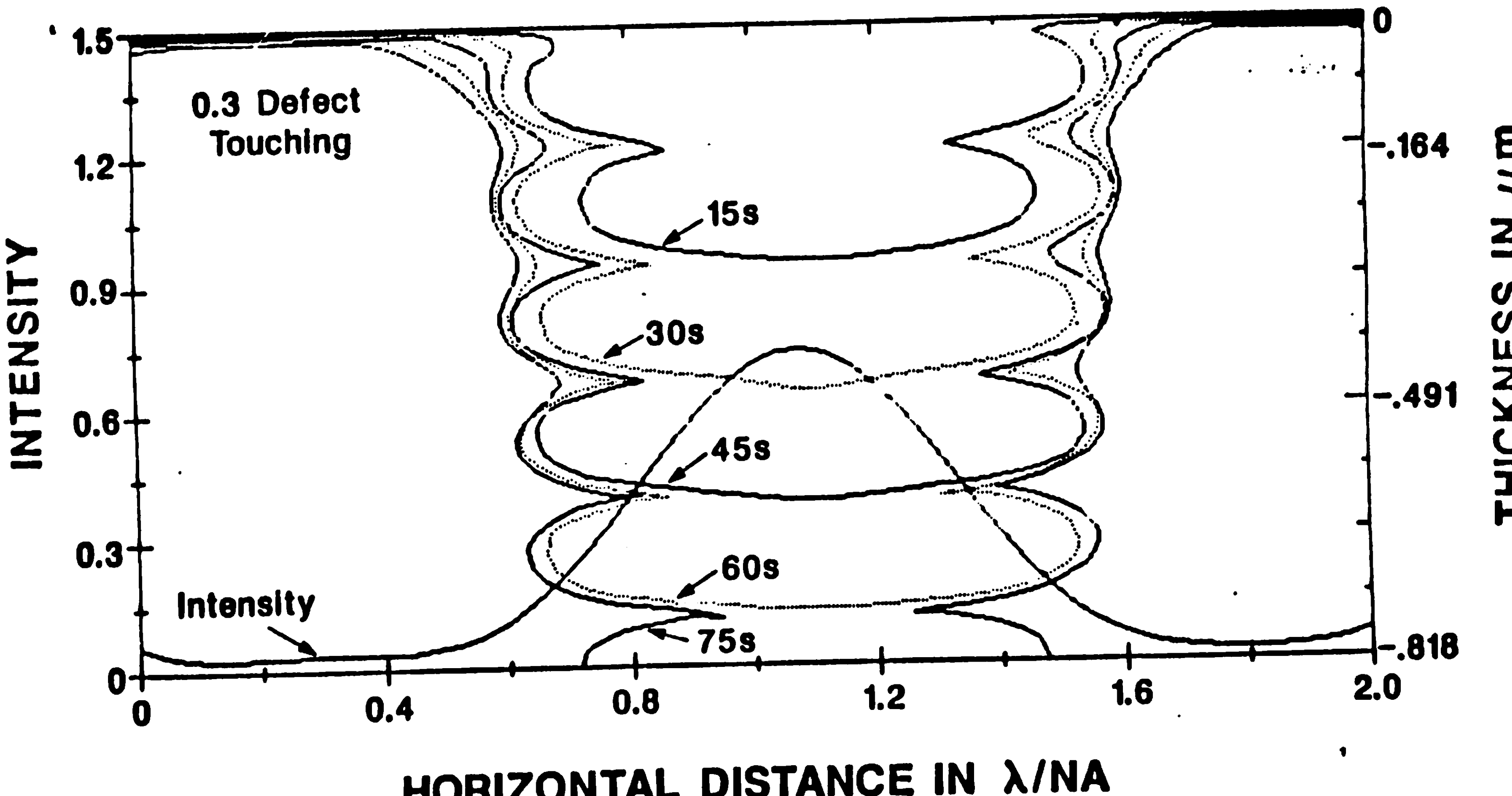
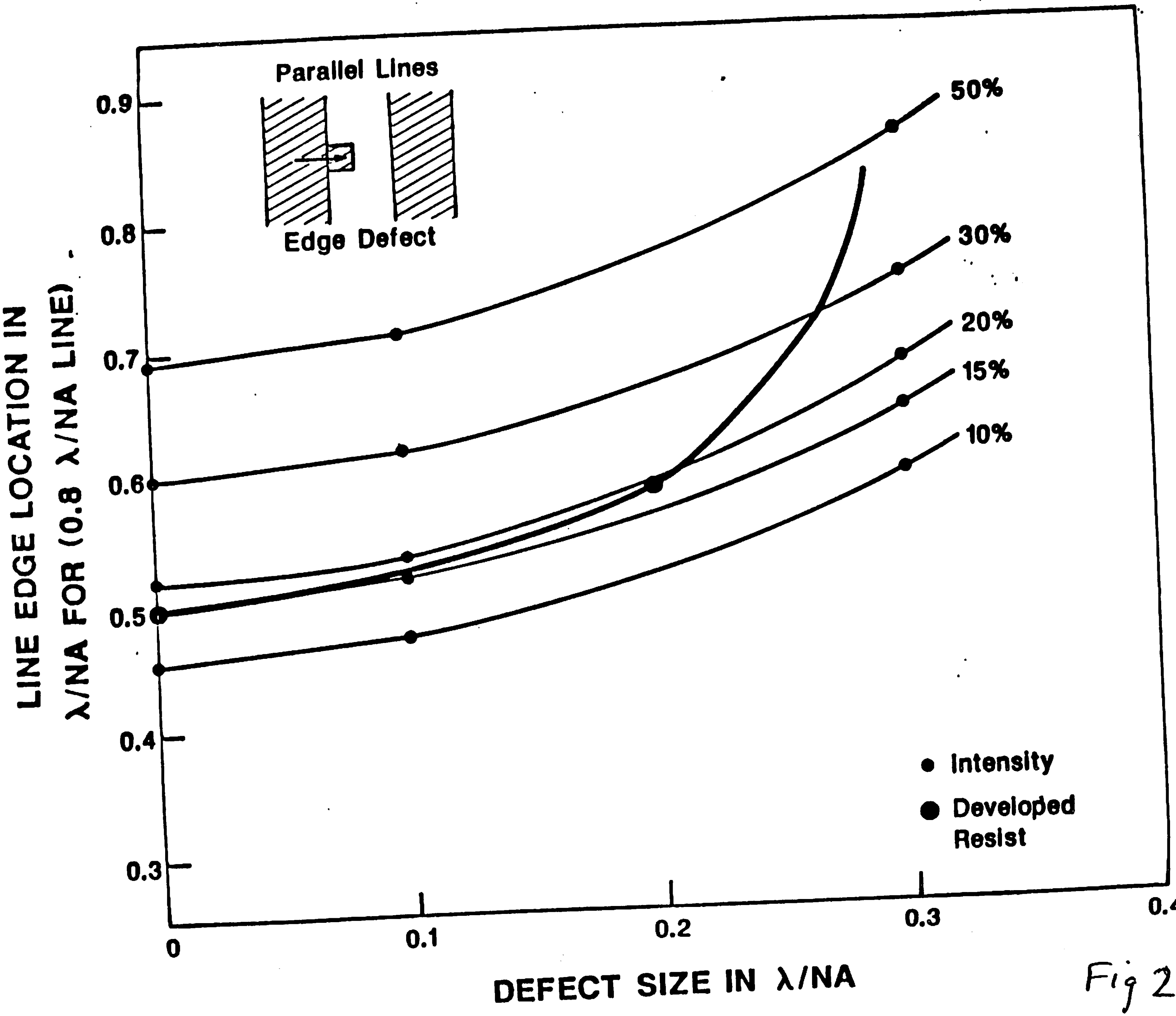

