

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

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**INVITED TALK FOR
1991 IEEE CCD WORKSHOP**

UNIVERSITY OF WATERLOO, ONTARIO, CANADA

*** THIS WORK WAS SUPPORTED BY THE DEPARTMENT OF AIR FORCE.**



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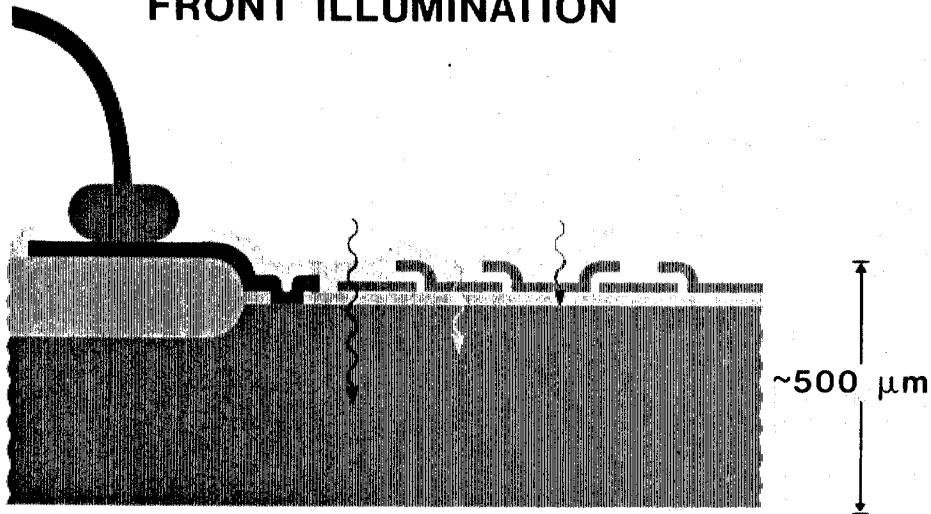
OUTLINE

- **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



FRONT vs BACK ILLUMINATION

FRONT ILLUMINATION



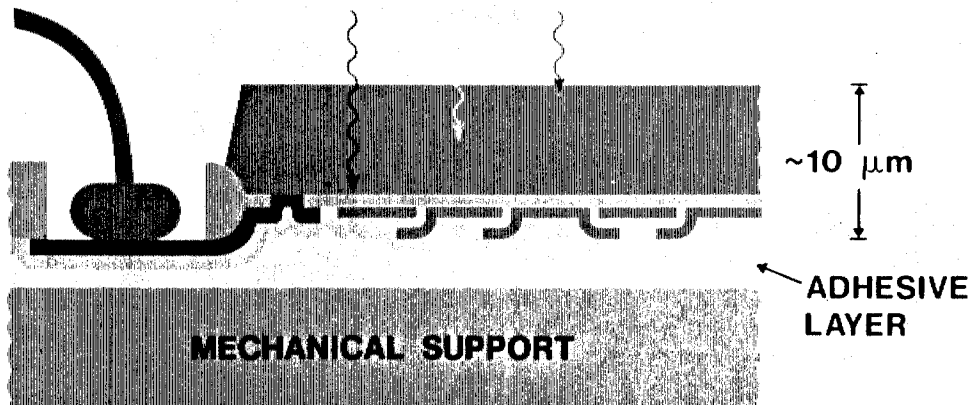
ADVANTAGES

- STANDARD PROCESSING

DISADVANTAGES

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

BACK ILLUMINATION



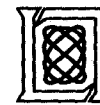
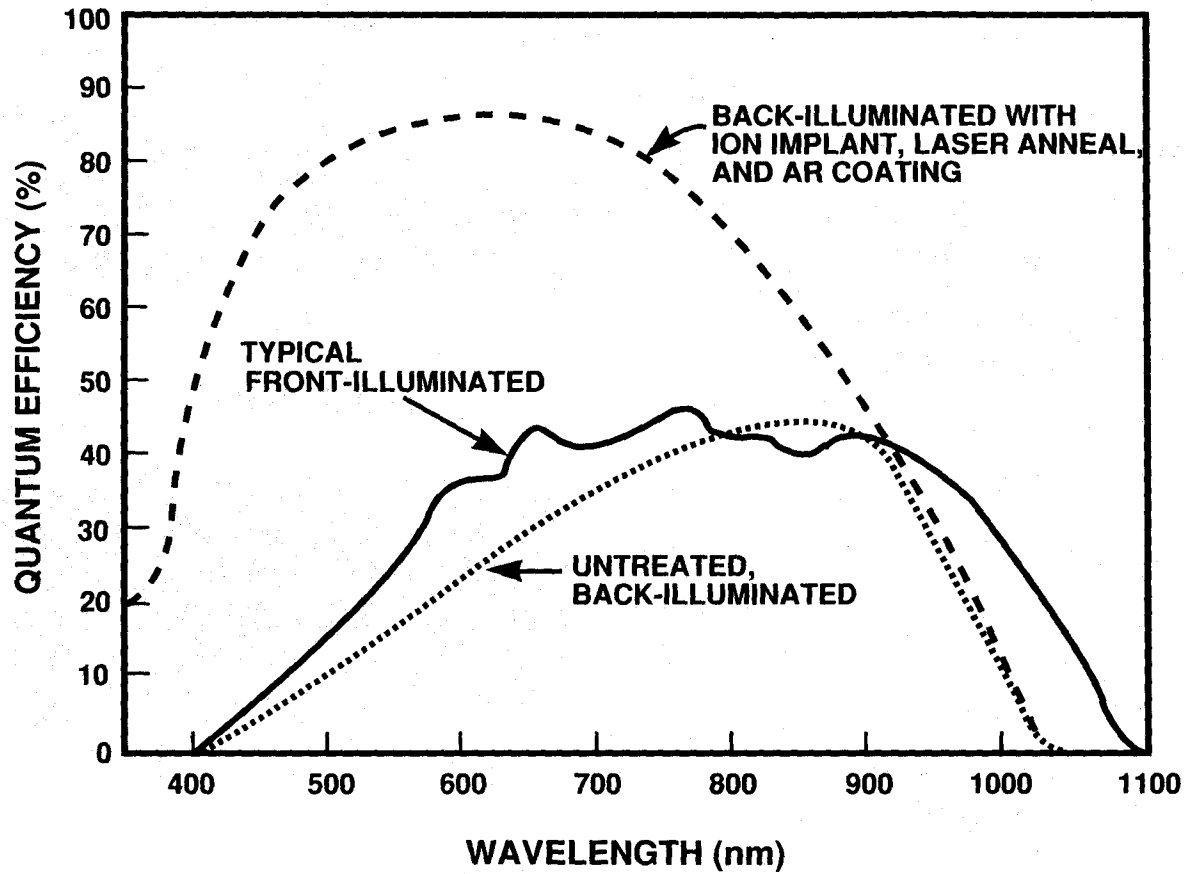
- HIGH Q.E. IN VISIBLE AND UV
- REDUCE VERTICAL CLOCK TIME
- 100% FILL FACTOR

- DIFFICULT, NON-STANDARD PROCESSING?



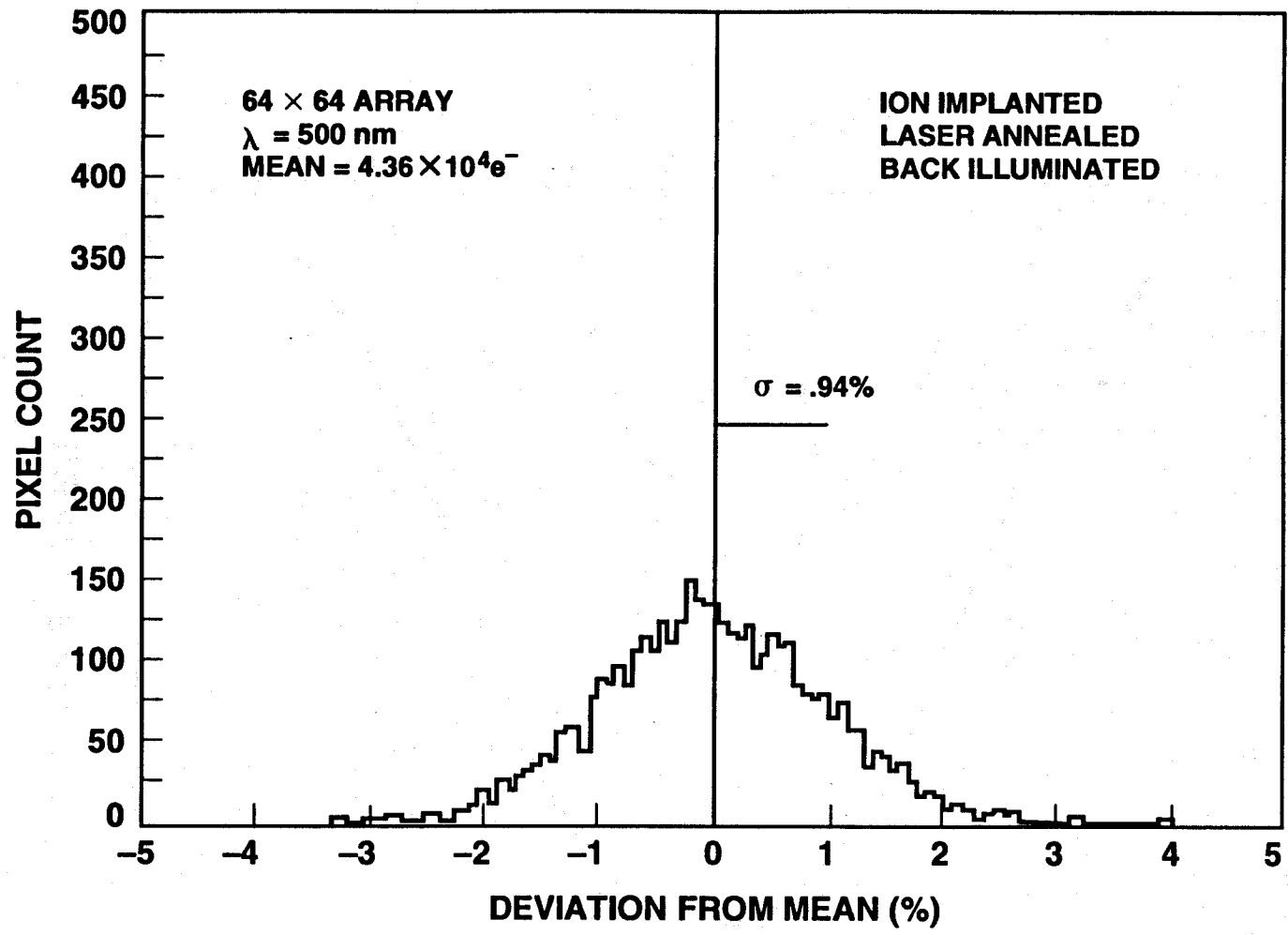
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CCD QUANTUM EFFICIENCY

