FUTURE DEVELOPMENT FOR THINNED, BACK-ILLUMINATED CCD IMAGER DEVICES*

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INVITED TALK FOR
1991 IEEE CCD WORKSHOP

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179142-1

vu 1.1

OUTLINE

- COMPARISON
  - FRONT- AND BACK-ILLUMINATED CCDs
- FABRICATION PROCESS
  - WAFER-SCALE MOUNTING AND THINNING
- BACK-SURFACE PASSIVATION
  - COMPATIBLE WITH FRONT METALLIZATION
- QUANTUM EFFICIENCY MODELING
  - SPECTRAL INSTABILITY AND UNIFORMITY
- CONCLUSIONS
  - IDEAL STRUCTURE FOR BACK-ILLUMINATED CCDs

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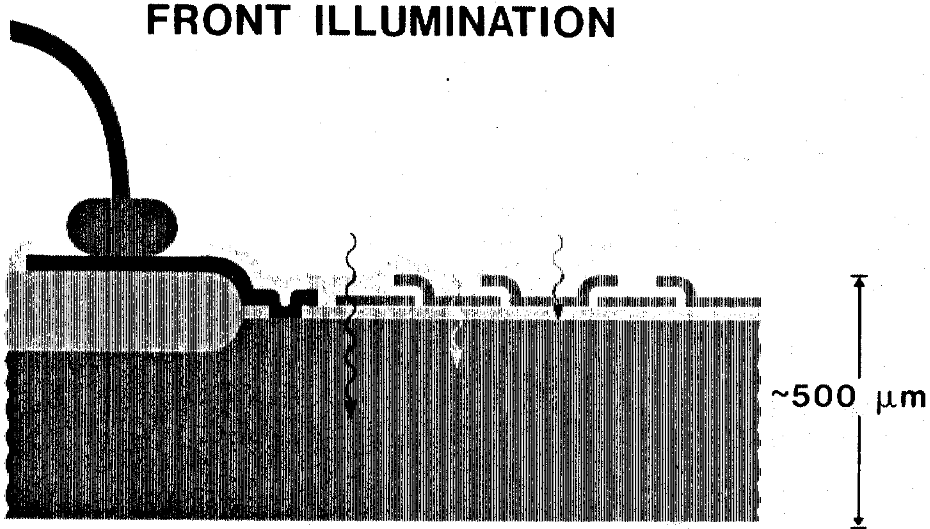
VU 1.2

FRONT vs BACK ILLUMINATION

FRONT ILLUMINATION



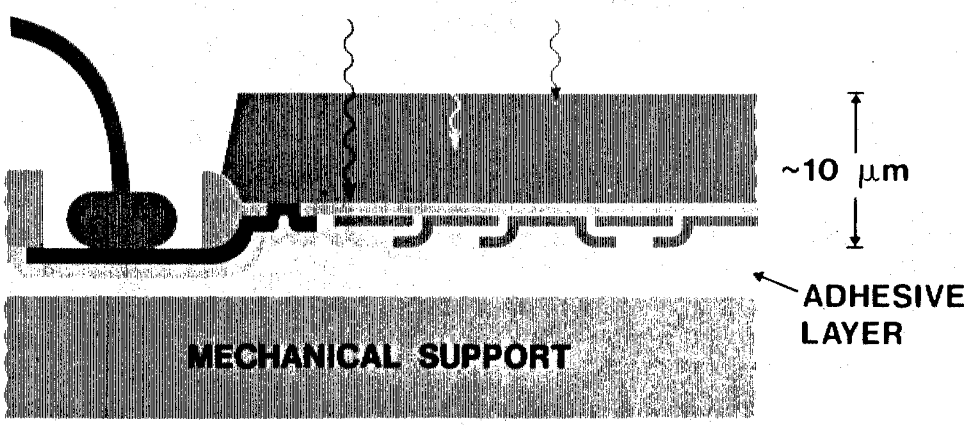
ADVANTAGES

- STANDARD PROCESSING

DISADVANTAGES

- LOW Q.E. IN BLUE AND UV
- NON-UNIFORM SPECTRAL RESPONSE

BACK ILLUMINATION



ADVANTAGES

- HIGH Q.E. IN VISIBLE AND UV
- REDUCE VERTICAL CLOCK TIME
- 100% FILL FACTOR

DISADVANTAGES

- DIFFICULT, NON-STANDARD PROCESSING?

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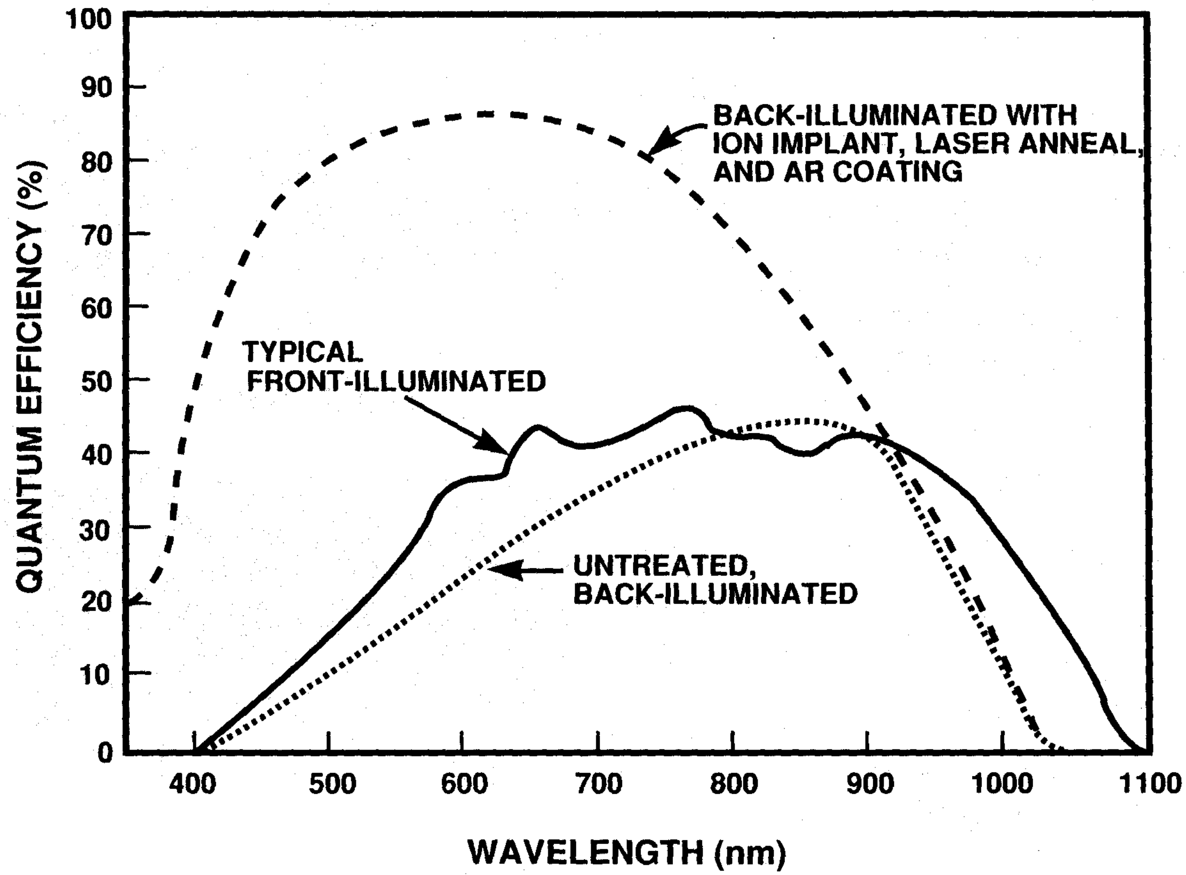
UV 1.3

CCD QUANTUM EFFICIENCY



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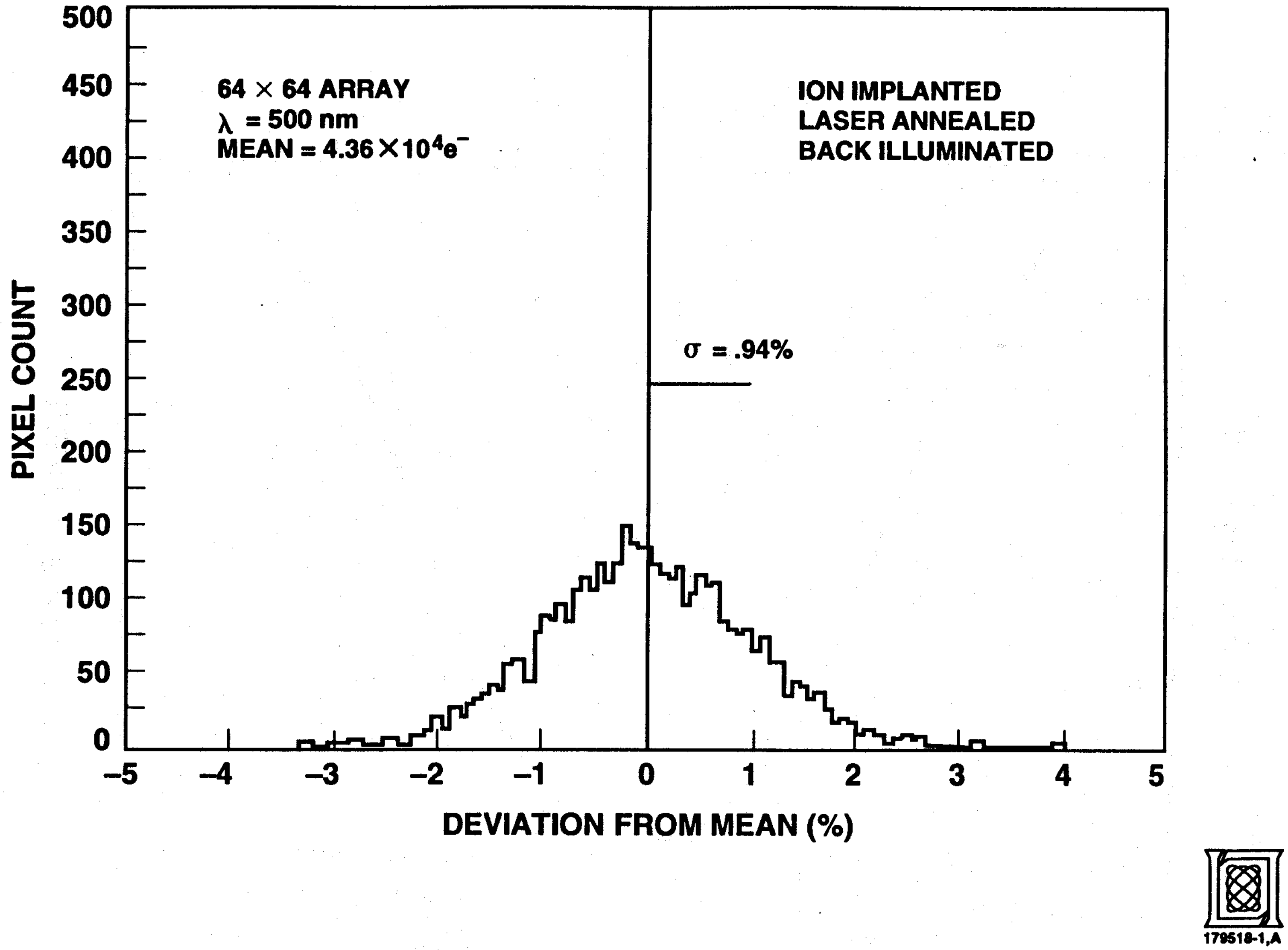
VU 1.4