Centered Defect
L
L
L
L=0.8 λ/NA
LINE EDGE LOCATION IN λ/NA
0.8
0.7
0.6
0.5
0.4
0.3
10%
15%
20%
30%
50%
Intensity
Developed Resist
0
0.1
0.2
0.3
0.4
DEFECT SIZE IN λ/NA

Fig 20



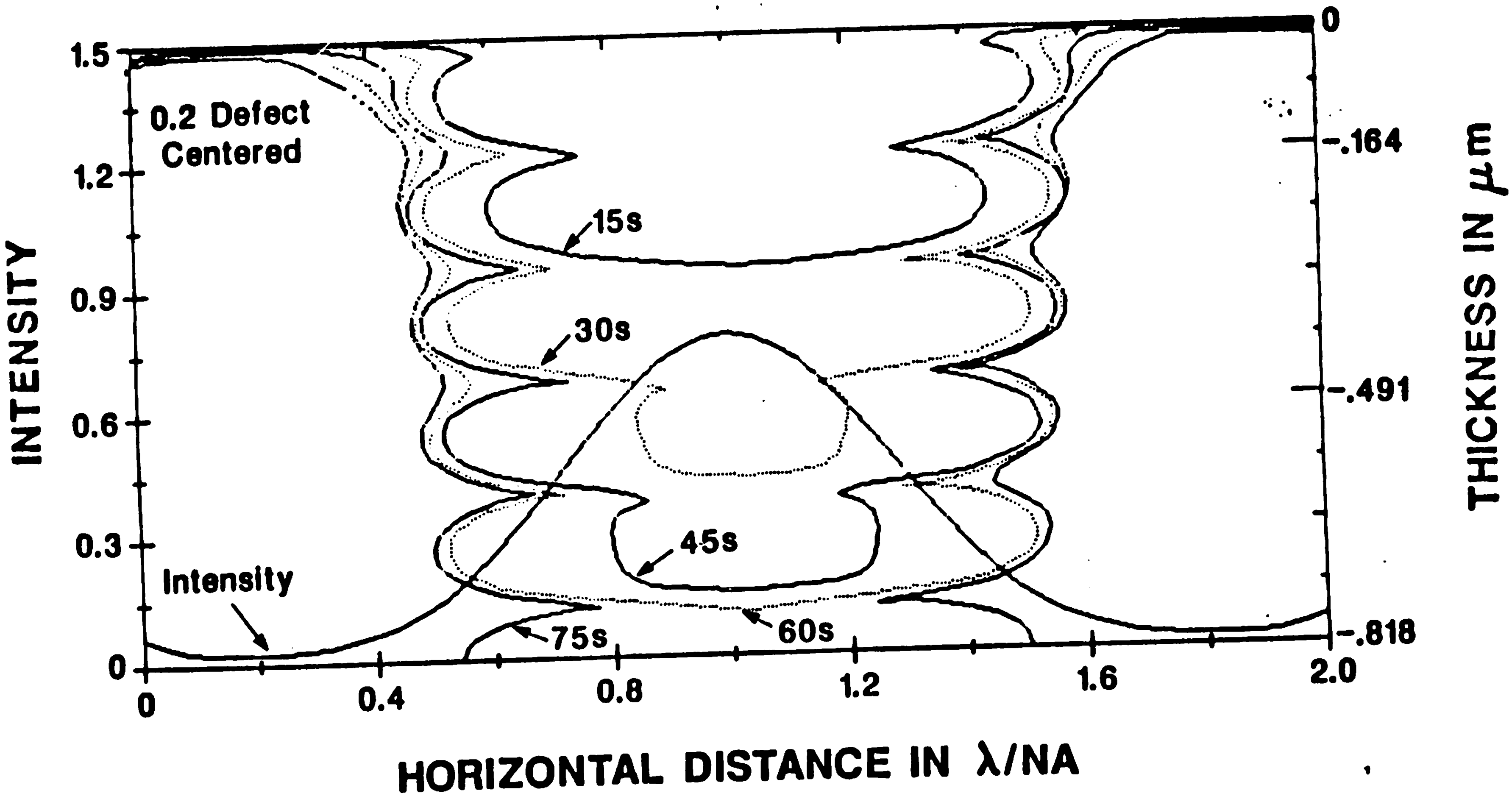
0.3 Defect
Touching
INTENSITY
THICKNESS IN μm
1.5
1.2
0.9
0.6
0.3
0
0
-.164
-.491
-.818
15s
30s
45s
60s
75s
Intensity
0
0.4
0.8
1.2
1.6
2.0
HORIZONTAL DISTANCE IN λ/NA

Fig. 21



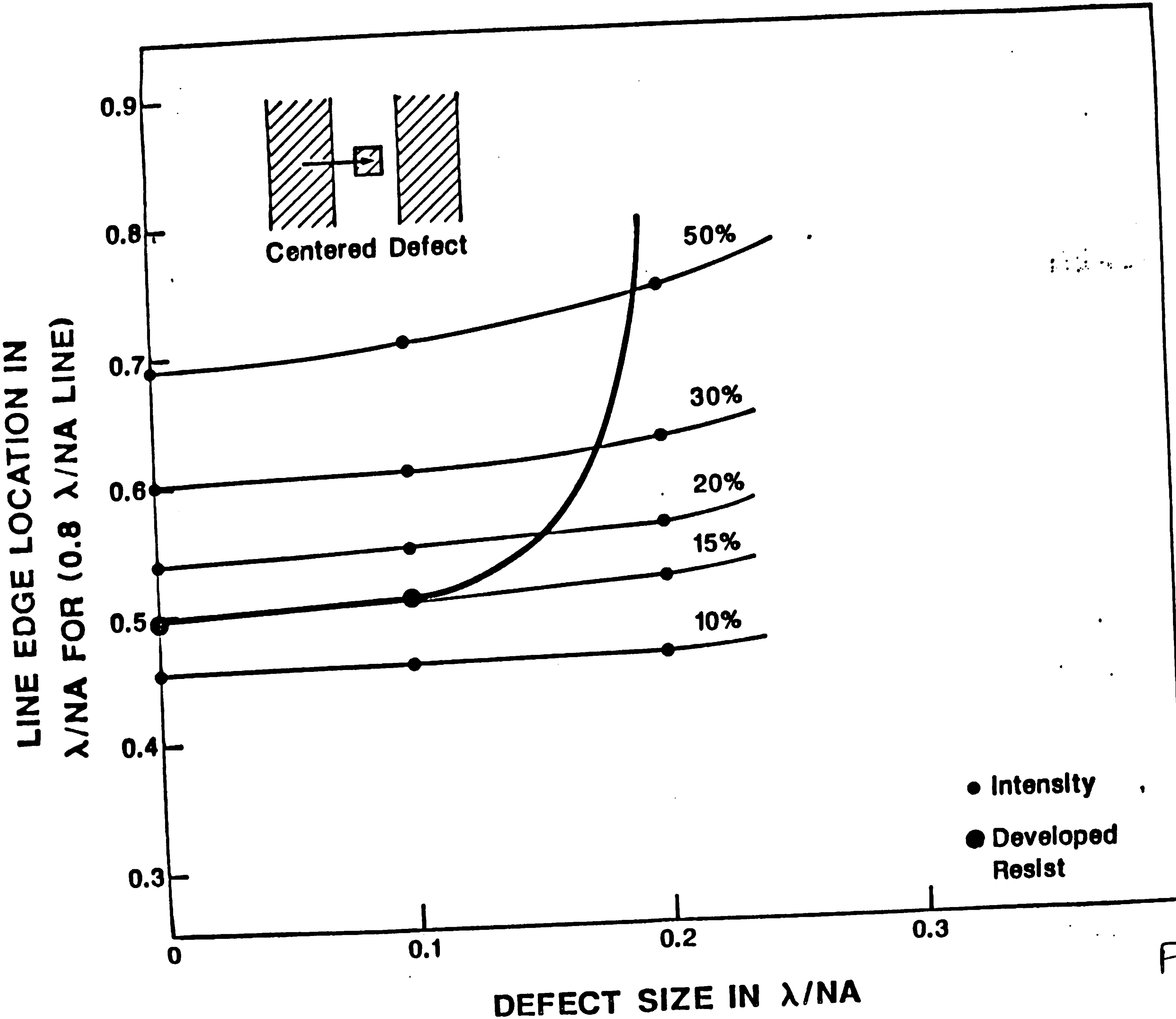
Parallel Lines
Edge Defect
0.9
0.8
0.7
0.6
0.5
0.4
0.3
LINE EDGE LOCATION IN
λ/NA FOR (0.8 λ/NA LINE)
50%
30%
20%
15%
10%
Intensity
Developed
Resist
0
0.1
0.2
0.3
0.4
DEFECT SIZE IN λ/NA