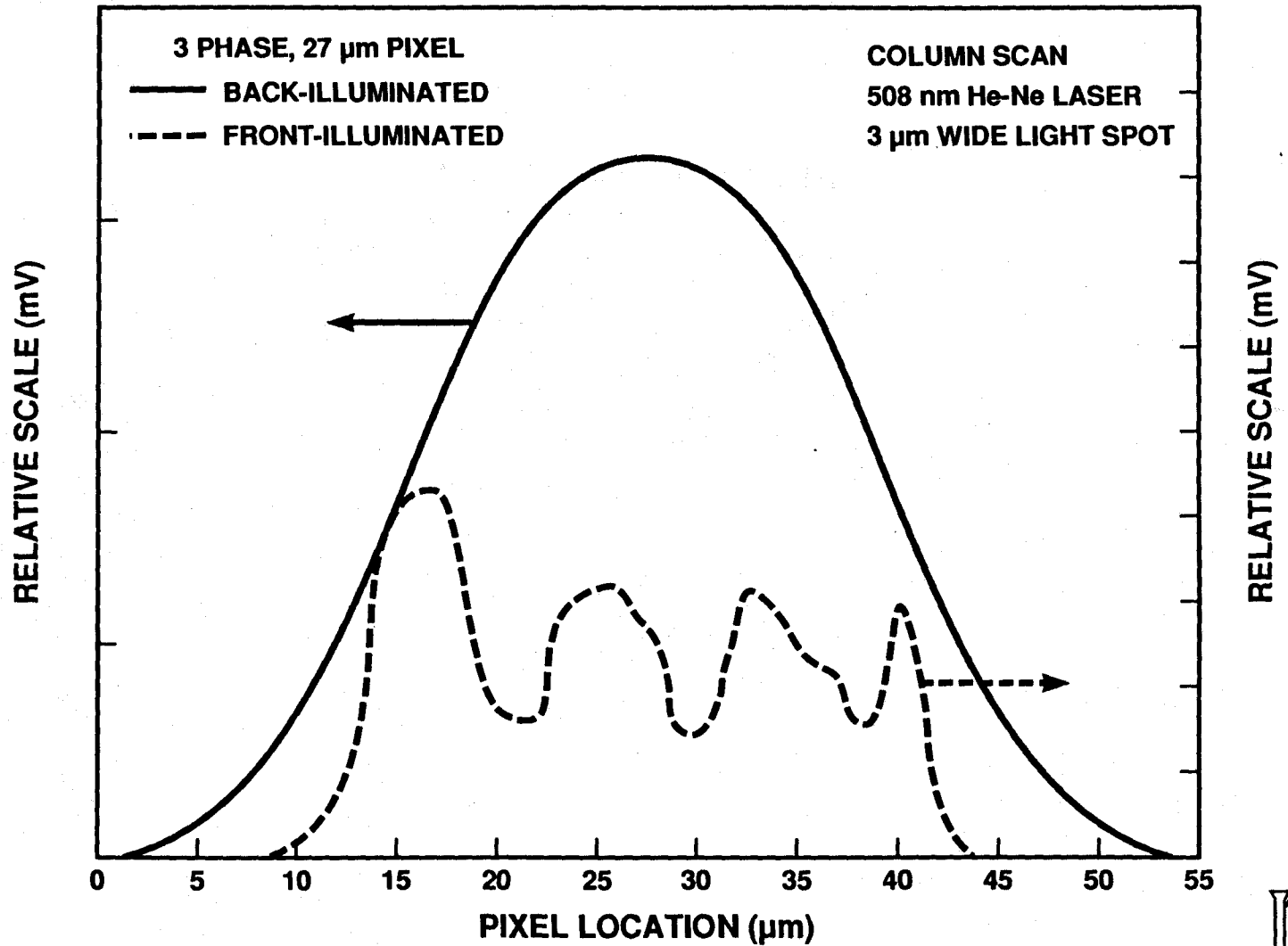


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OPTICAL UNIFORMITY

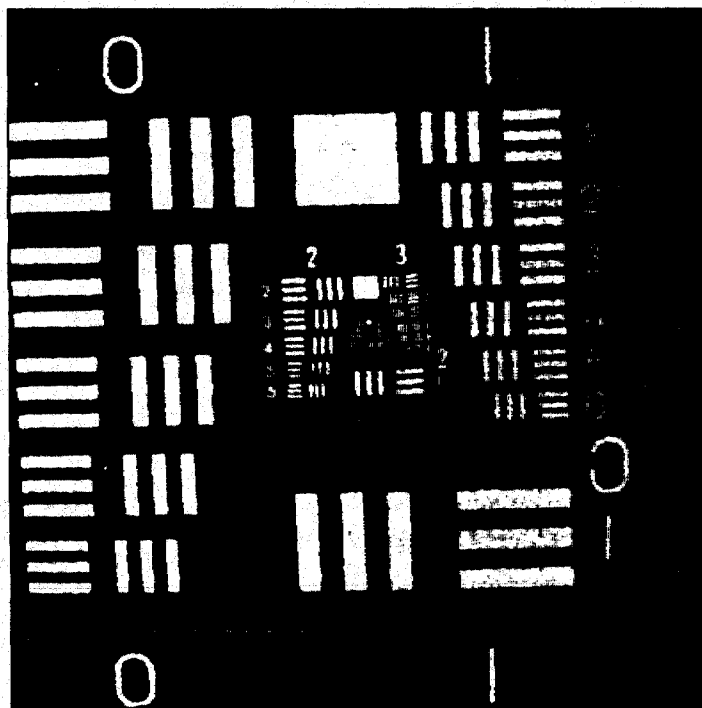


RELATIVE INTRA-PIXEL OPTICAL RESPONSE

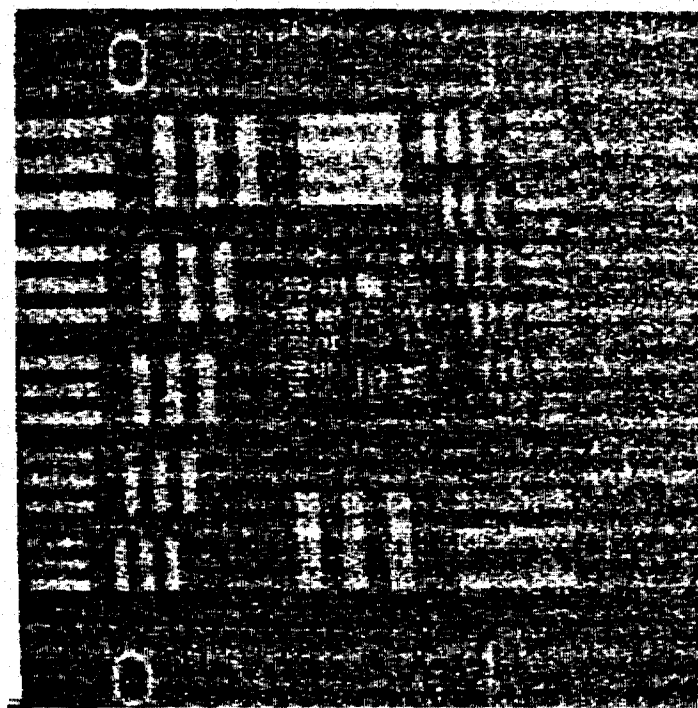


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LOW LIGHT LEVEL IMAGING WITH 420×420 BACK-ILLUMINATED CCD



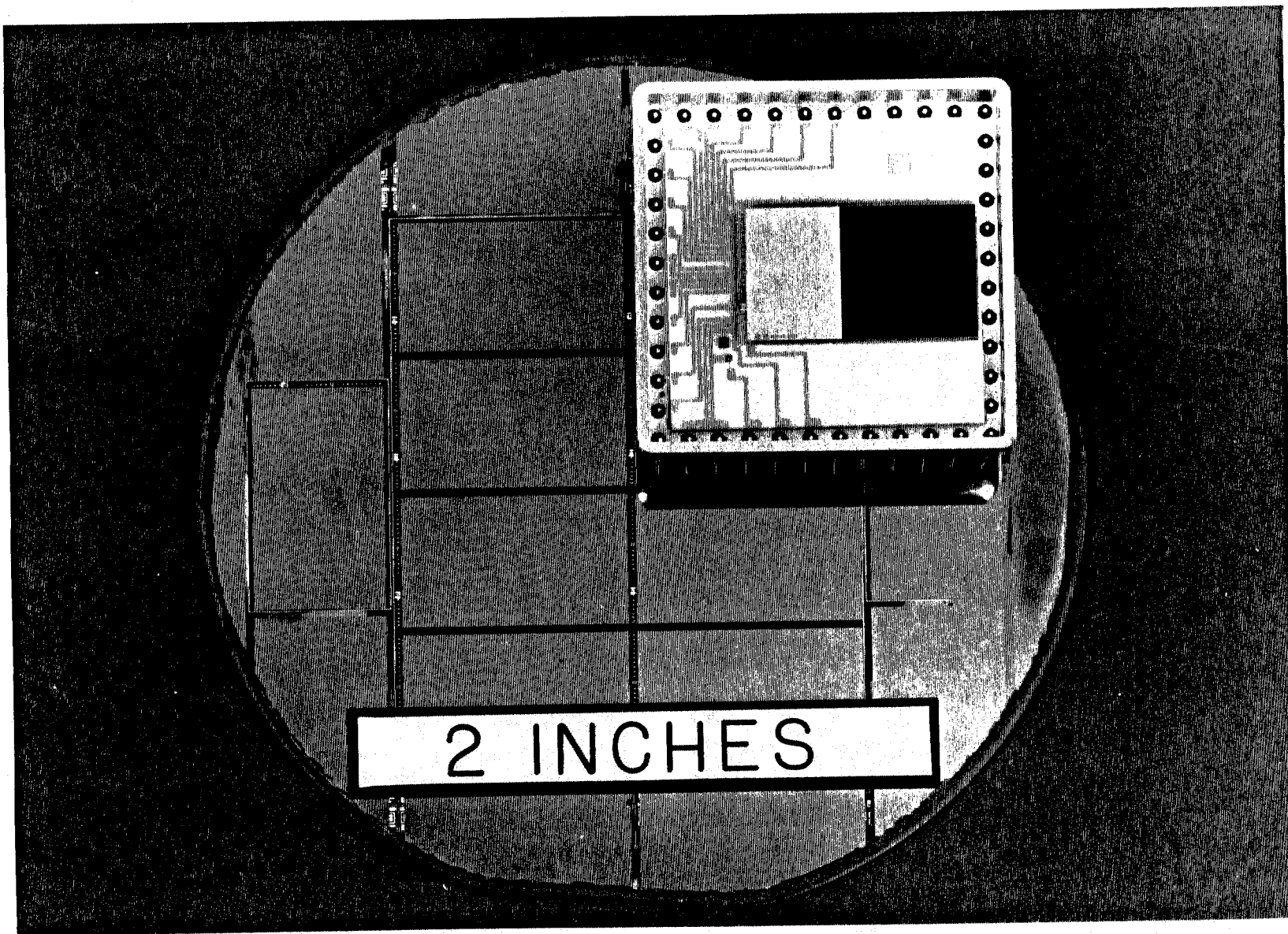
**BRIGHT AREAS
= $127 e^-/\text{PIXEL}$**



$25 e^-/\text{PIXEL}$



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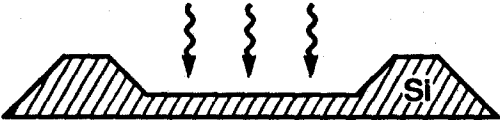


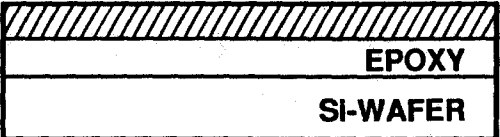
2 INCHES

FABRICATION PROCESS

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

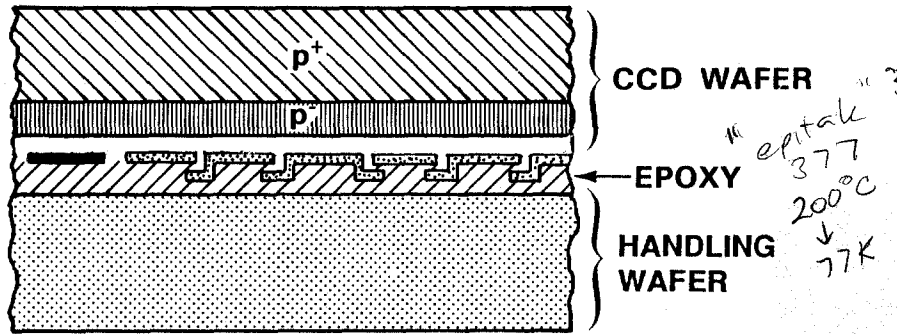