OPTICAL UNIFORMITY



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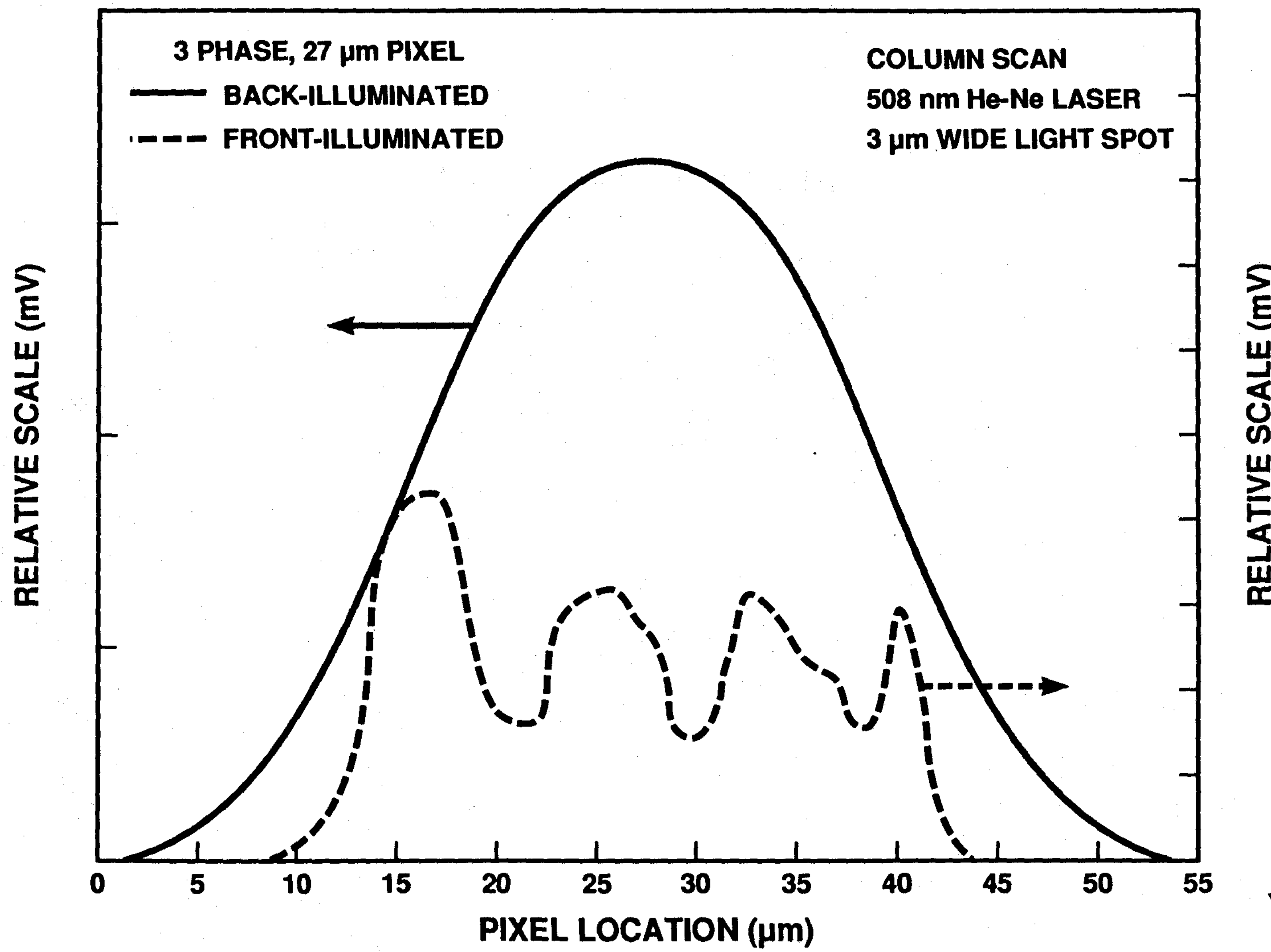
RELATIVE INTRA-PIXEL OPTICAL RESPONSE



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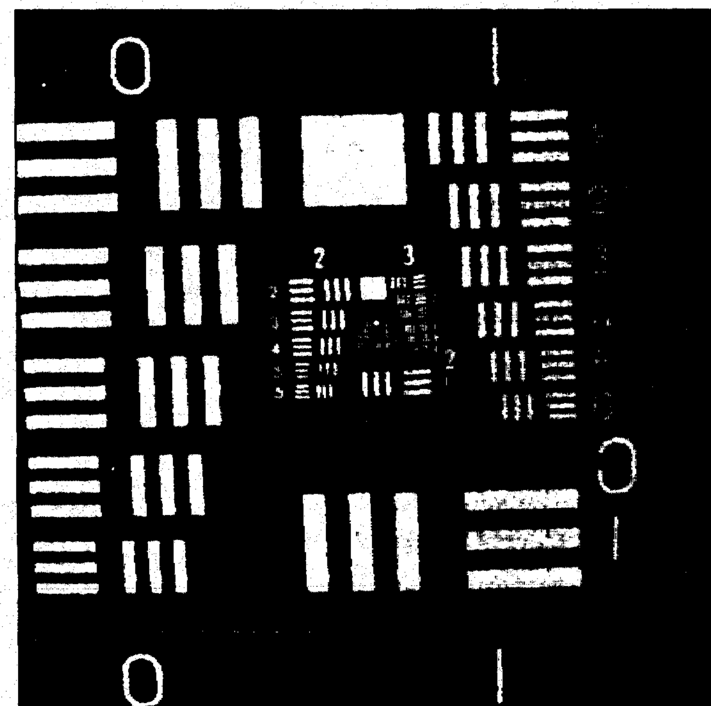
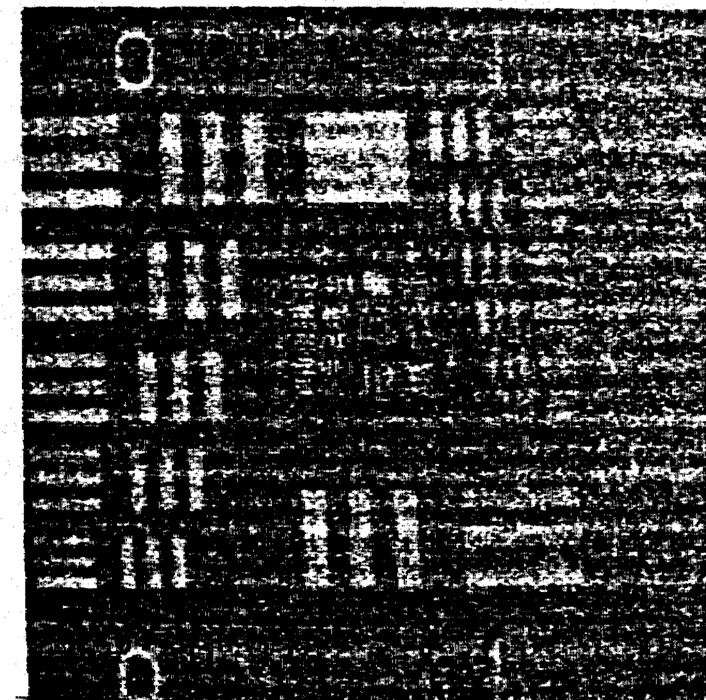
VU 1.6

LOW LIGHT LEVEL IMAGING
WITH 420 × 420 BACK-ILLUMINATED CCD



BRIGHT AREAS
= 127 e⁻/PIXEL



25 e⁻/PIXEL

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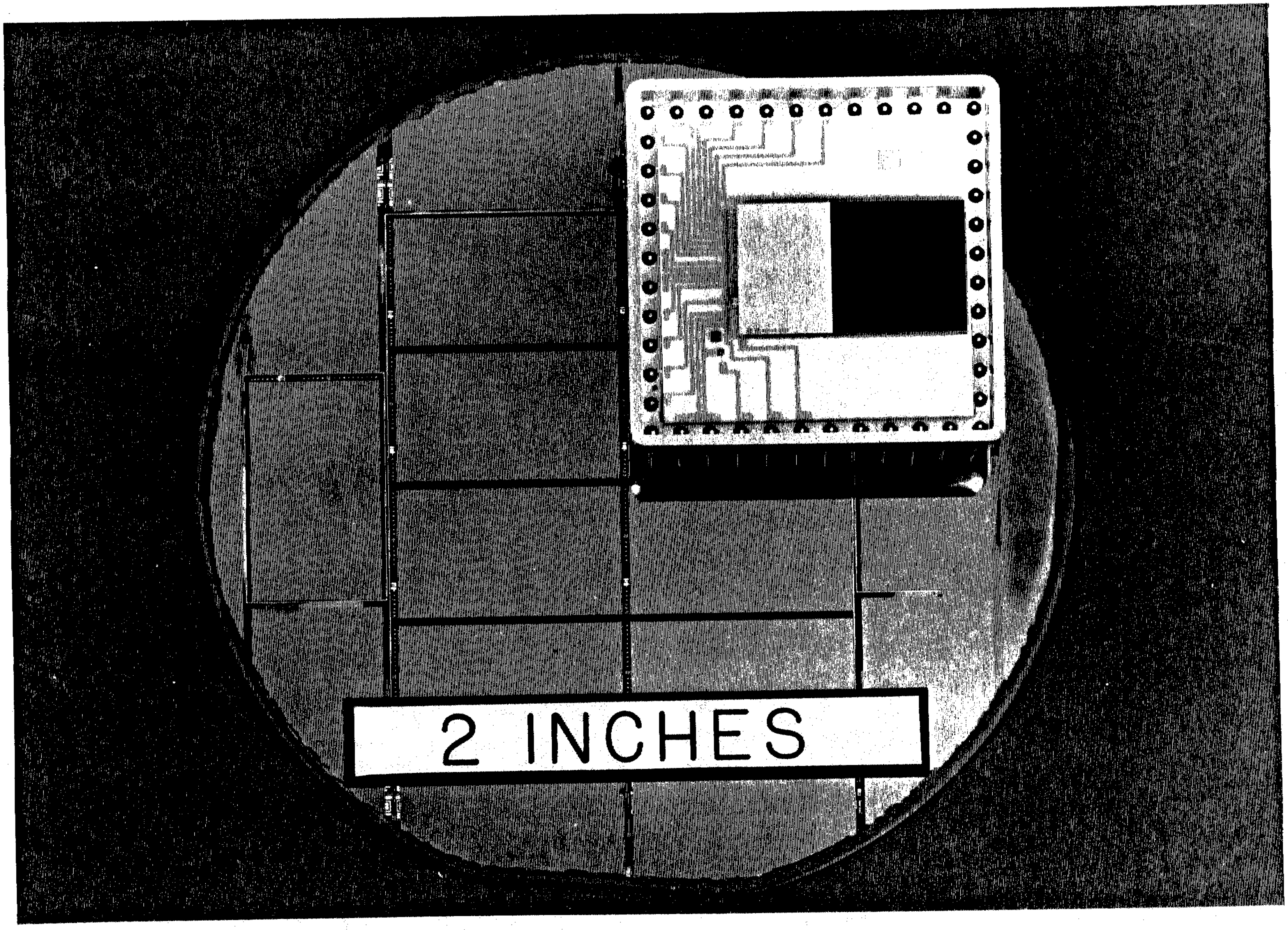