Fig 22



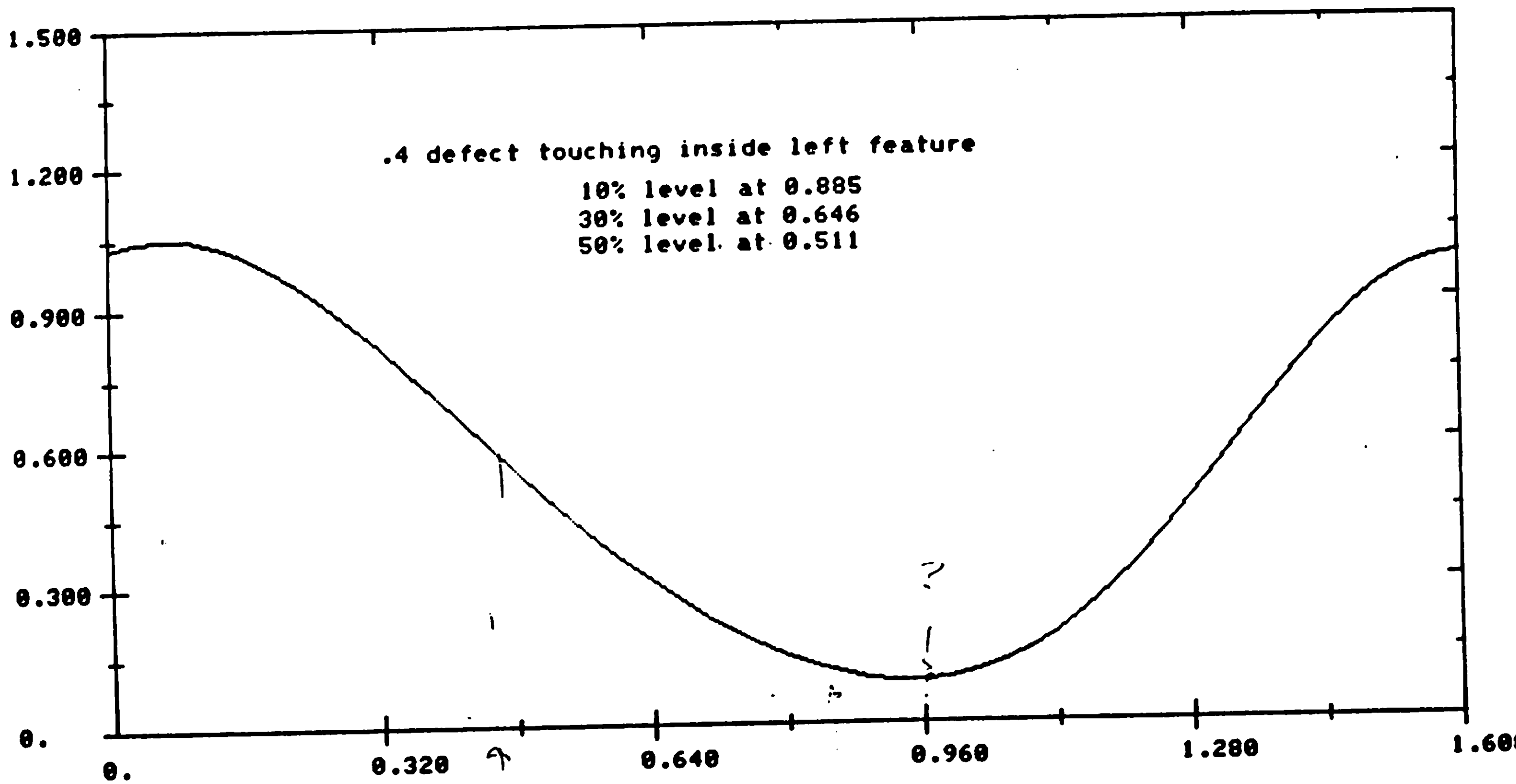
0.2 Defect
Centered
INTENSITY
THICKNESS IN μm
HORIZONTAL DISTANCE IN λ/NA
15s
30s
45s
60s
75s
Intensity
1.5
1.2
0.9
0.6
0.3
0
0.4
0.8
1.2
1.6
2.0
-.164
-.491
-.818