FABRICATION APPROACHES FOR BACK-ILLUMINATED CCD IMAGER

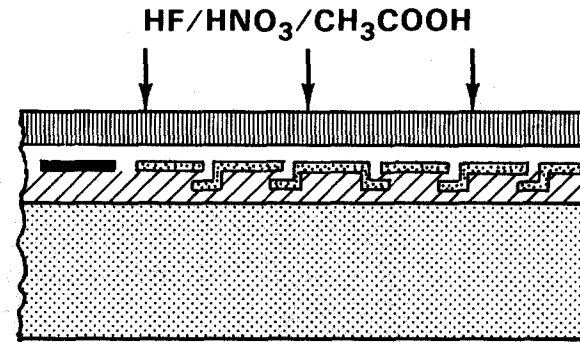
ORGANIZATION	STRUCTURE	COMMENTS
TI (1974)		<p>FREE-STANDING MEMBRANE NOT ABUTTABLE</p>
RCA (1985)		<p>NOT UV SENSITIVE</p>
TEKTRONIX (1987)		<p>DETAILS PROPRIETARY</p>
LINCOLN LAB (1989)		<p>COMPATIBLE WITH PRODUCTION EQUIPMENT</p>



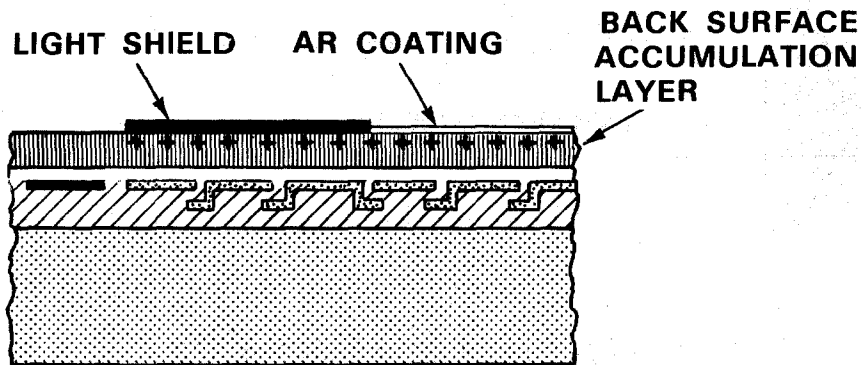
BACK-ILLUMINATED IMAGER FABRICATION



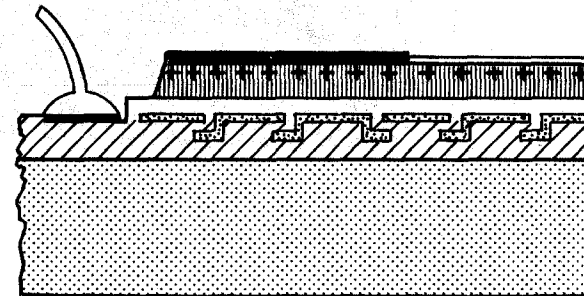
1. WAFER MOUNTING



2. WAFER THINNING



3. BACK SURFACE PROCESSING



4. ETCH Si AND SiO_2 TO EXPOSE BONDING PADS

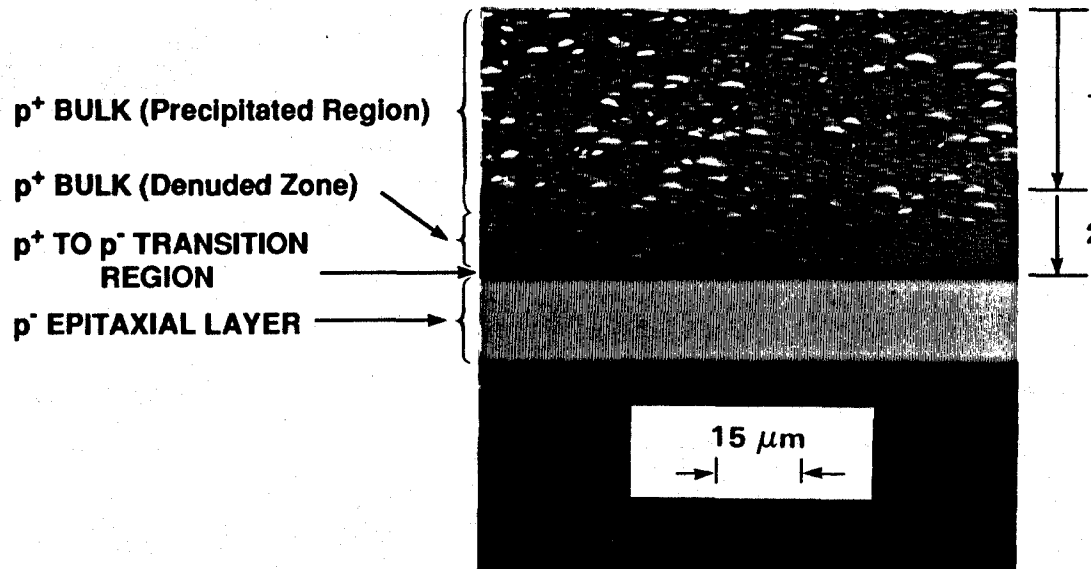


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APPROACH TO THINNING CCD WAFERS