VU1.8

FABRICATION PROCESS

- COMPARISON OF FABRICATION APPROACHES
- CONVERSION OF A CCD FROM FRONT-ILLUMINATION TO BACK-ILLUMINATION
- WAFER-SCALE THINNING
- ISSUES IN WAFER-SCALE MOUNTING

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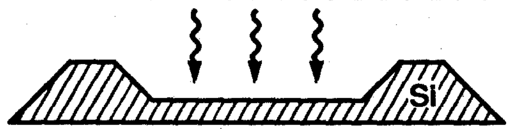
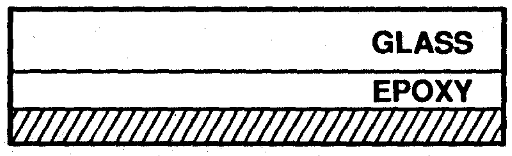
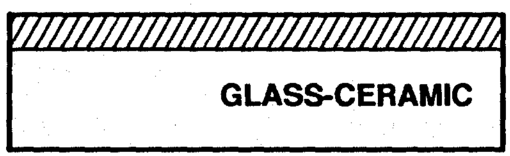
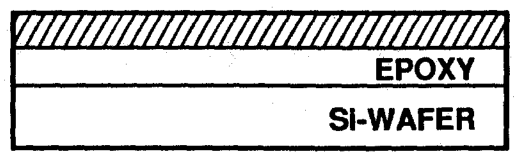
FABRICATION APPROACHES FOR BACK-ILLUMINATED CCD IMAGER

ORGANIZATION	STRUCTURE	COMMENTS
TI (1974)		FREE-STANDING MEMBRANE NOT ABUTTABLE
RCA (1985)		NOT UV SENSITIVE
TEKTRONIX (1987)		DETAILS PROPRIETARY
LINCOLN LAB (1989)		COMPATIBLE WITH PRODUCTION EQUIPMENT

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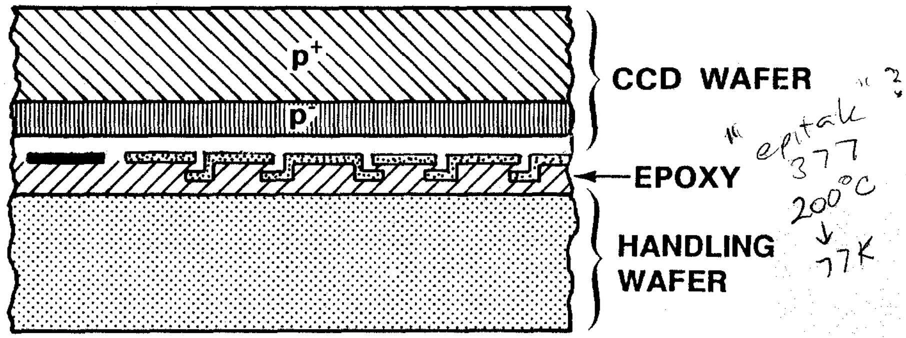
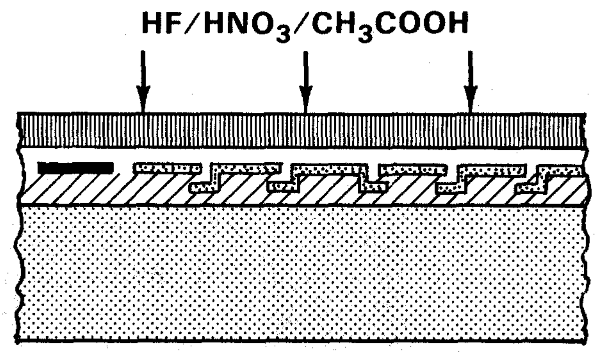
VU 2.2

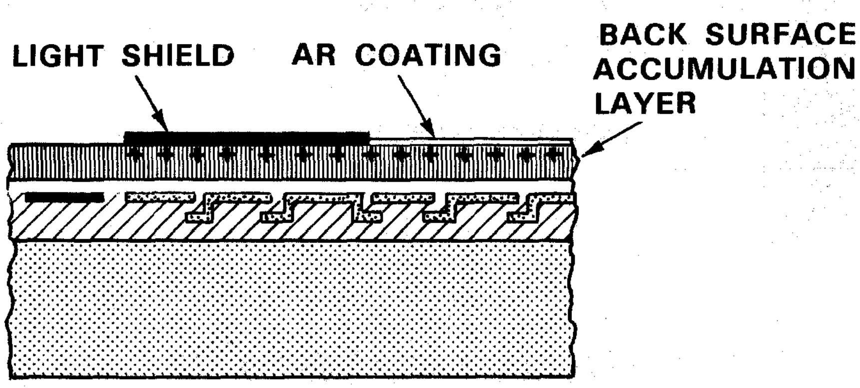
BACK-ILLUMINATED IMAGER FABRICATION



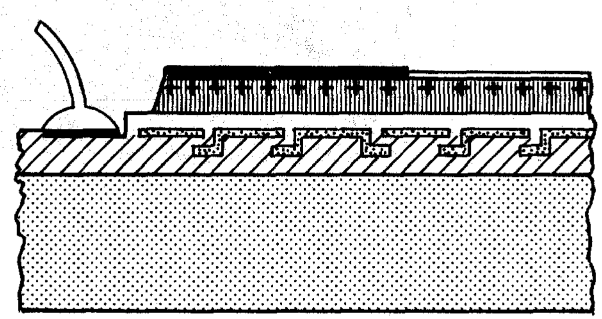
1. WAFER MOUNTING



2. WAFER THINNING



3. BACK SURFACE PROCESSING



4. ETCH Si AND SiO_2 TO EXPOSE BONDING PADS

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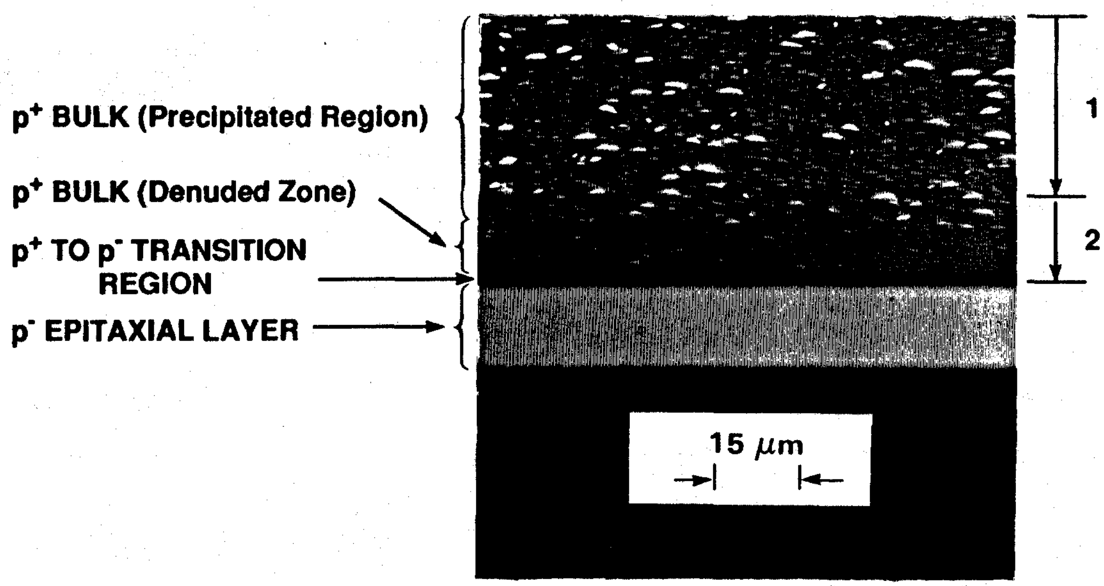
VU 2.3

APPROACH TO THINNING CCD WAFERS

1. LAPPING AND POLISHING MOST OF p^+ BULK
2. SELECTIVE ETCHING ($HF:HNO_3:CH_3COOH$, 1:3:10)
3. REMOVING STAINS

Dick sez try etching is dark



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VU2.4

IMPROVING ETCHING SELECTIVITY

IMPROVEMENT	MECHANISM	COMMENTS
H_2O_2 TITRATION	CONVERTS NITROUS ACID TO NITRIC ACID	AMOUNT OF H_2O_2 CRITICAL
WASH-TUB AGITATION	REMOVES NITROUS ACID FROM ETCHED SURFACE	SPECIAL JIG REQUIRED
ULTRASONIC AGITATION	REMOVES NITROUS ACID FROM ETCHED SURFACE	CONTROL OF ULTRASONIC ENERGY CRITICAL