Fig. 23

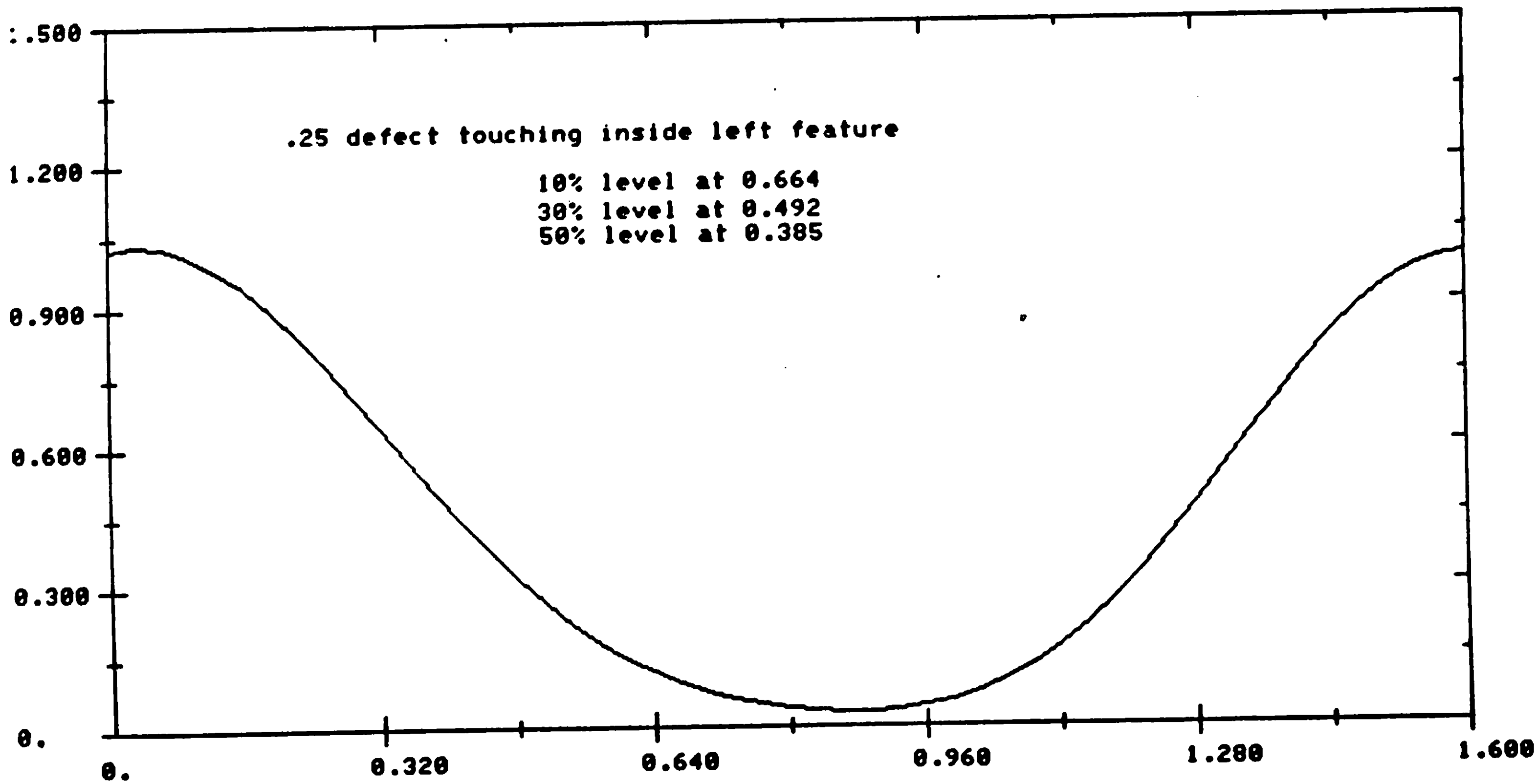


LINE EDGE LOCATION IN λ/NA FOR (0.8 λ/NA LINE)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
Centered Defect
50%
30%
20%
15%
10%
Intensity
Developed Resist
0
0.1
0.2
0.3
DEFECT SIZE IN λ/NA

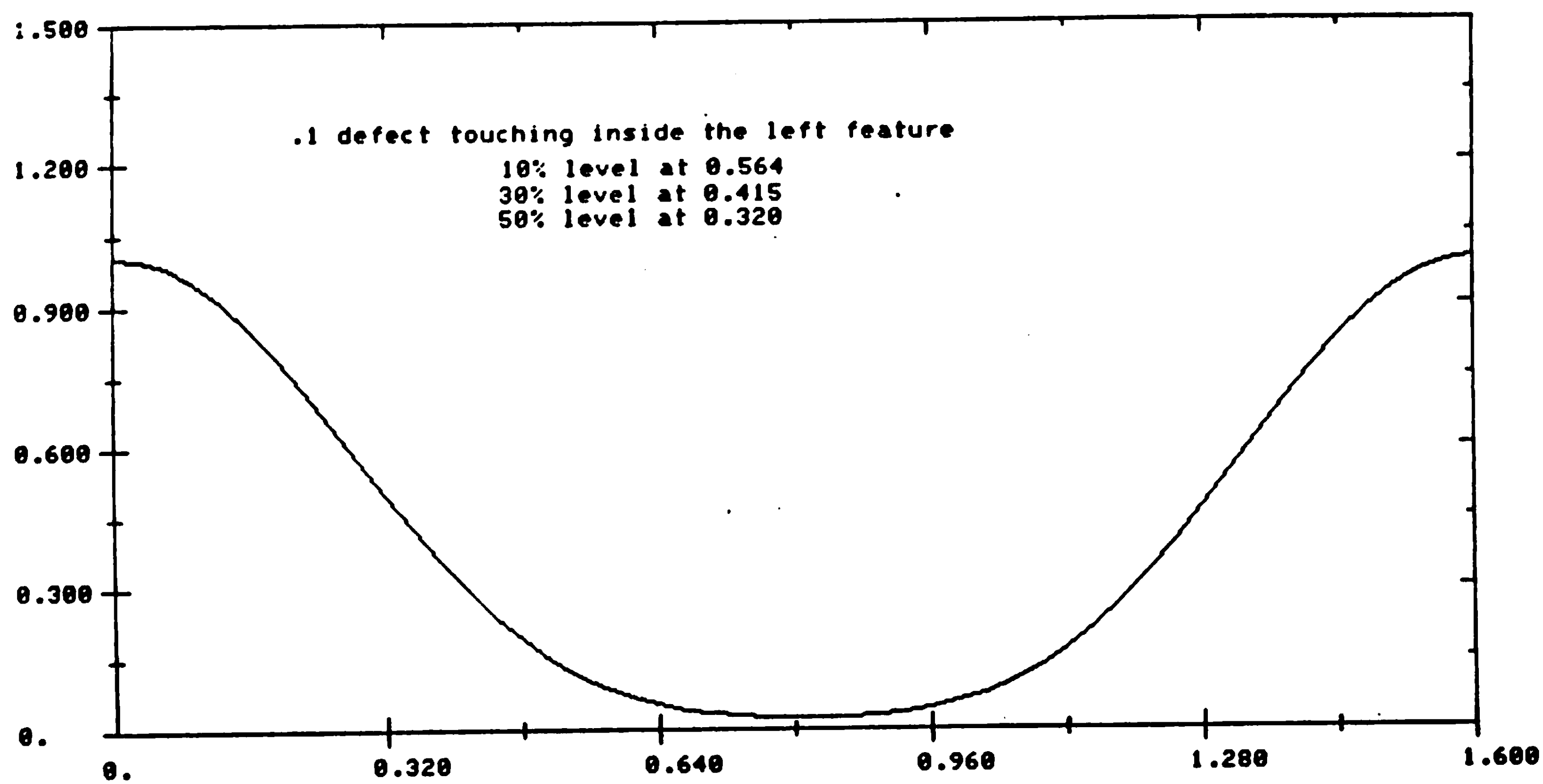
Fig. 24



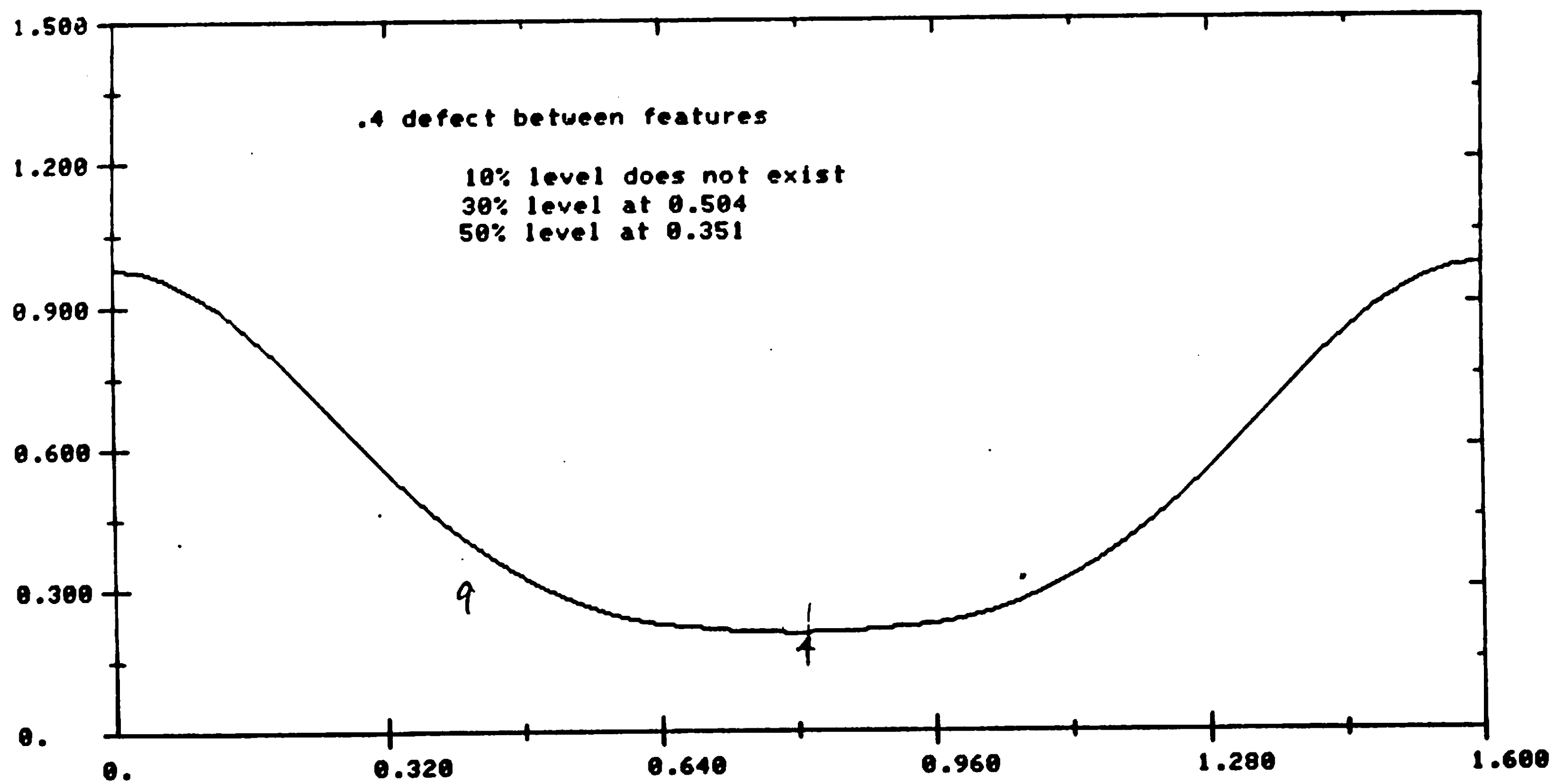
1.500
1.200
0.900
0.600
0.300
0.
.4 defect touching inside left feature
10% level at 0.885
30% level at 0.646
50% level at 0.511
0.
0.320
0.640
0.960
1.280
1.600