1. LAPPING AND POLISHING MOST OF p⁺ BULK
2. SELECTIVE ETCHING (HF:HNO₃:CH₃COOH, 1:3:10)
3. REMOVING STAINS

*Dick sez
try etching 15 dark*

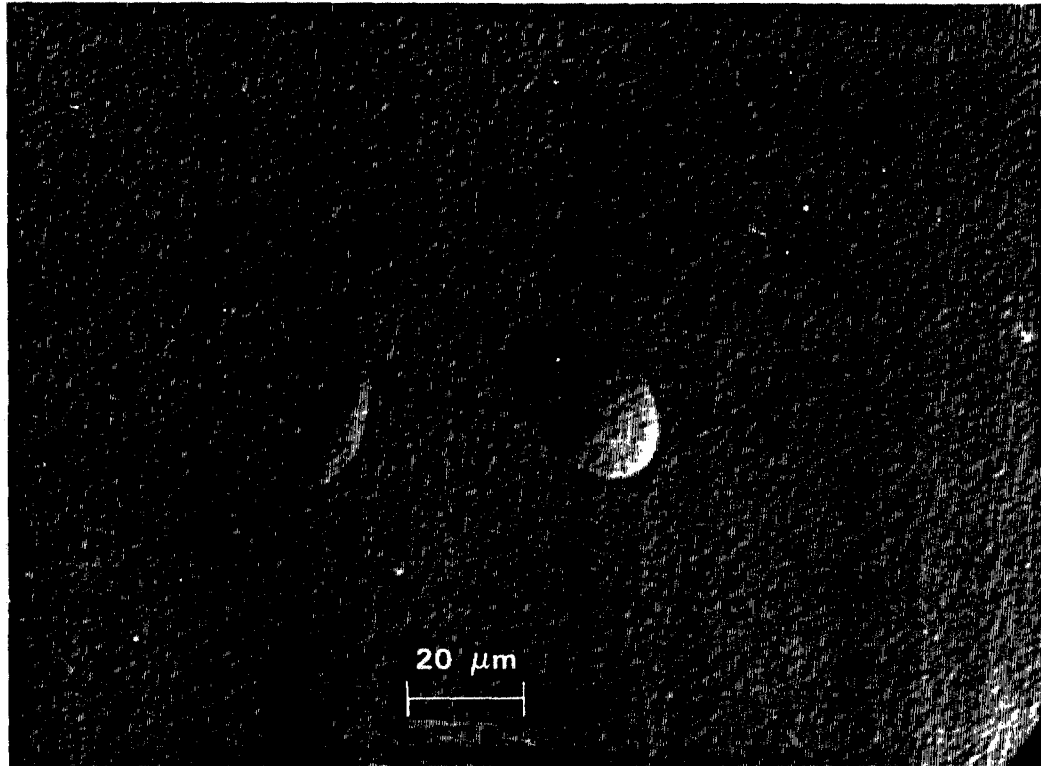


IMPROVING ETCHING SELECTIVITY


IMPROVEMENT	MECHANISM	COMMENTS
H ₂ O ₂ TITRATION	CONVERTS NITROUS ACID TO NITRIC ACID	AMOUNT OF H ₂ O 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



MORPHOLOGY OF AN ETCHED SURFACE

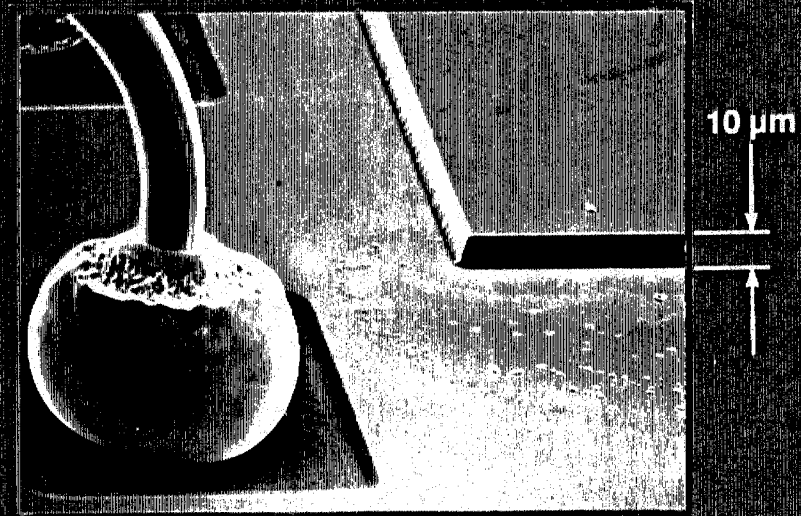
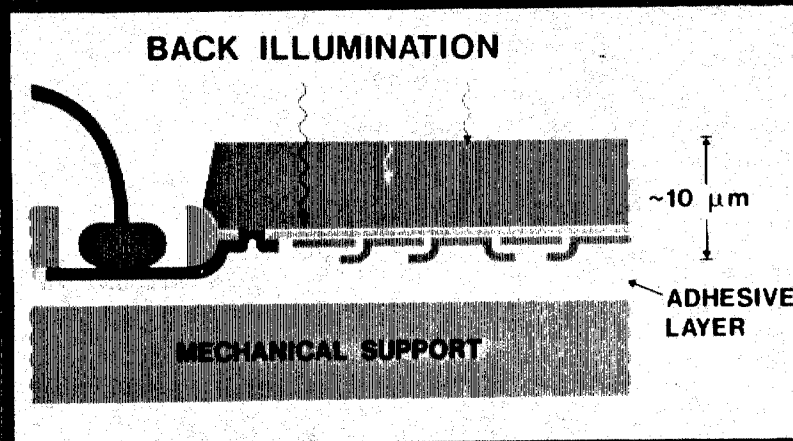


DENSITY OF ETCH PITS = $2000/\text{cm}^2$
DEPTH VARIATION = 500 \AA

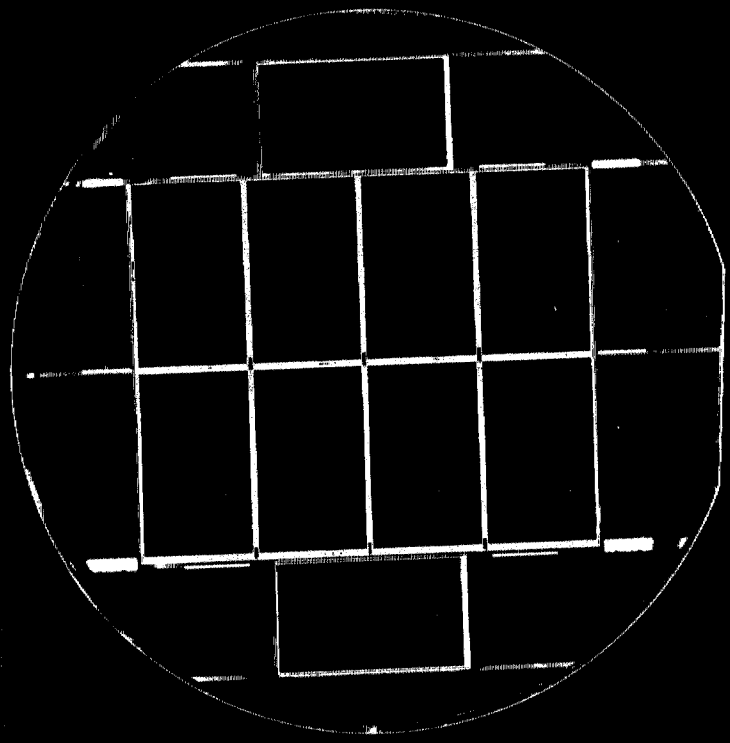

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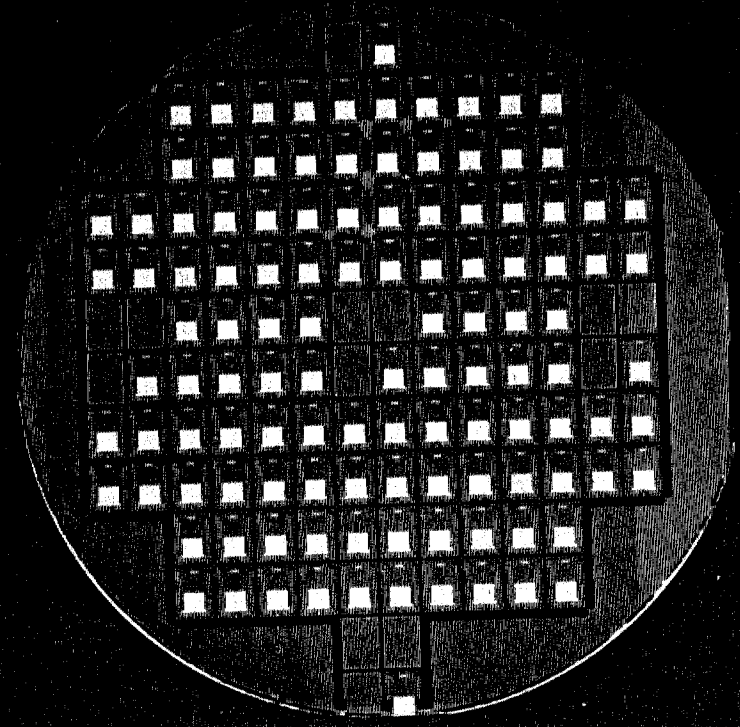
WIRE BONDING RELIABILITY IN BACK-ILLUMINATED CCDs