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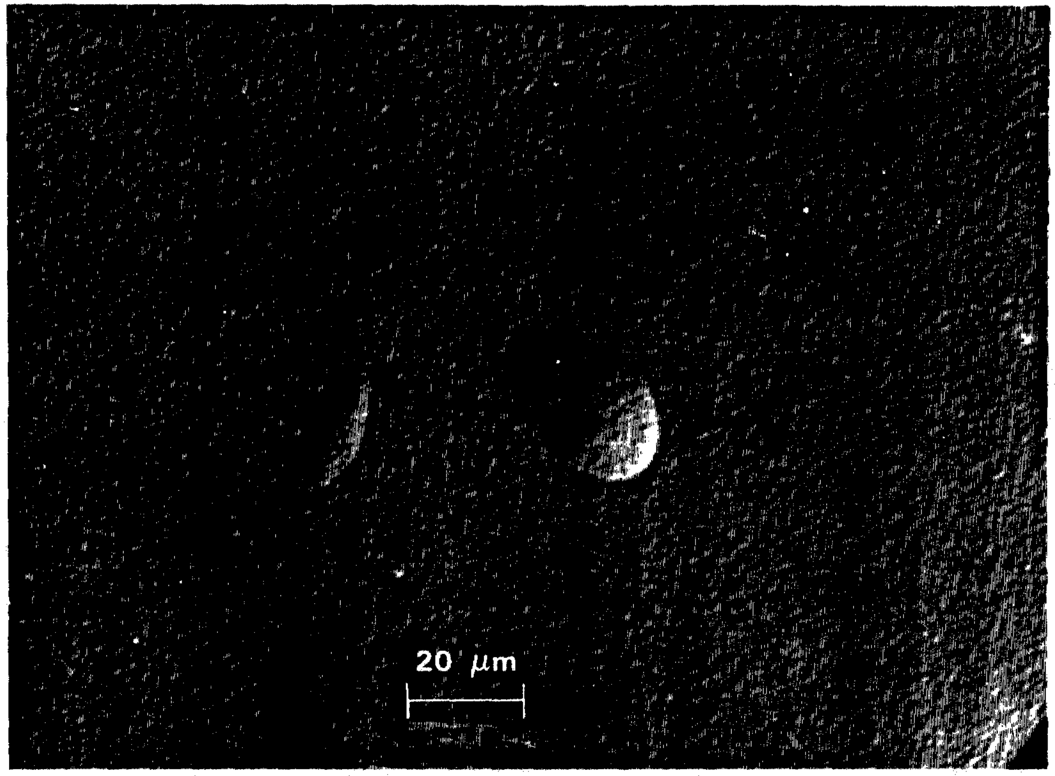
VU2.5

MORPHOLOGY OF AN ETCHED SURFACE



DENSITY OF ETCH PITS = 2000/cm^2
DEPTH VARIATION · 500 Å

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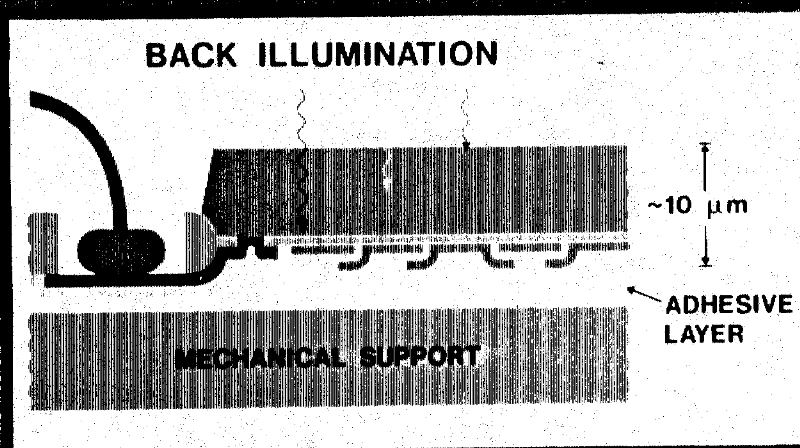
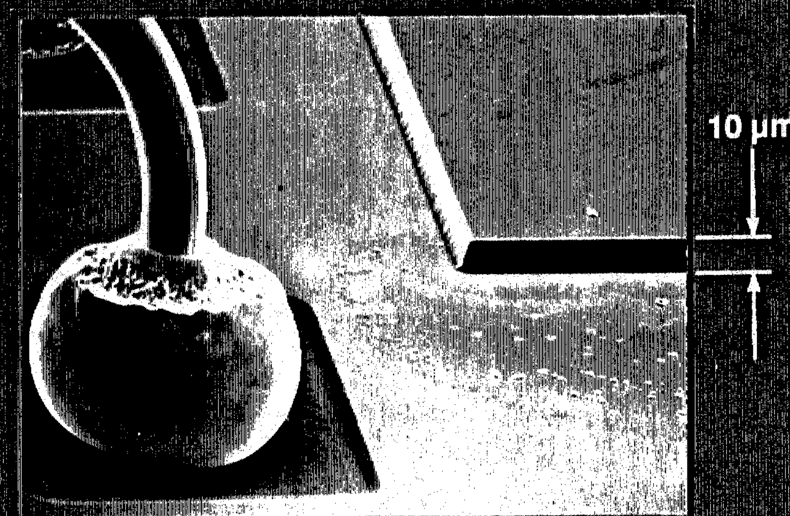
VU 2.6

WIRE BONDING RELIABILITY IN BACK-ILLUMINATED CCDs





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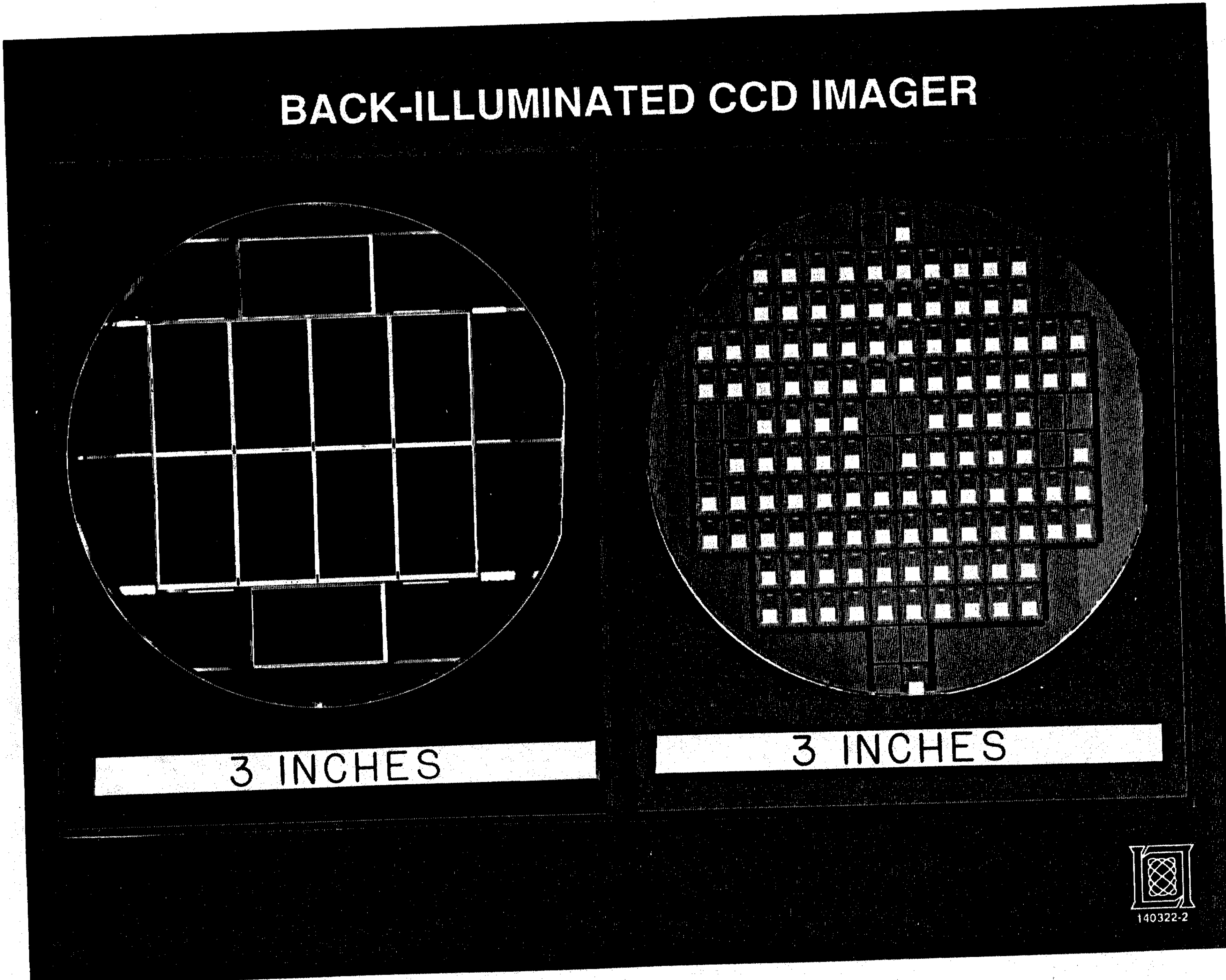
VU 2.7