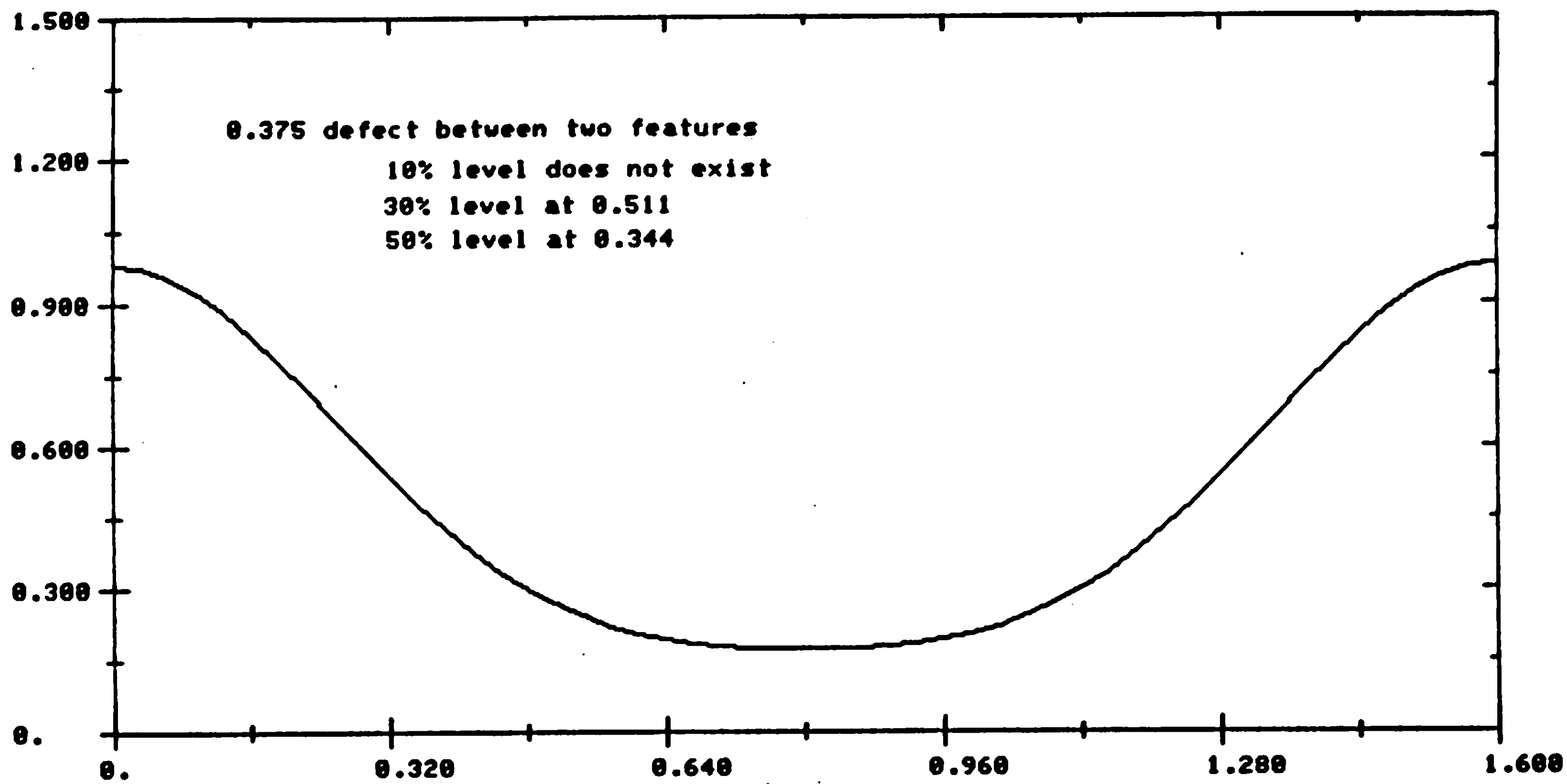
.25 defect touching inside left feature
10% level at 0.664
30% level at 0.492
50% level at 0.385
.500
1.200
0.900
0.600
0.300
0.
0.
0.320
0.640
0.960
1.280
1.600