BACK-ILLUMINATED CCD IMAGER



3 INCHES



3 INCHES



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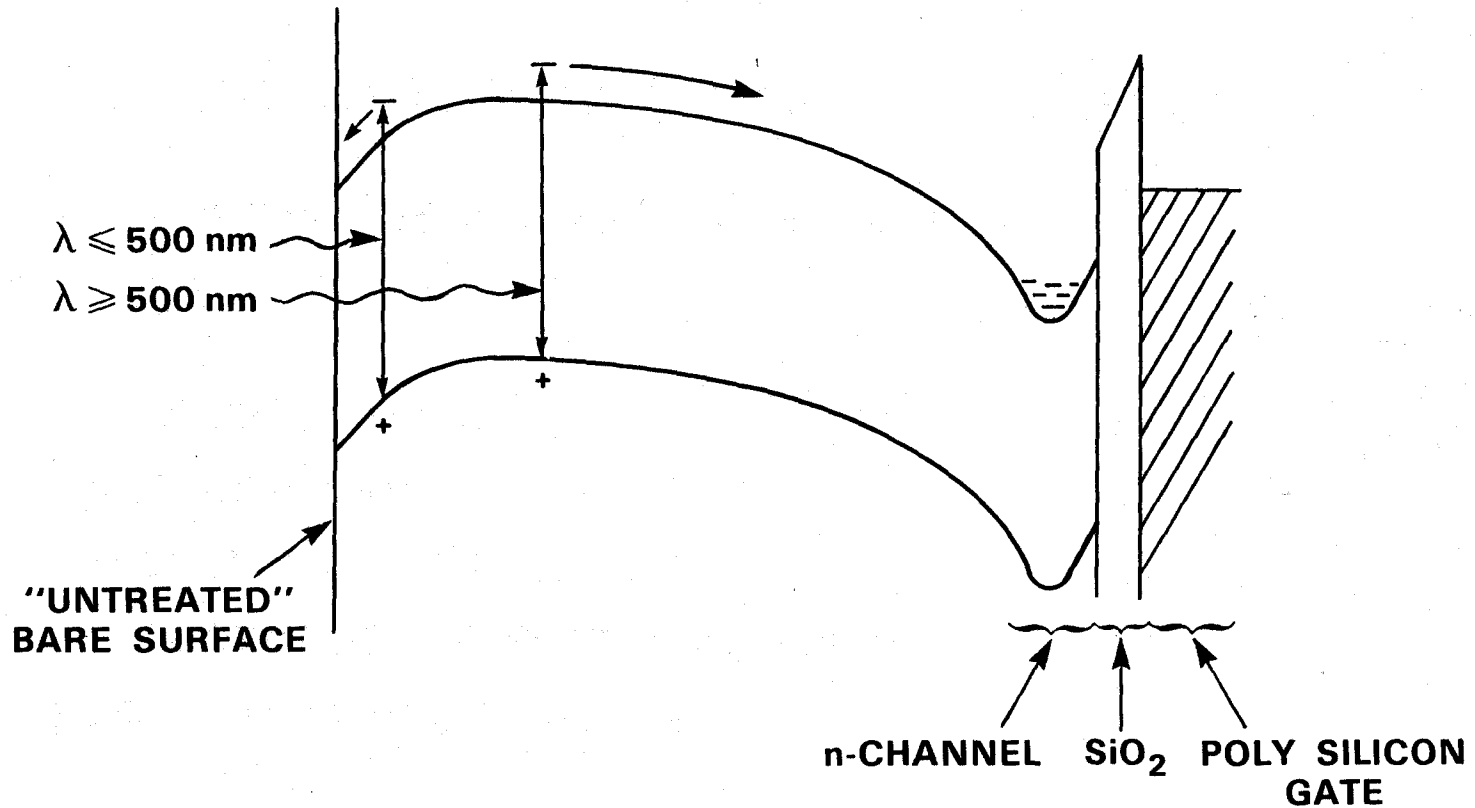
VU 2.8

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

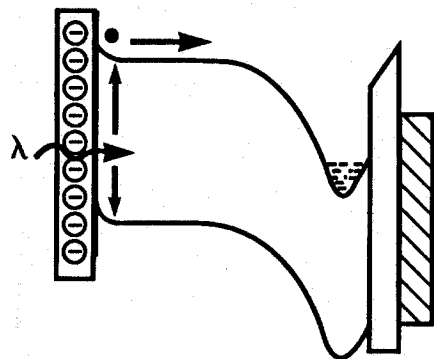


BACK SURFACE EFFECTS ON QUANTUM EFFICIENCY OF BACK ILLUMINATED IMAGERS

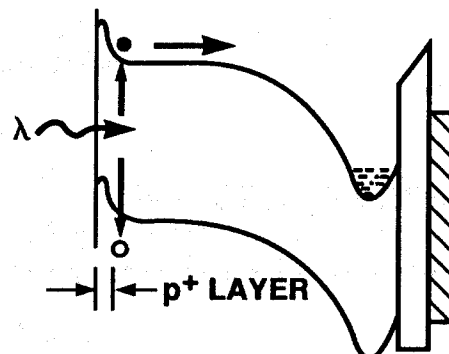


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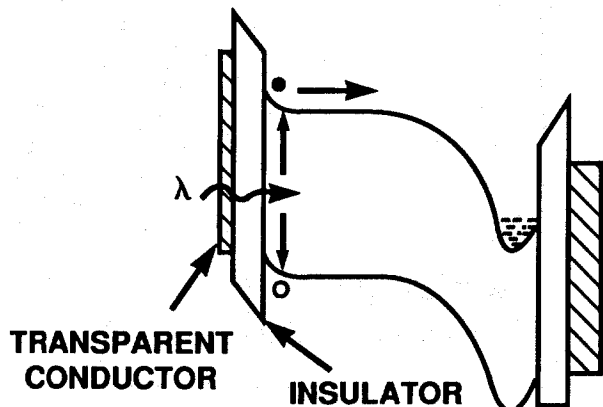
APPROACHES TO BACK-SURFACE TREATMENTS



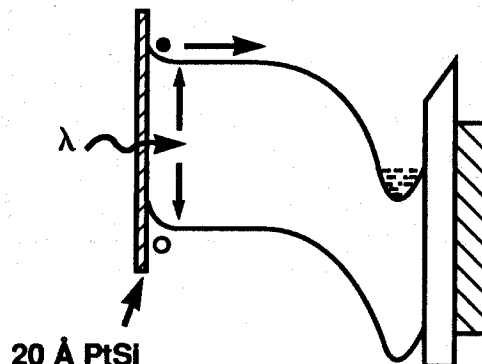
NEGATIVELY CHARGED THIN FILM



SHALLOW p⁺ LAYER



BIASED GATE

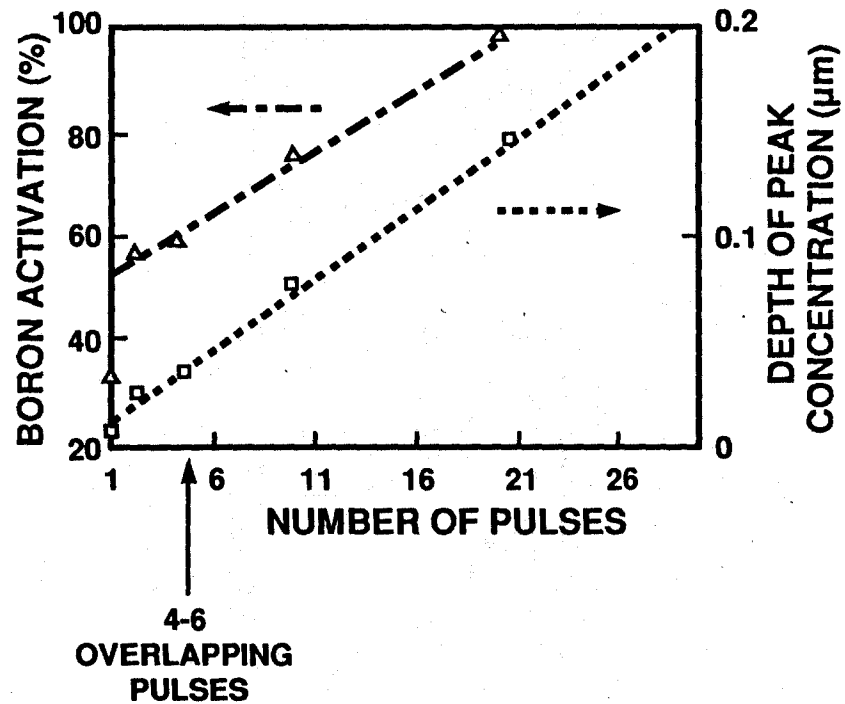
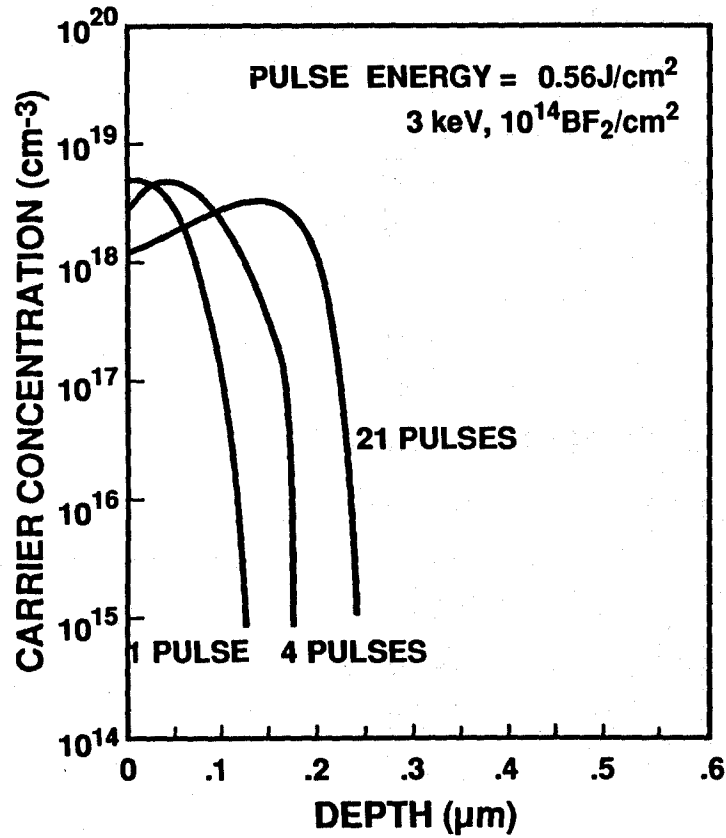