VU 2.8

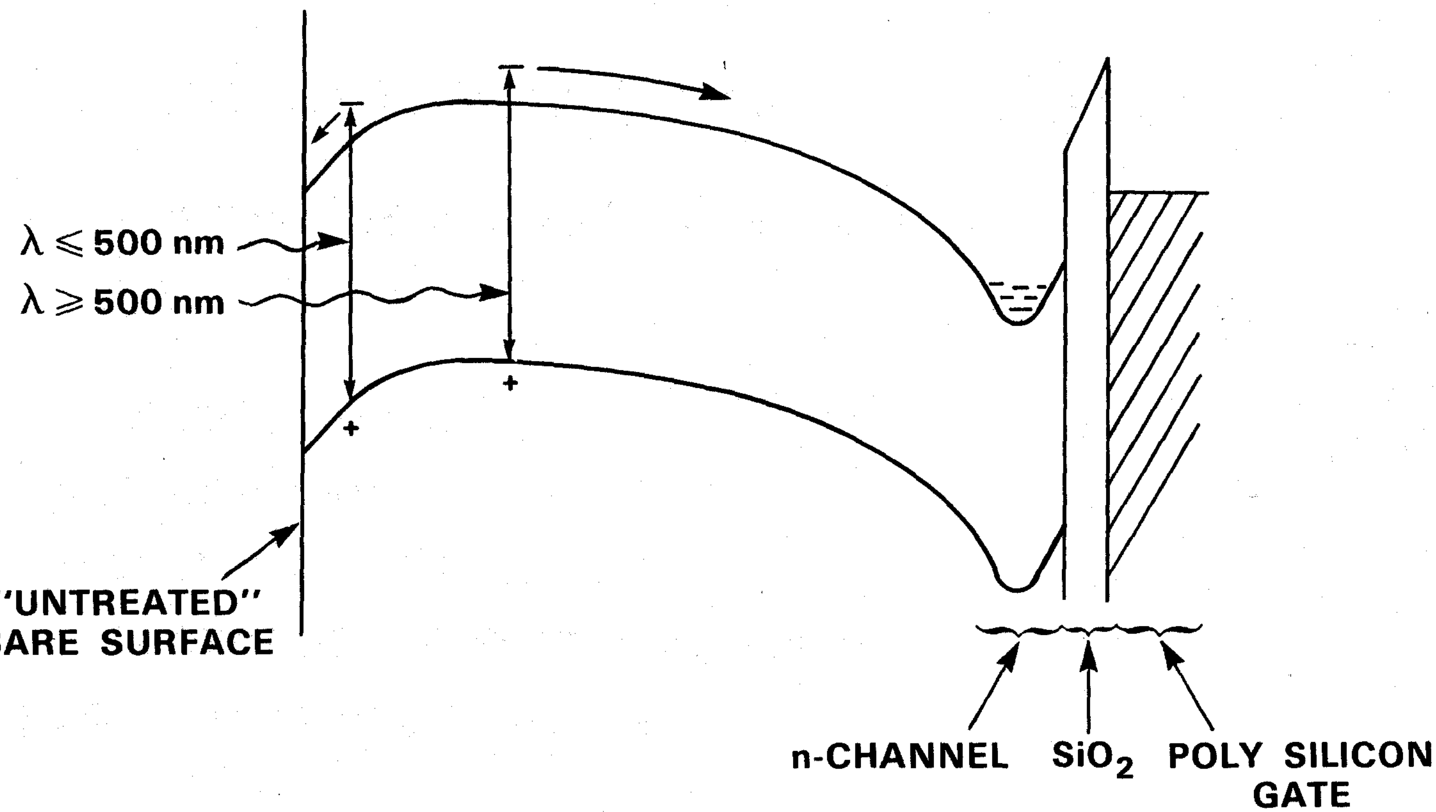
BACK-SURFACE PASSIVATION

- BACK-SURFACE EFFECTS ON QUANTUM EFFICIENCY
- PASSIVATION APPROACHES
  - NEGATIVELY CHARGED THIN OXIDE
  - SHALLOW p^+ LAYER
  - BIASED GATE
  - SILICIDE SURFACE
- EXAMPLE
  - ION-IMPLANTATION/LASER ANNEALING
- APPROACHES TO REDUCING p^+ LAYER THICKNESS

179517-3

VU3.1

BACK SURFACE EFFECTS ON QUANTUM EFFICIENCY OF BACK ILLUMINATED IMAGERS



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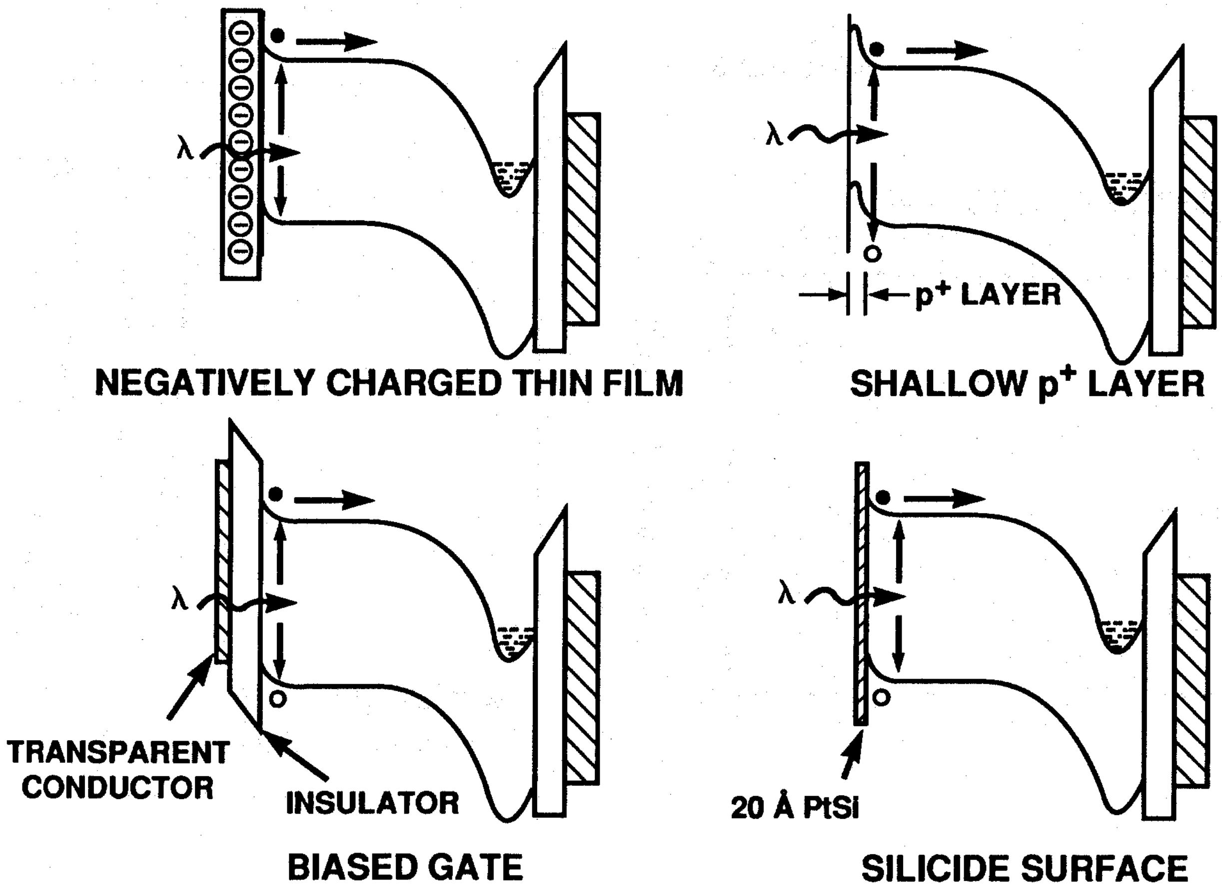
VU 3.2

APPROACHES TO BACK-SURFACE TREATMENTS



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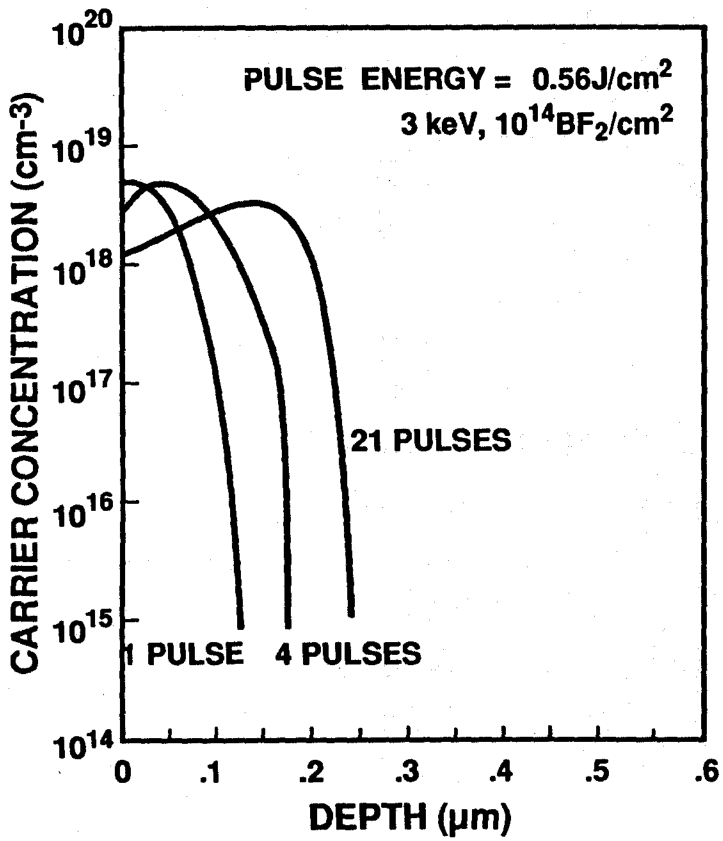
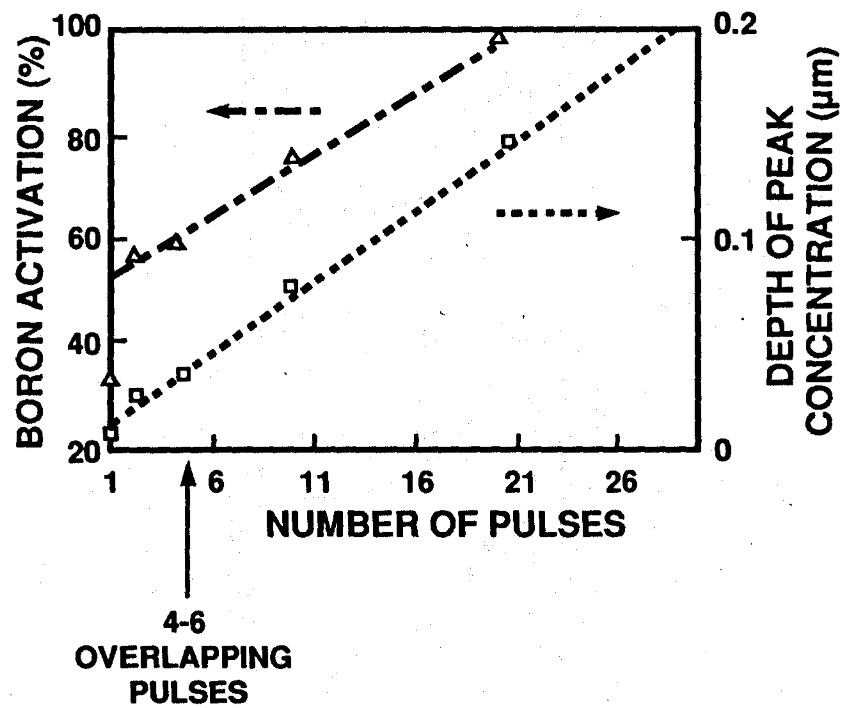
VU 3.3