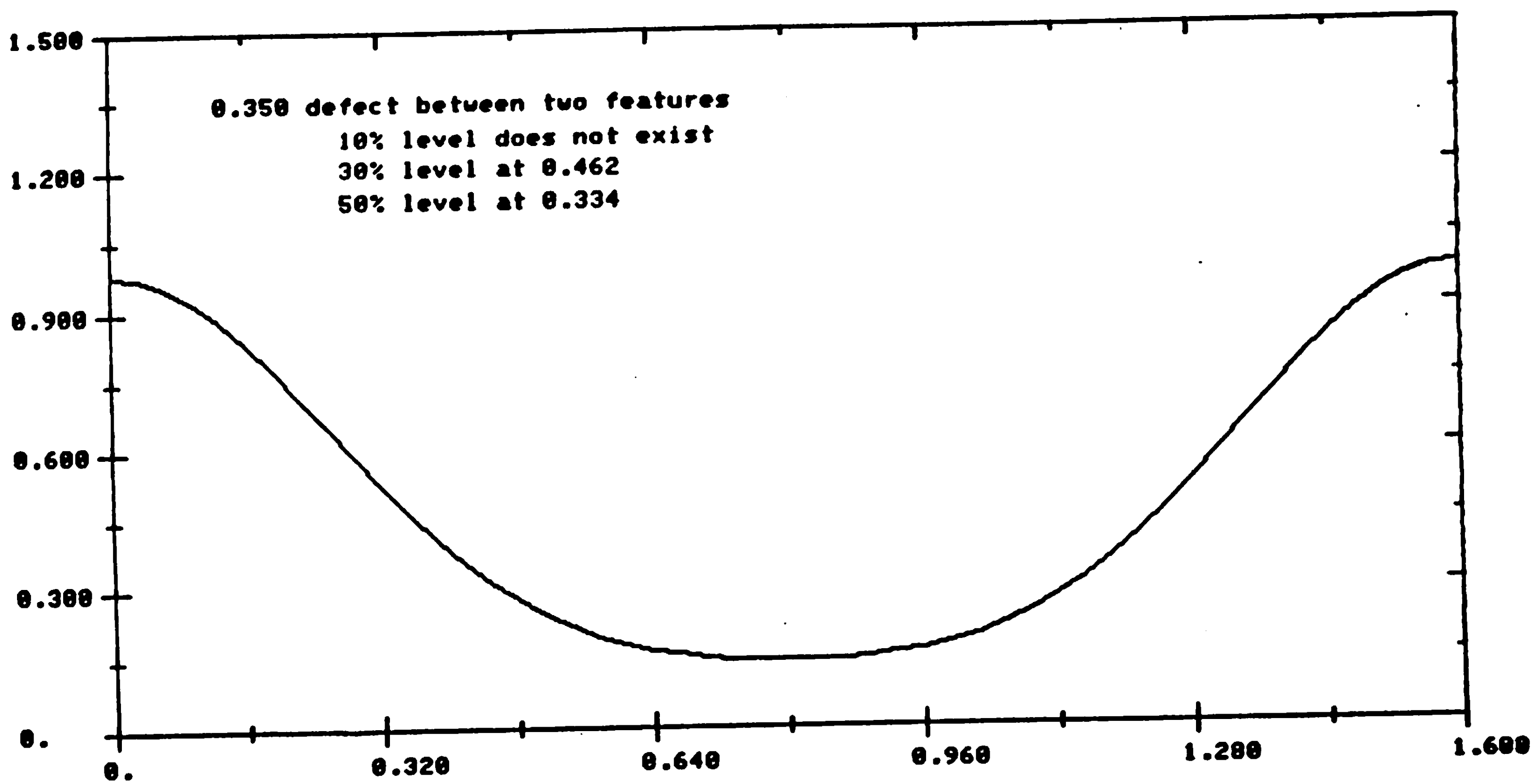
.1 defect touching inside the left feature
10% level at 0.564
30% level at 0.415
50% level at 0.320
1.500
1.200
0.900
0.600
0.300
0.
0.
0.320
0.640
0.960
1.280
1.600