SILICIDE SURFACE

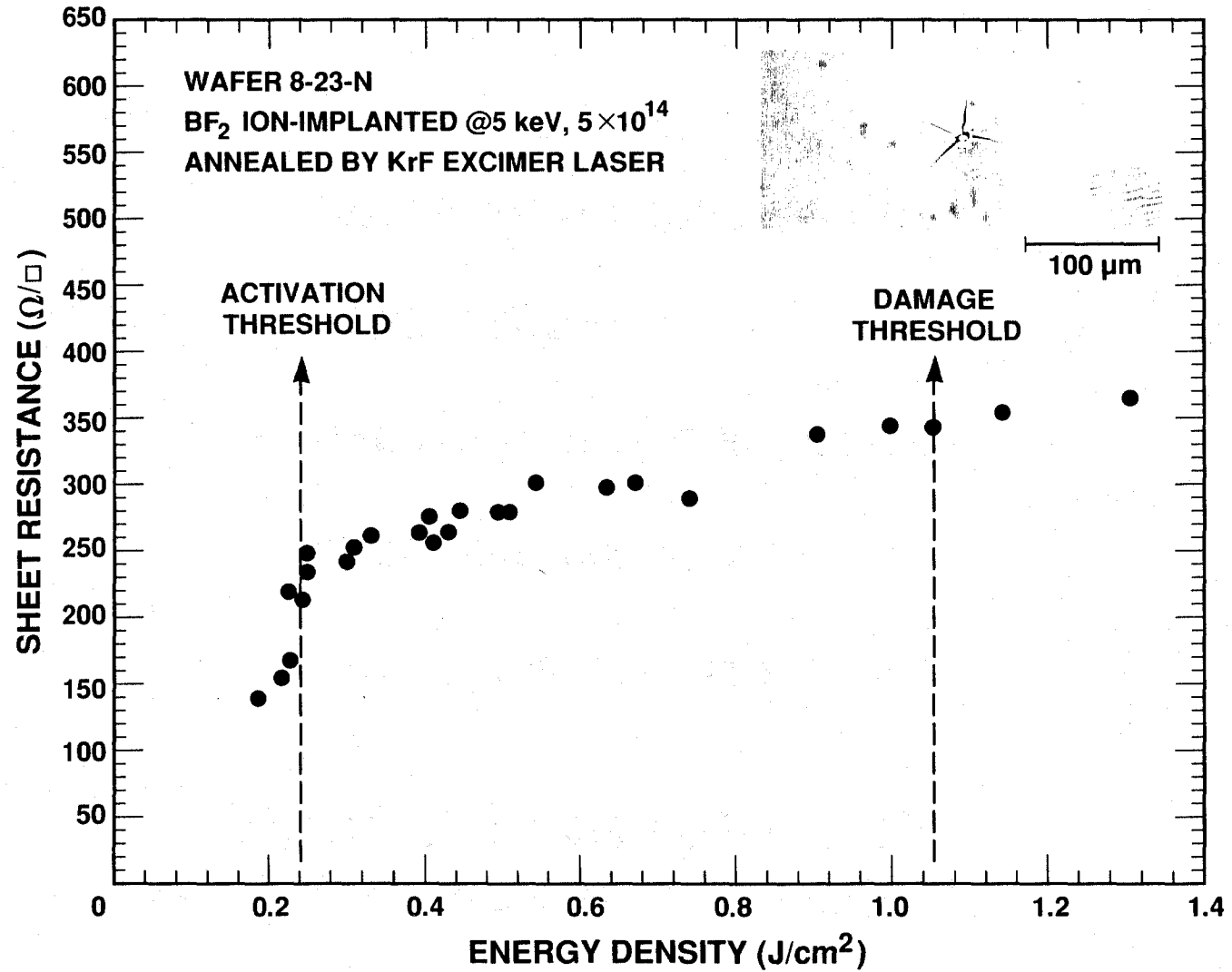


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PROCESS OPTIMIZATION vs NUMBER OF OVERLAPPING PULSES



ACTIVATION OF DOPANT vs LASER ANNEALING ENERGY



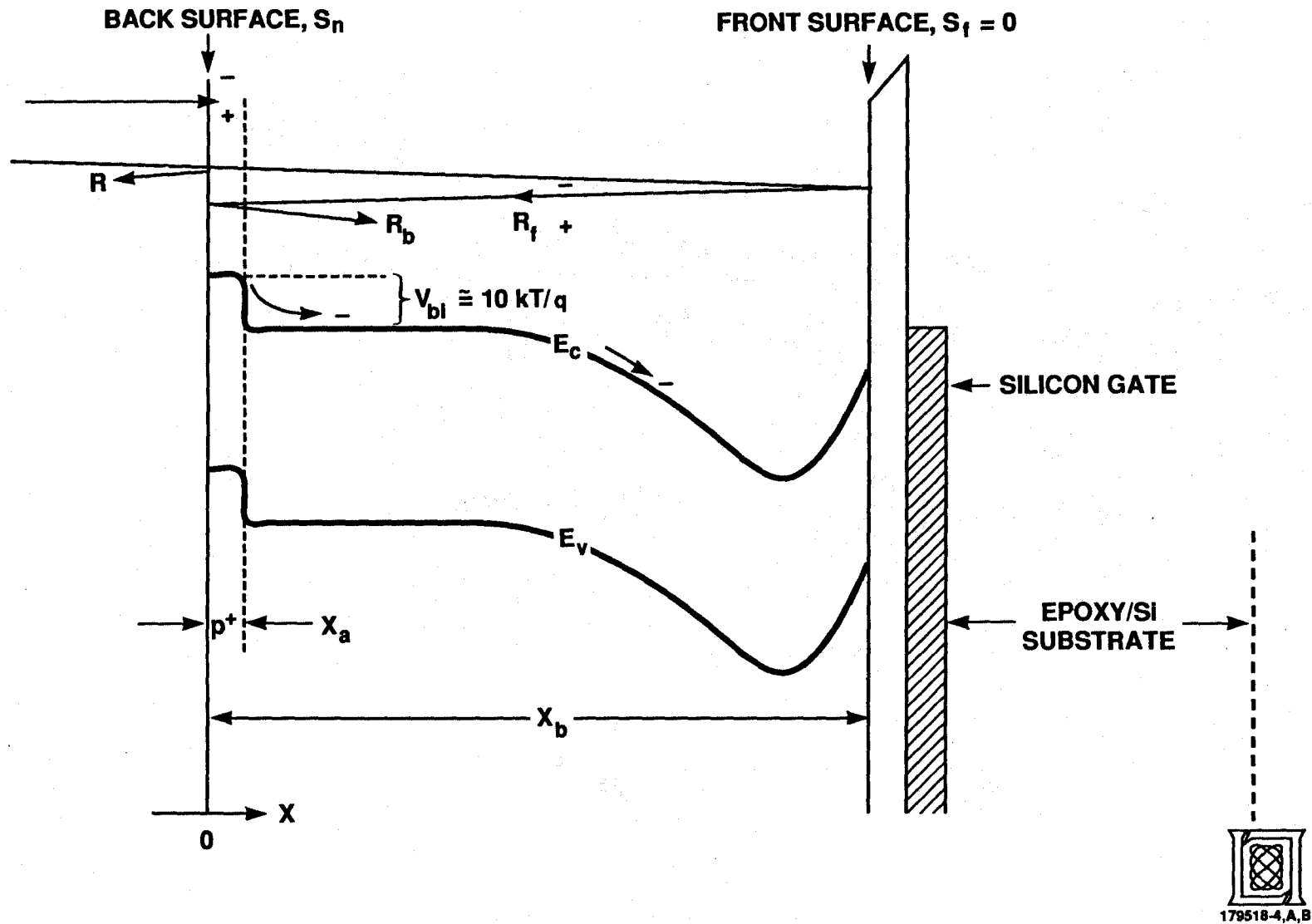
VU 3.5

QUANTUM EFFICIENCY MODELING OF BACK-ILLUMINATED CCDs

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



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



EXTERNAL QUANTUM EFFICIENCY IN THE p⁺ REGION

SOLVE $D_n \frac{d^2 n_p}{dx^2} + \alpha F(1-R) e^{-\alpha x} \frac{n_p - n_{p0}}{\tau_n} = 0$

SUBJECT TO $n_p - n_{p0} = 0$ AT $x = X_a$

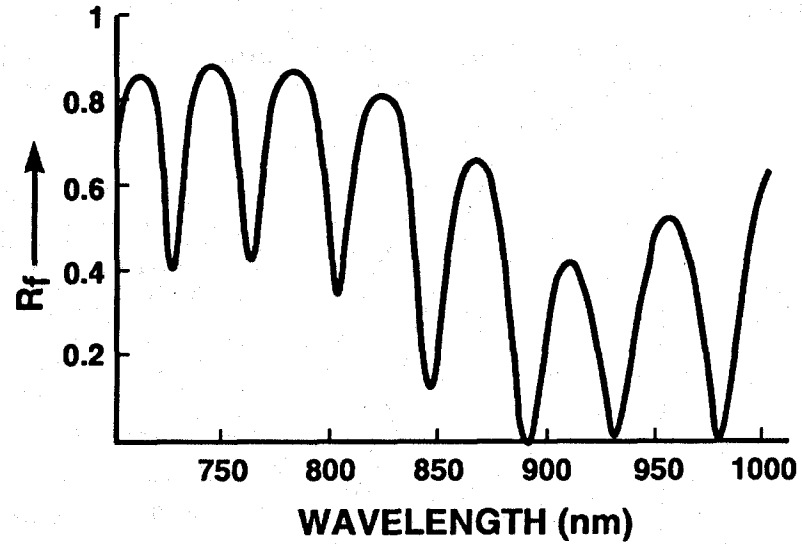
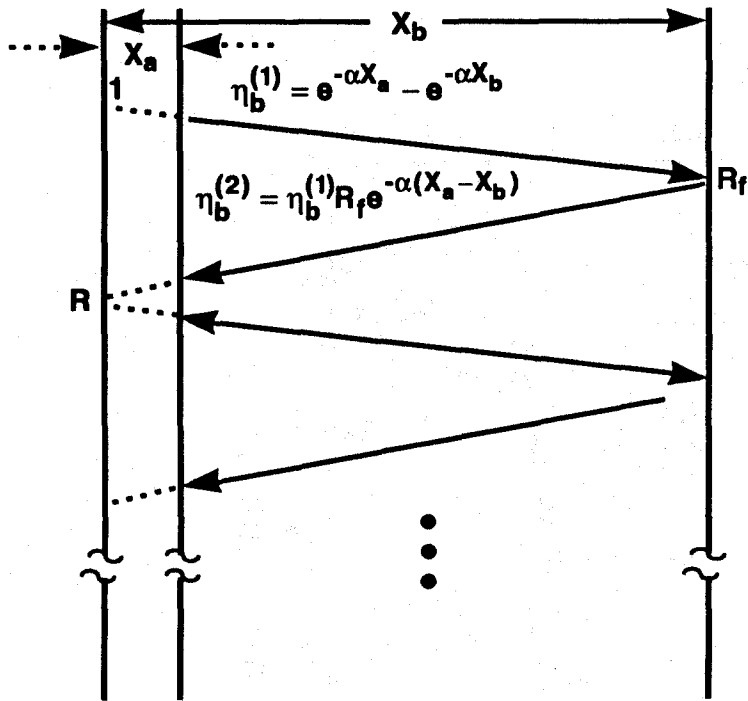
AND $S_n(n_p - n_{p0}) = D_n \frac{d(n_p - n_{p0})}{dx}$ AT $x = 0$