PROCESS OPTIMIZATION vs NUMBER OF OVERLAPPING PULSES

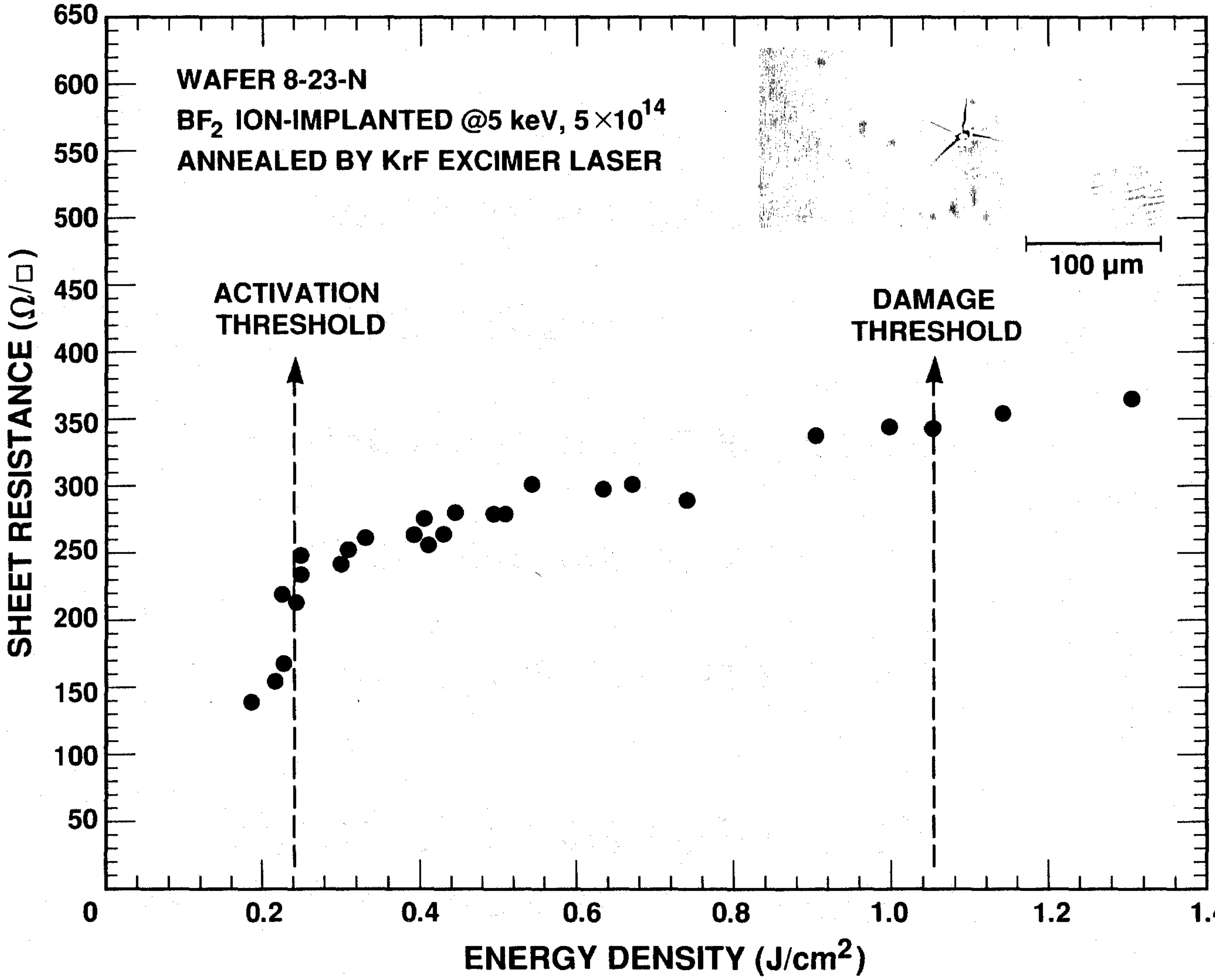




178125-4,A,B

VU 3.4

ACTIVATION OF DOPANT vs LASER ANNEALING ENERGY



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VU 3.5

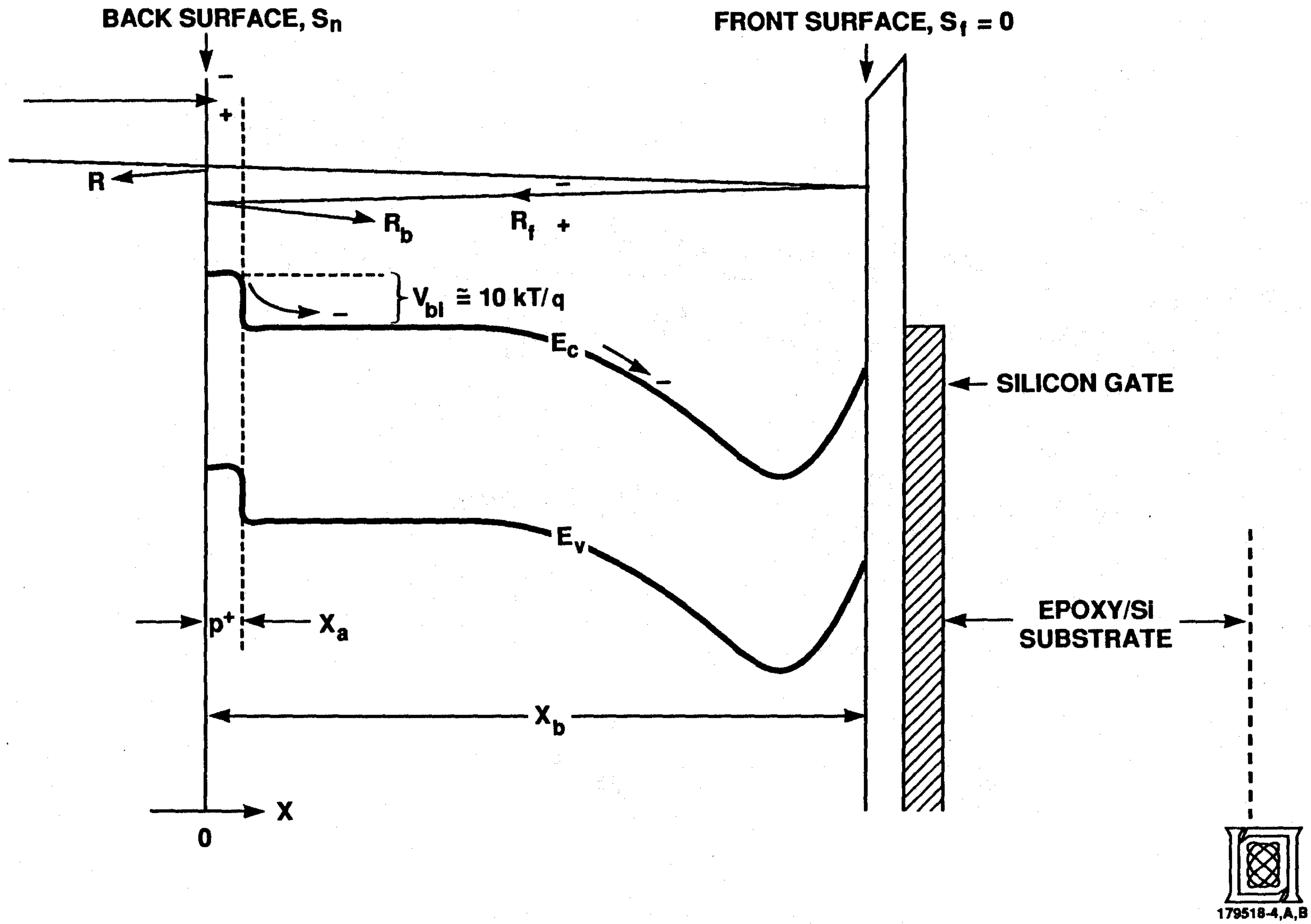
QUANTUM EFFICIENCY MODELING OF BACK-ILLUMINATED CCDs

- ANALYTICAL Q.E. MODELING
- SPECTRAL INSTABILITY
- SPECTRAL NON-UNIFORMITY
- COMPARISON
- PREDICATED PERFORMANCE

179142-2

VU 9.1

CROSS SECTION OF THE p^+ ACCUMULATED BACK-ILLUMINATED CCD IMAGER



VU 4.2

EXTERNAL QUANTUM EFFICIENCY IN THE p^+ REGION

SOLVE $$D_n \frac{d^2 n_p}{dx^2} + \alpha F(1-R)\, e^{-\alpha X} - \frac{n_p - n_{po}}{\tau_n} = 0$$

SUBJECT TO $n_p - n_{po} \approx 0$ AT $x = X_a$

AND $$S_n\left(n_p - n_{po}\right) = D_n \frac{d\left(n_p - n_{po}\right)}{dx}$$ AT $x = 0$

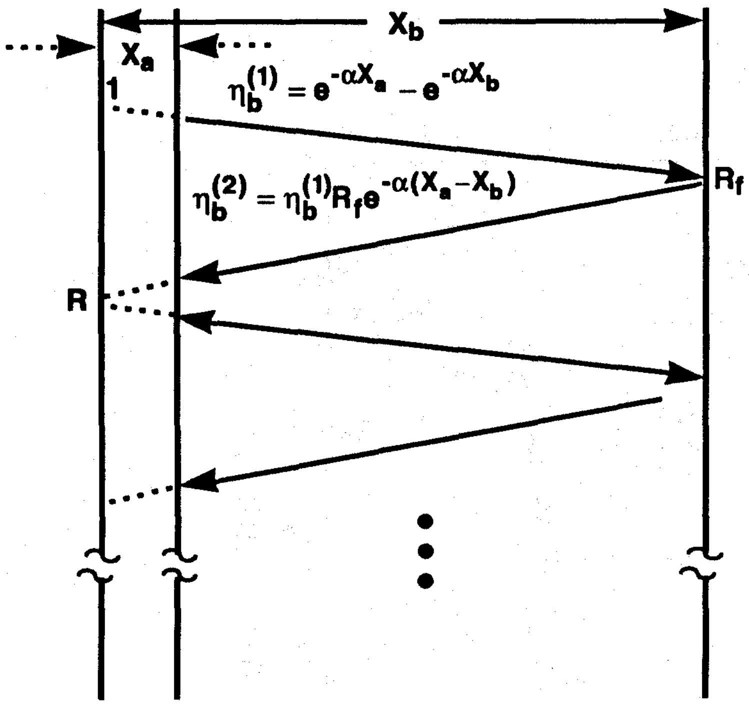
$$\eta_a = (1-R)\left[\alpha L_n \Big/ \left(\alpha^2 L_n^2 - 1\right)\right] \times \left[\frac{\left[\frac{S_n L_n}{D_n} + \alpha L_n\right] - e^{-\alpha X_a}\left[\frac{S_n L_n}{D_n}\cosh\frac{X_a}{L_n} + \sinh\frac{X_a}{L_n}\right]}{\left(S_n L_n/D_n\right)\sinh\left(X_a/L_n\right)\cosh\left(X_a/L_n\right)} - \alpha L_n e^{-\alpha X_a} \right]$$