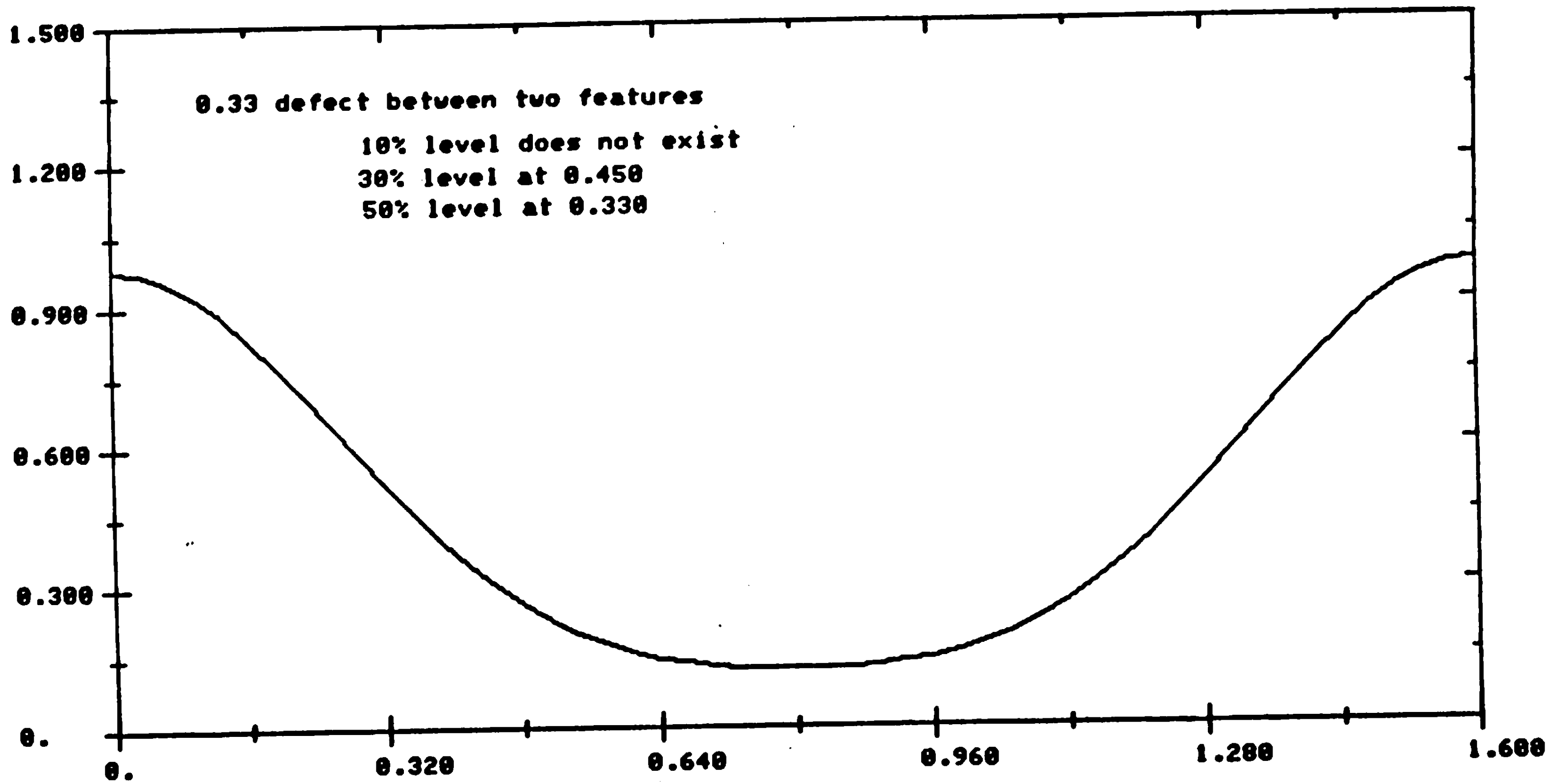


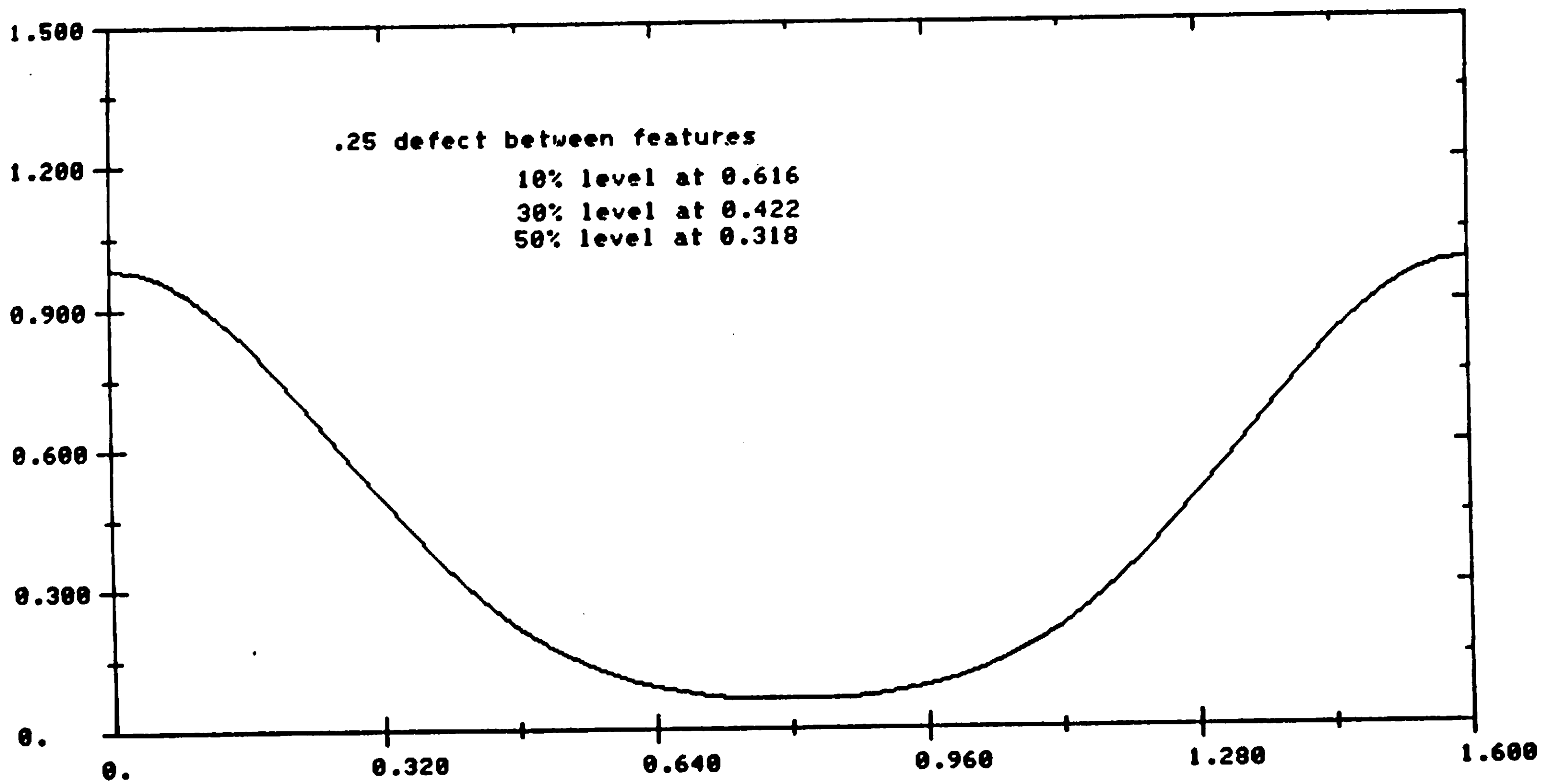
.4 defect between features
10% level does not exist
30% level at 0.504
50% level at 0.351
1.500
1.200
0.900
0.600
0.300
0.
0.
0.320
0.640
0.960
1.280
1.600

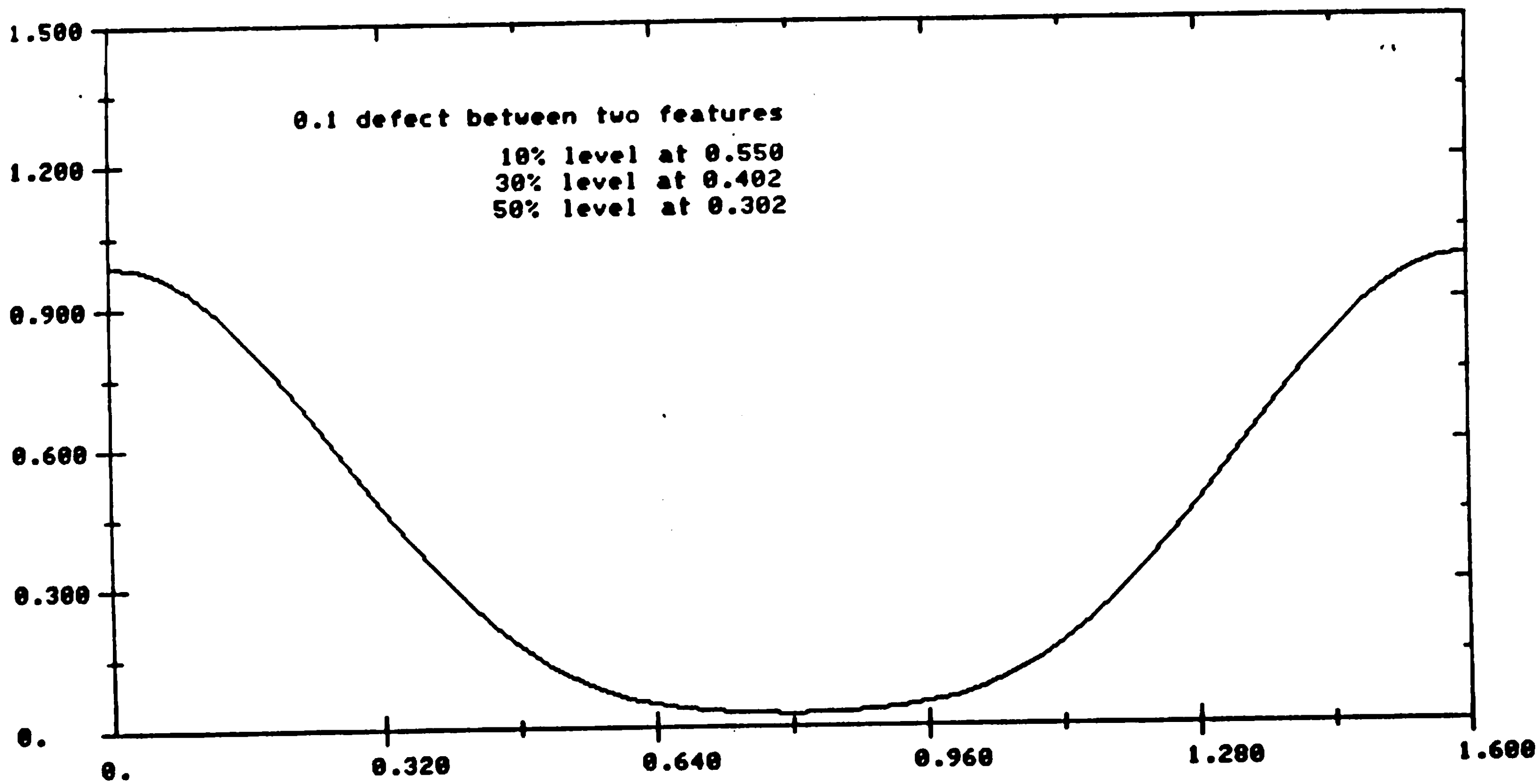


0.375 defect between two features
10% level does not exist
30% level at 0.511
50% level at 0.344
1.500
1.200
0.900
0.600
0.300
0.
0.
0.320
0.640
0.960
1.280
1.600