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

$$= (1-R) (1 - e^{-\alpha X_a}) \quad S_n = 0, \quad L_n \gg \alpha^{-1}$$



MODELING Q.E. IN THE BULK REGION

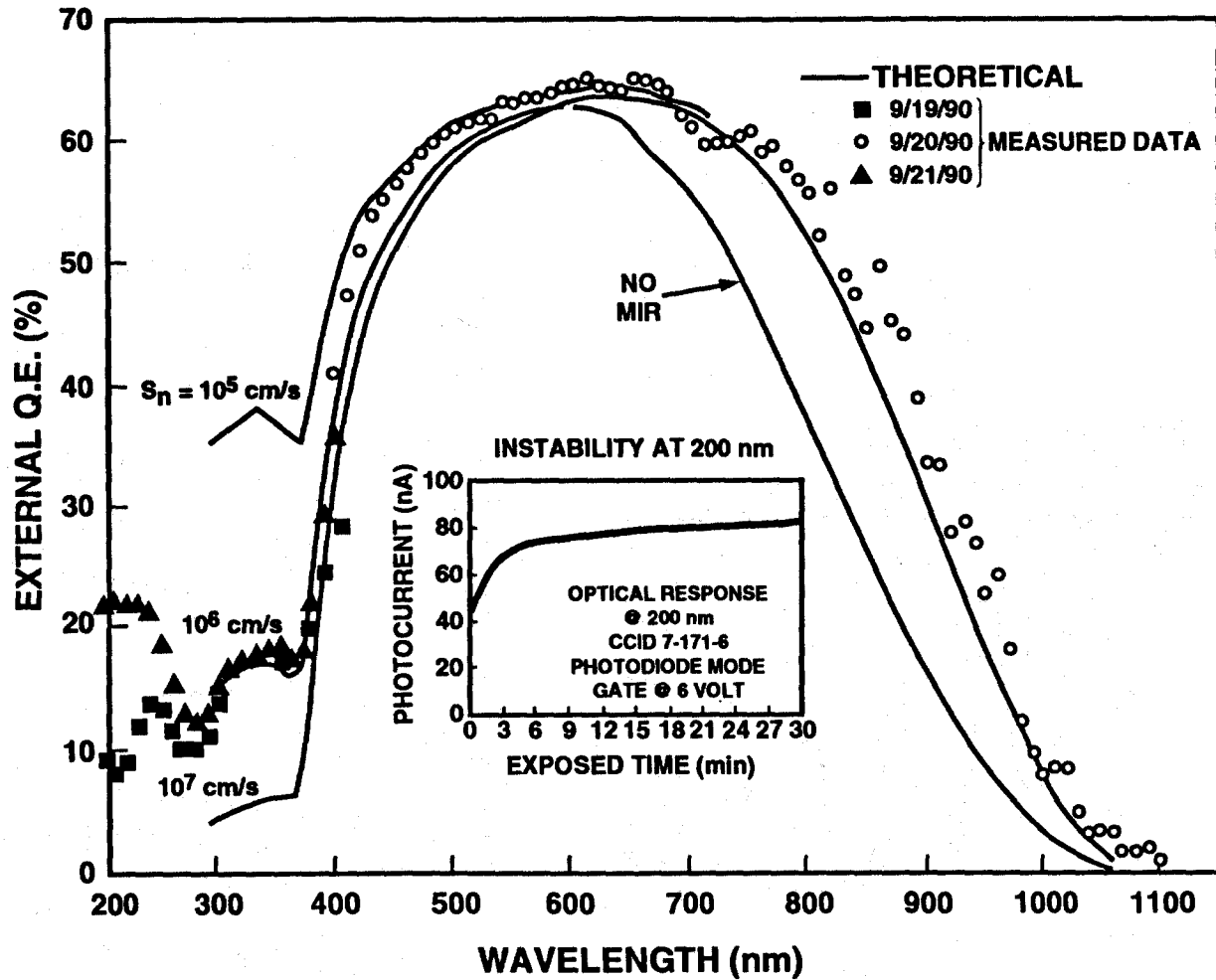


$$\eta_b = (1-R)(e^{-\alpha X_a} - e^{-\alpha X_b})(1 + R_f e^{-\alpha(X_a - X_b)}) / (1-r)$$

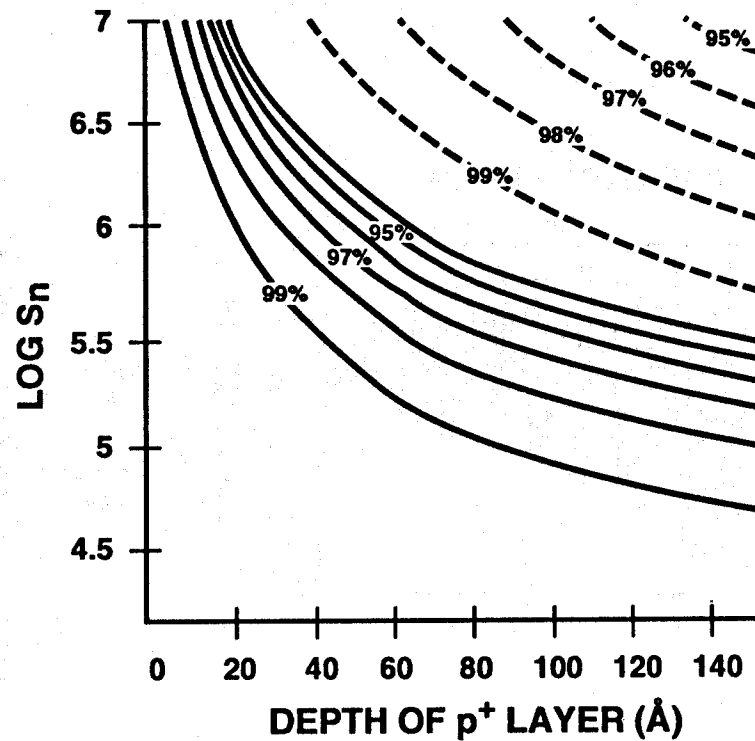
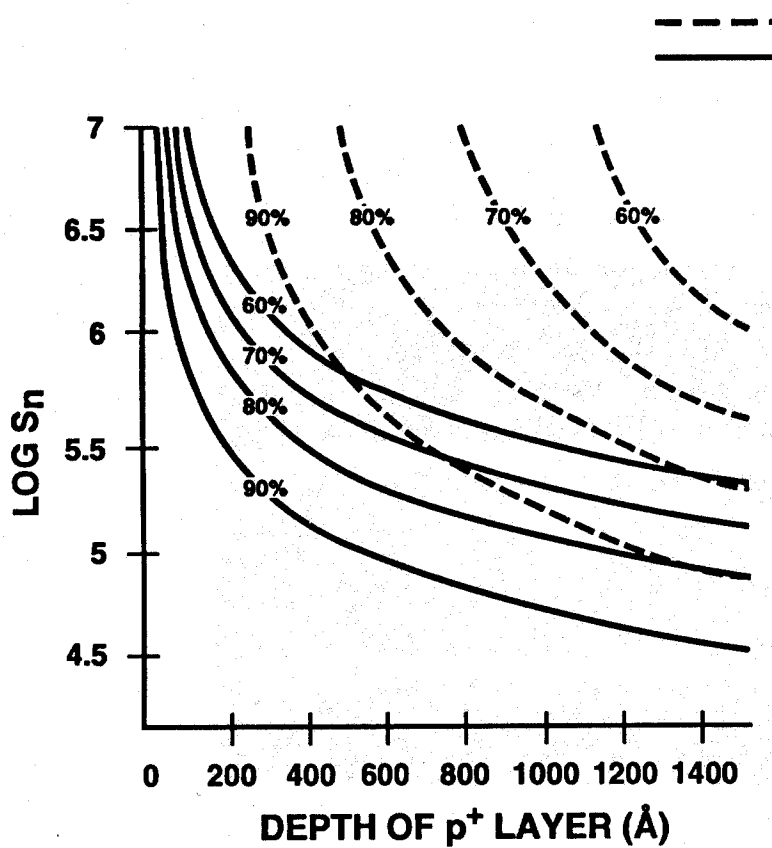
$$r = R_f R e^{-2\alpha X_b}$$



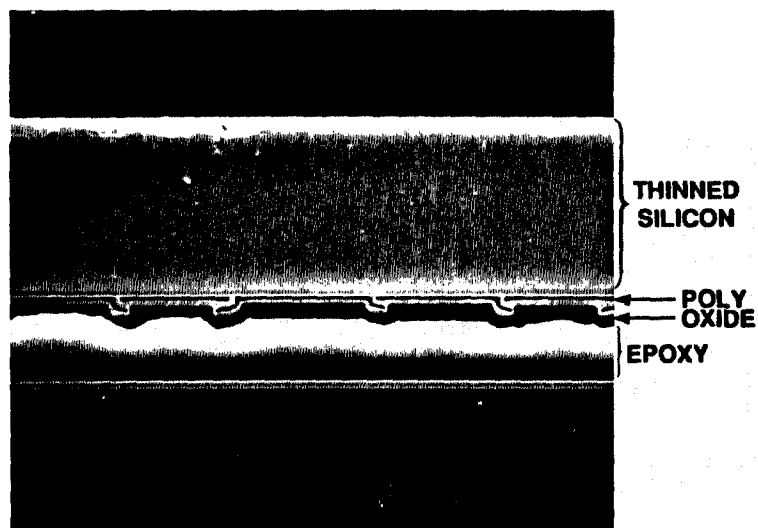
COMPARISON OF MODELING WITH MEASURED DATA