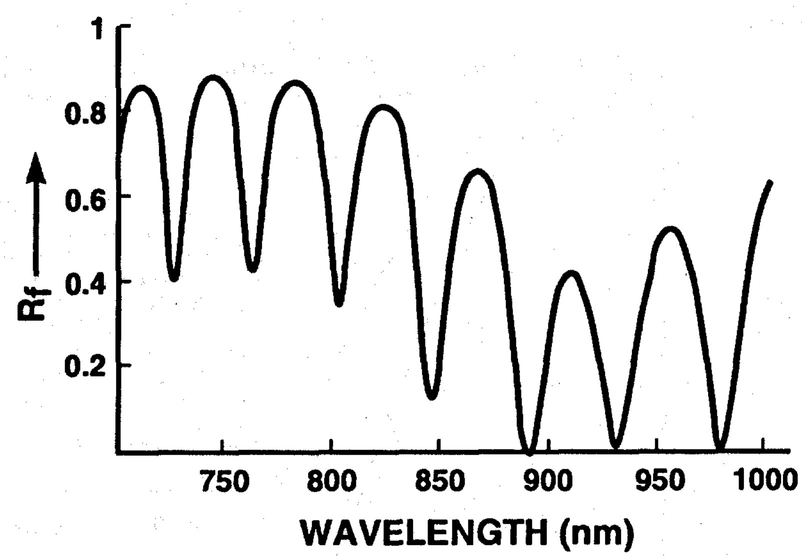
$$= (1-R)\left(1 - e^{-\alpha X_a}\right) \qquad S_n = 0, \quad L_n >> \alpha^{-1}$$

179145-2

VU 43

MODELING Q.E. IN THE BULK REGION





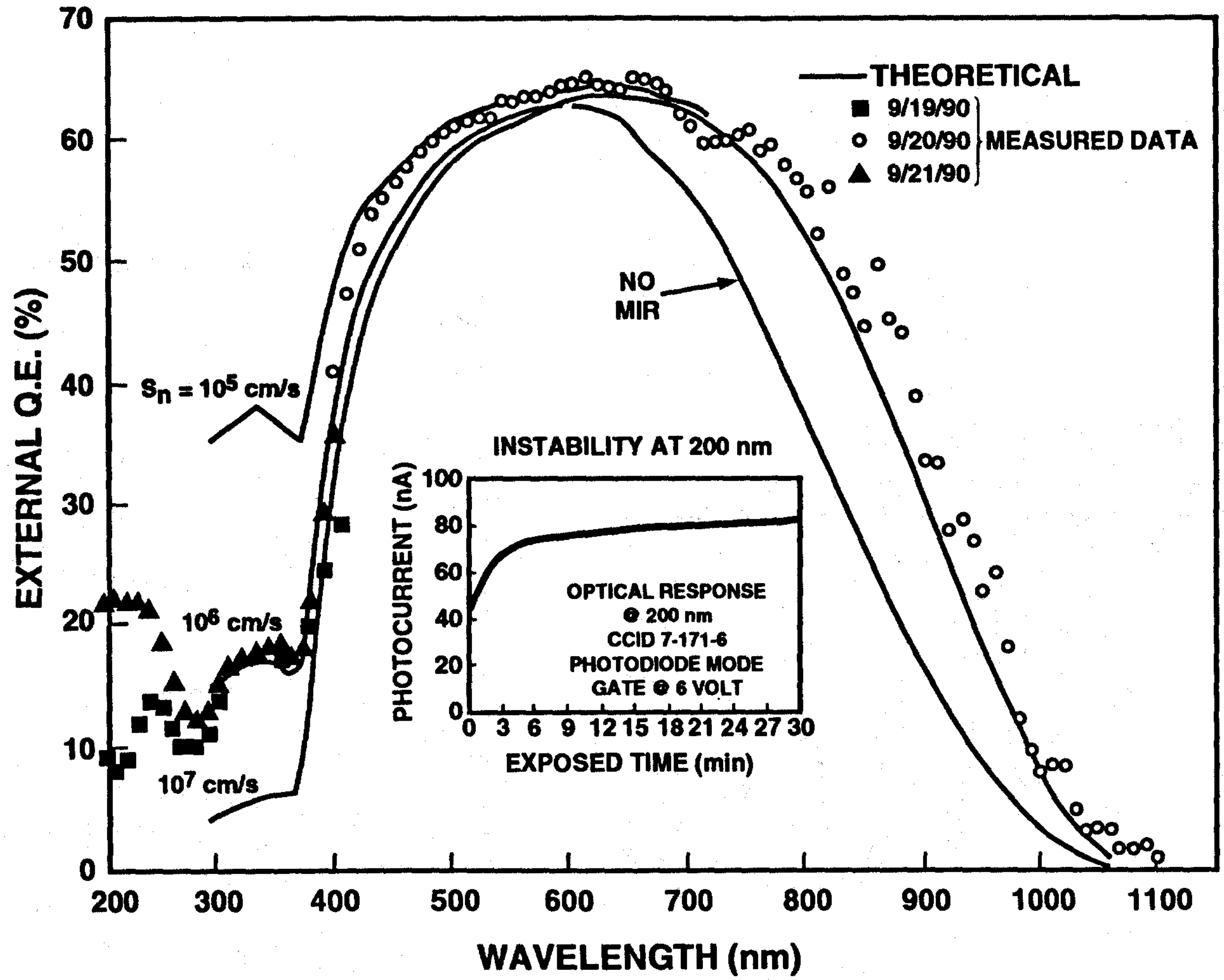
$$\eta_b = (1-R)(e^{-\alpha X_a} - e^{-\alpha X_b})(1+R_f e^{-\alpha(X_a - X_b)})/(1-r)$$

$$r = R_f R e^{-2\alpha x_b}$$

179145-8

VU4.4

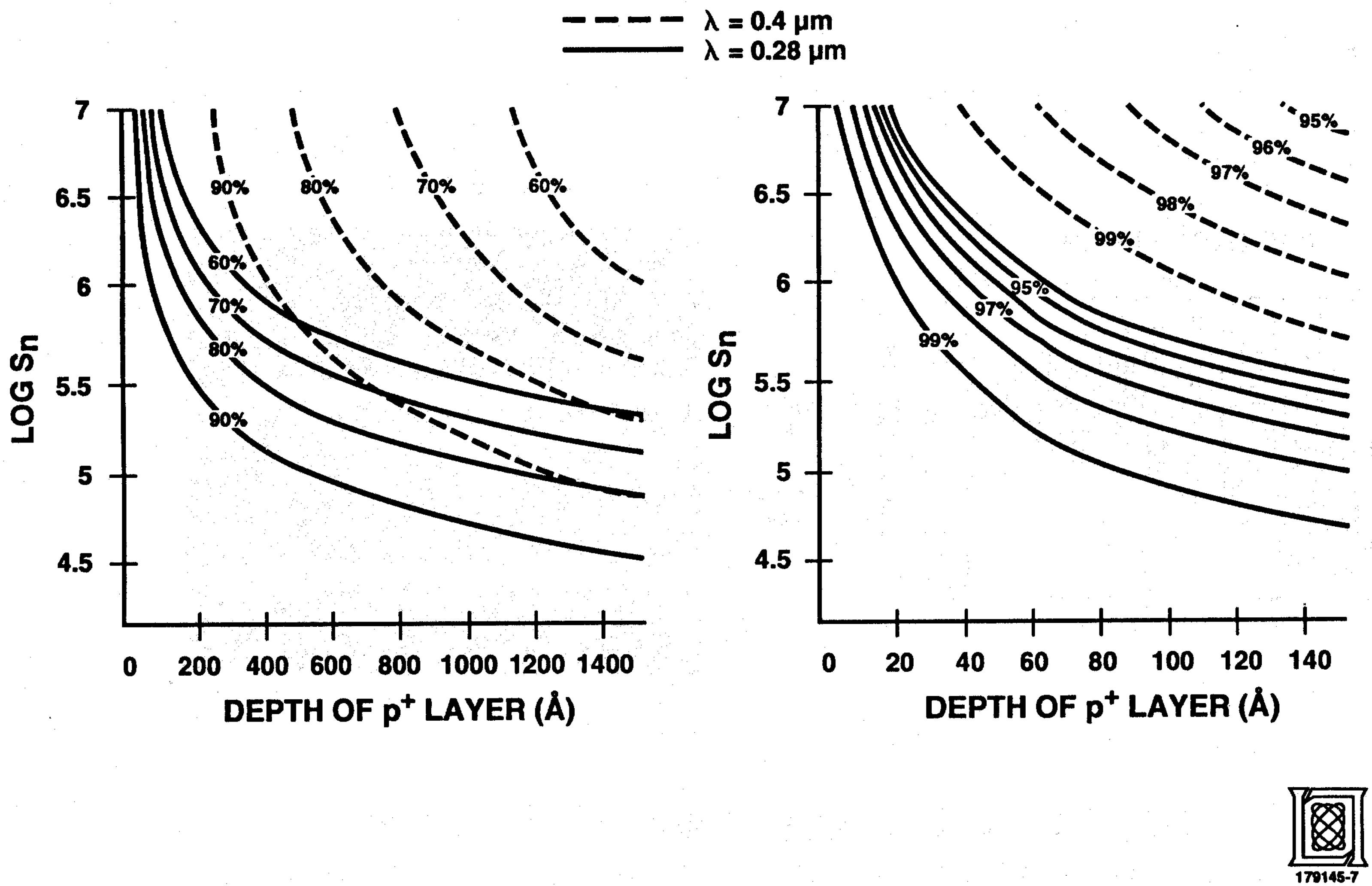
COMPARISON OF MODELING WITH MEASURED DATA