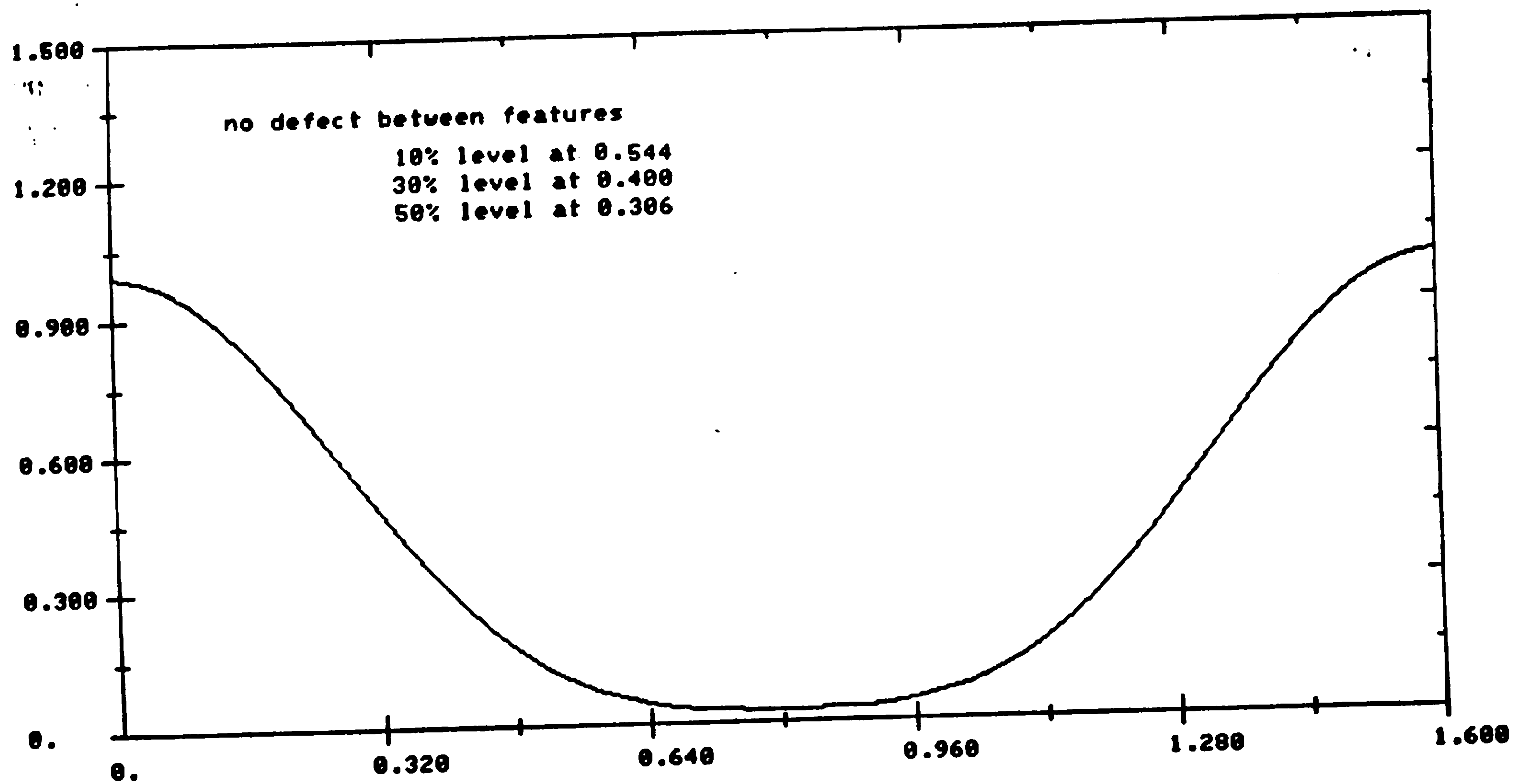

0.350 defect between two features
10% level does not exist
30% level at 0.462
50% level at 0.334
1.500
1.200
0.900
0.600
0.300
0.
0.
0.320
0.640
0.960
1.280
1.600


0.33 defect between two features
10% level does not exist
30% level at 0.450
50% level at 0.330
1.500
1.200
0.900
0.600
0.300
0.
0.
0.320
0.640
0.960
1.280
1.600

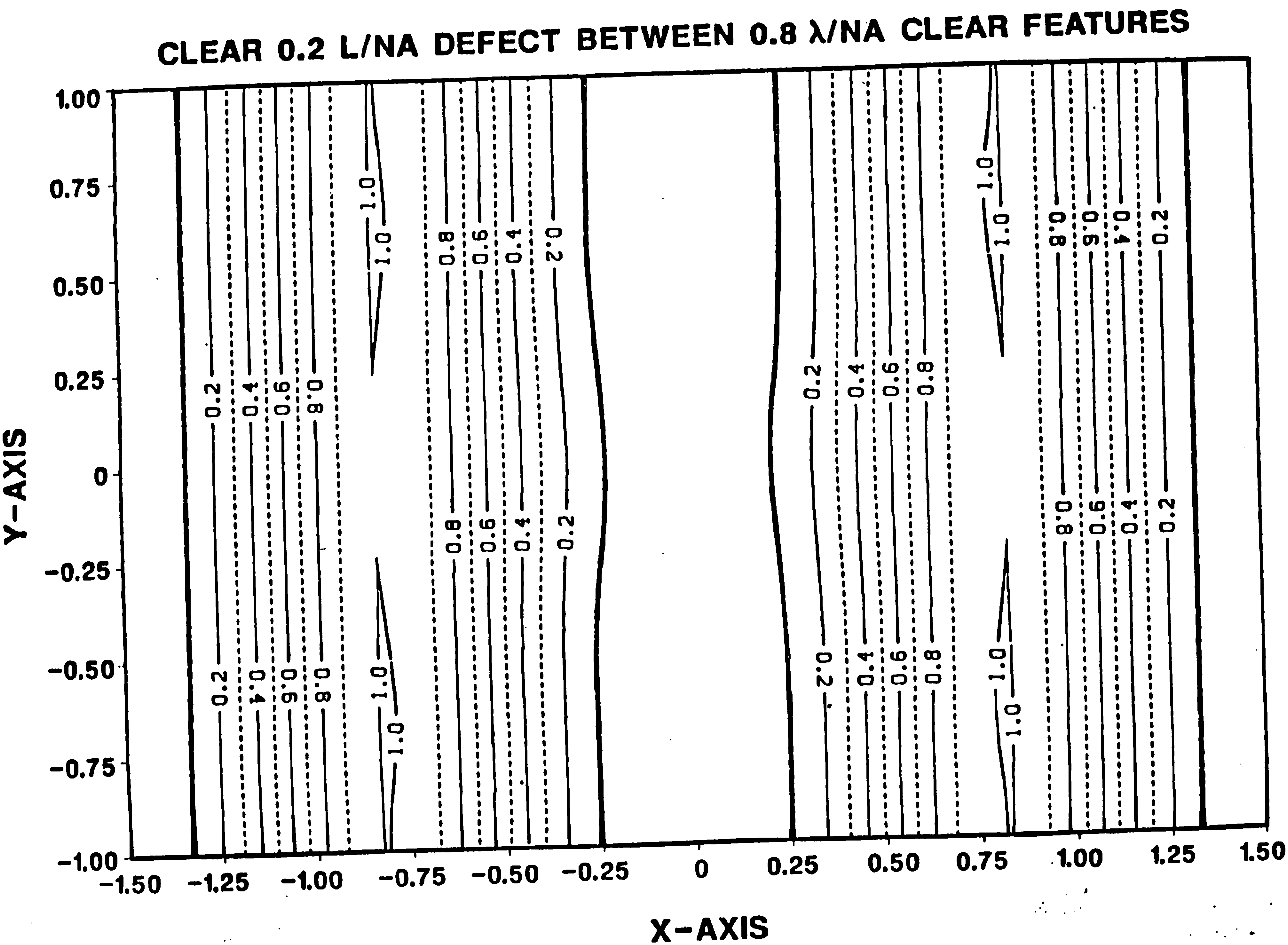

.25 defect between features
10% level at 0.616
30% level at 0.422
50% level at 0.318
1.500
1.200
0.900
0.600
0.300
0.
0.
0.320
0.640
0.960
1.280
1.600



0.1 defect between two features
10% level at 0.550
30% level at 0.402
50% level at 0.302
1.500
1.200
0.900
0.600
0.300
0.
0.
0.320
0.640
0.960
1.280
1.600



no defect between features
10% level at 0.544
30% level at 0.400
50% level at 0.306
1.500
1.200
0.900
0.600
0.300
0.
0.
0.320
0.640
0.960
1.280
1.600



CLEAR 0.2 L/NA DEFECT BETWEEN 0.8 λ/NA CLEAR FEATURES
Y-AXIS
X-AXIS
1.00
0.75
0.50
0.25
0
-0.25
-0.50
-0.75
-1.00
-1.50
-1.25
-1.00
-0.75
-0.50
-0.25
0
0.25
0.50
0.75
1.00
1.25
1.50
0.2
0.4
0.6
0.8
1.0

OPAQUE 0.2 λ/NA DEFECT BETWEEN 0.8 λ/NA OPAQUE FEATURES