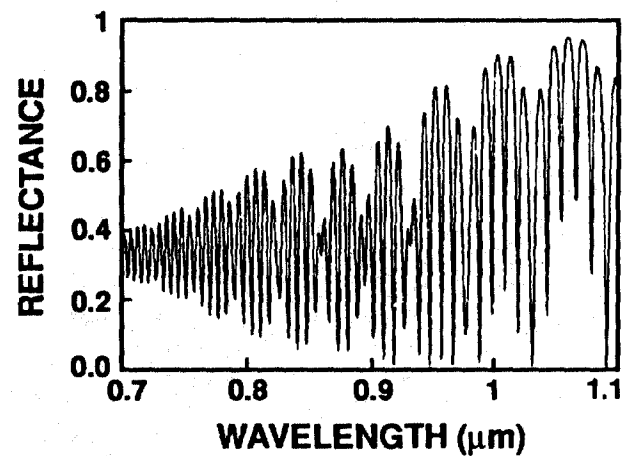
UV STABILITY vs THE DEPTH OF p⁺ LAYER



EFFECTIVE REFLECTANCE OF A THINNED, BACK-ILLUMINATED CCD IMAGER



→ | 10 μm | ←

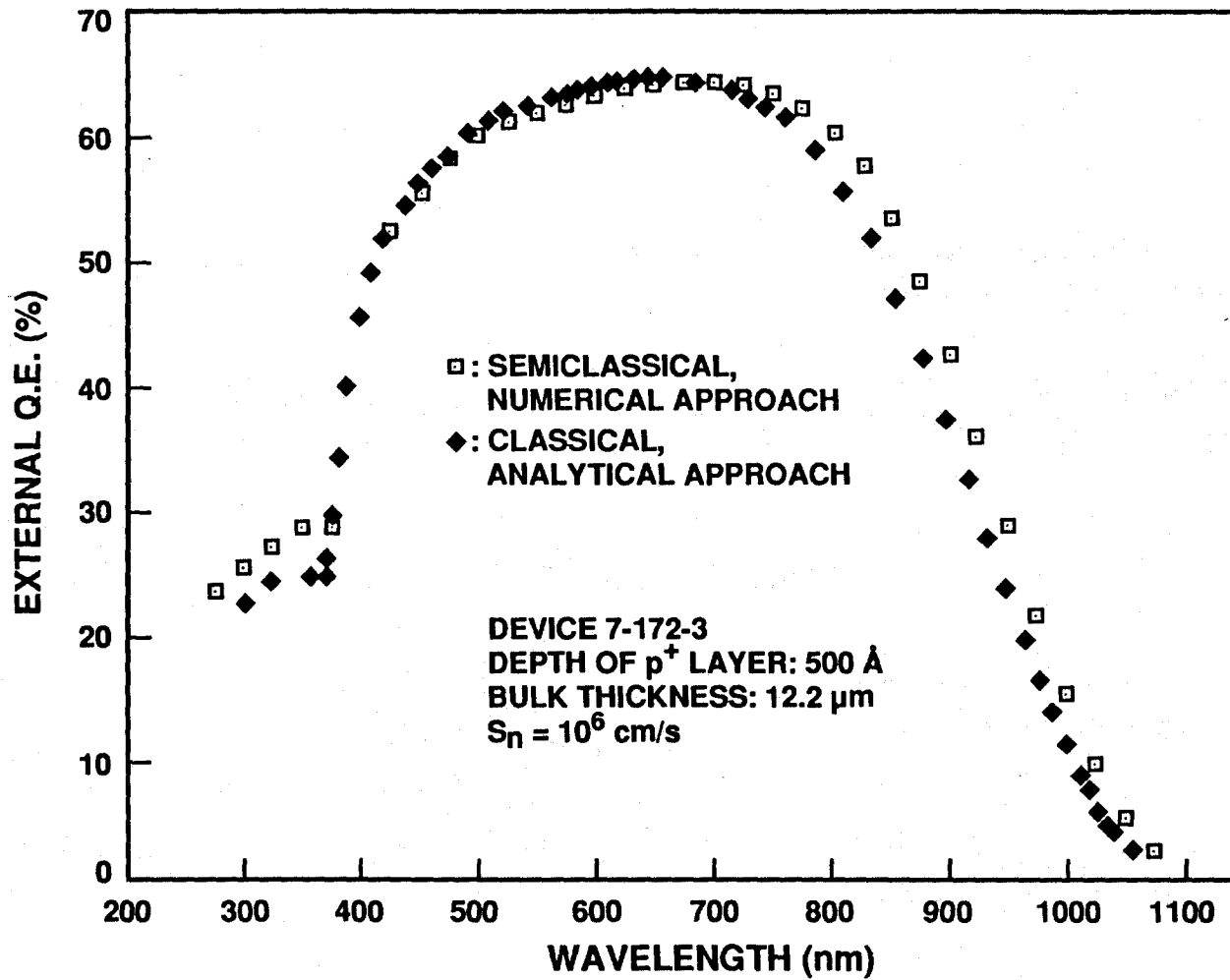


MODELS ON BACK-ILLUMINATED CCD IMAGER

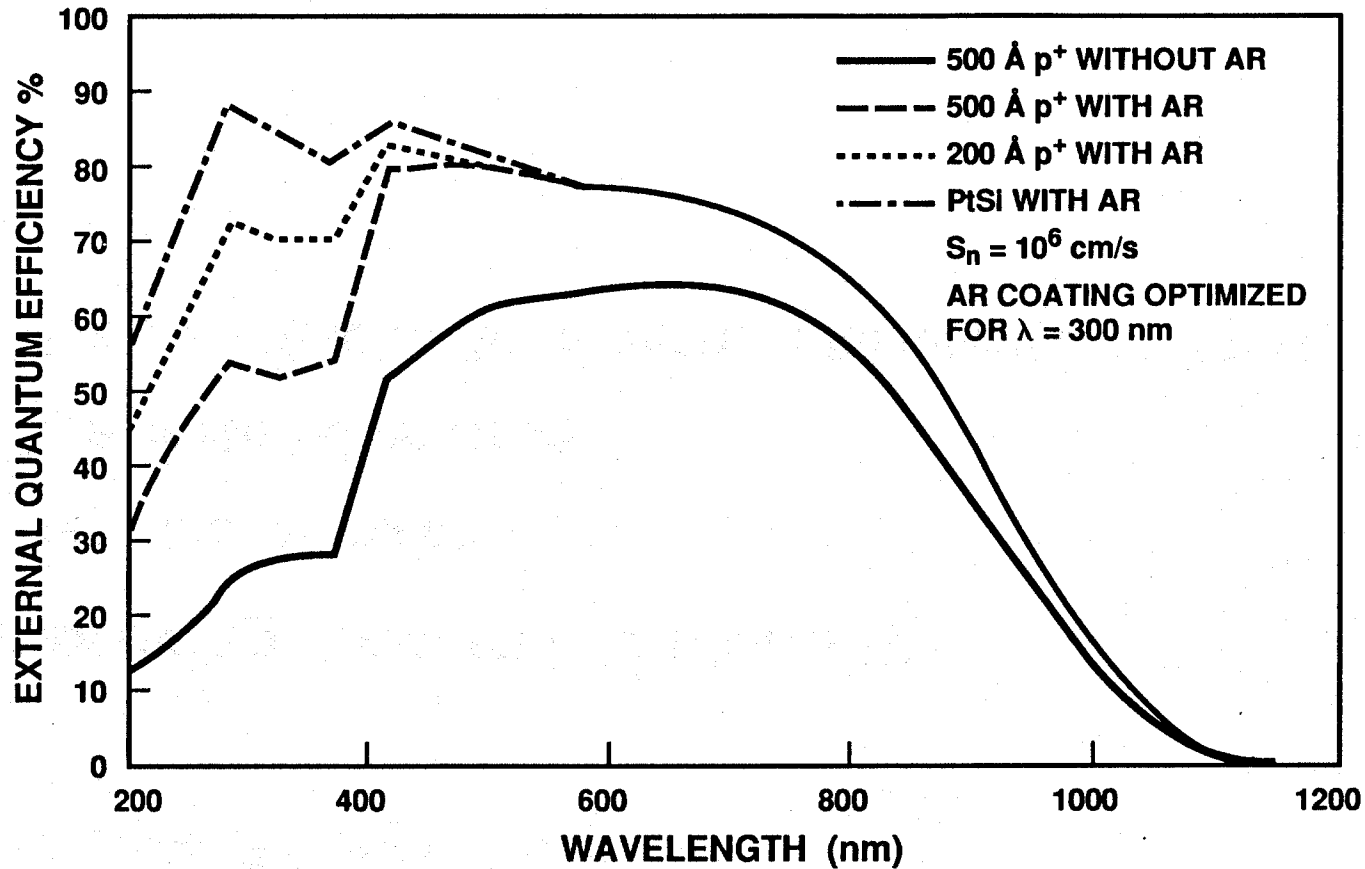
AUTHORS	MODEL	COMMENTS
J.W. WALKER et al. (CCD Proceedings 1978)	$\eta = (1 - R) \left(\frac{1}{1 + kT\alpha/qE} + e^{-\alpha X_a} \right)$	ASSUME E IS UNIFORM E-FIELD IN p ⁺ LAYER, NO MIRs
J. JANESICK et al. (IEDM, 1986)	$\eta = (1 - R) \left(\int_0^{X_a} \left(\frac{x}{X_a} \right)^{\log(E_s +10)^{-1}} \alpha e^{-\alpha x} dx + \left(e^{-\alpha X_a} - e^{-\alpha X_b} \right) \right)$	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



COMPARISON BETWEEN ANALYTICAL AND NUMERICAL SOLUTION



PREDICATED PERFORMANCE



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



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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**