179145-6

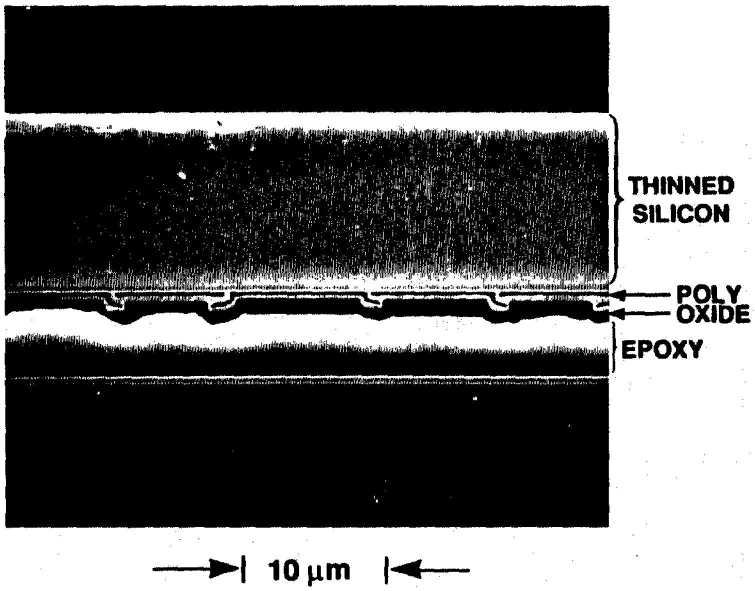
VU45

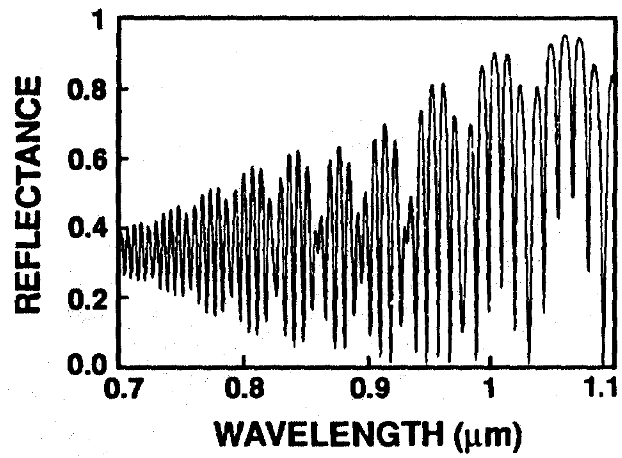
UV STABILITY vs THE DEPTH OF p+ LAYER



VU 45

EFFECTIVE REFLECTANCE OF A THINNED, BACK-ILLUMINATED CCD IMAGER





179145-9

VU 4.7

MODELS ON BACK-ILLUMINATED CCD IMAGER

AUTHORS	MODEL	COMMENTS
J.W. WALKER et al. (CCD Proceedings 1978)	$\eta = (1-R)\left(\frac{1}{1+kT\alpha/qE} + e^{-\alpha X_a}\right)$	ASSUME E IS UNIFORM E-FIELD IN p^+ LAYER, NO MIRs
J. JANESICK et al. (IEDM, 1986)	$\eta = (1-R)\left(\int_0^{X_a}\left(\frac{x}{X_a}\right)^{\log(\lvert E_s\rvert+10)^{-1}} \alpha e^{-\alpha X} dx + \left(e^{-\alpha X_a} - e^{-\alpha X_b}\right)\right)$	GOOD FOR FLASH GATE, NO MIRs
R. STERN et al. (Opt. Eng. 1987)	$\eta = (1-R)e^{-\alpha X_a}$	NO CONTRIBUTION FROM ABSORPTION IN p^+ LAYER, NO MIRs
THIS WORK (SPIE 1991)	$\eta = \eta_a + \eta_b$	SURFACE RECOMBINATION EFFECT AND MIRs INCLUDED

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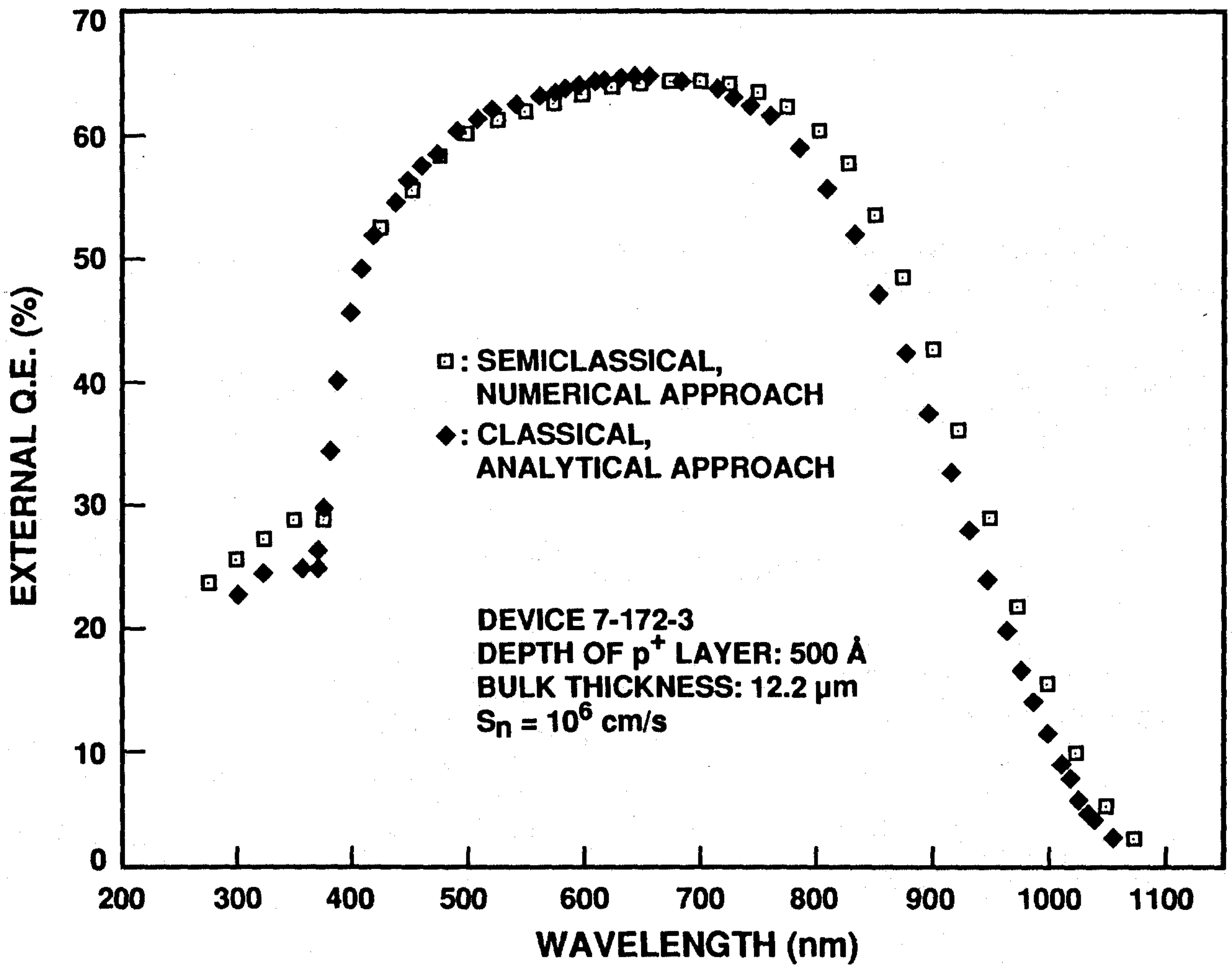
VU4.8

COMPARISON BETWEEN ANALYTICAL AND NUMERICAL SOLUTION



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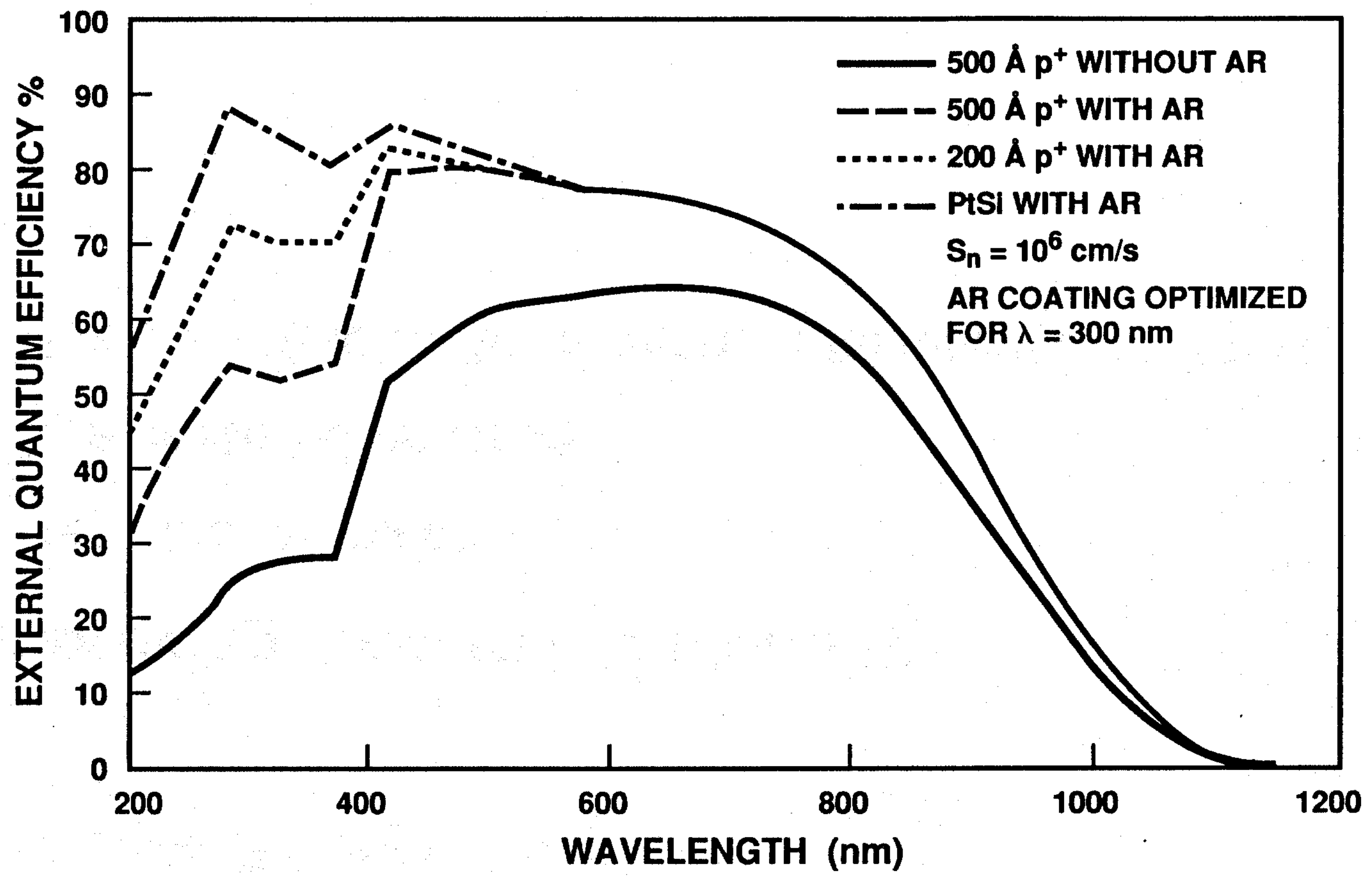
VU4.9

PREDICATED PERFORMANCE



	STATUS	NEAR	FUTURE
INSTABILITY @ 200 nm	~ 40%	~ 20%	~ 1%
NON-UNIFORMITY @ 400 nm	≤6%	≤3%	≤1%
ALL OTHER PARAMETERS	SAME AS FRONT-ILLUMINATED CCD IMAGES		

179145-3

VU 4.10

CONCLUSIONS

- **Improving UV Stability**

  Reduce P^+ layer thickness

- **Improving Spectral Uniformity**

  Use thicker silicon

  Use textured surface

  Use Al reflector to prevent interference in epoxy