PHOTORESPONSE FROM FERROELECTRIC CAPACITORS: OPTiCAL PROBING/CONDITIONING OF FERROELECTRIC THIN FILM MEMORIES

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OUTLINE

- WHAT IS PHOTORESPONSE?
  - A SENSITIVE PHENOMENON THAT REFLECTS THE **"STATE OF AFFAIRS" OF THE FERRO-FILM/CAPACITOR**

- HOW DOES ONE MEASURE IT?
  - **USE** OF **ACCOUSTO-OPTICALLY** SWITCHED PULSED LASER FOR NOISE REDUCTION

- WHAT DOES ONE DO WITH **IT?**
  - PROBING AND CONDITIONING OF FATIGUED SAMPLES
  - PROBING FOR "HISTORY" OF THE SAMPLES

- CONCLUSIONS

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INTRODUCTION

- KINDS OF PHOTO RESPONSE:
    - PHOTO INDUCED CURRENT/VOLTAGE
    - TRANSMITTED LIGHT
    - REFLECTED LIGHT
- INCIDENT LIGHT PARAMETERS
    - WAVELENGTH
    - INTENSITY
    - POLARIZATION
    - CONTINUOUS/PULSED
    - ANGLE OF INCIDENCE

NON-DESTRUCTIVE LASER PULSE PROBING OF THE FERROELECTRIC CAPACITOR

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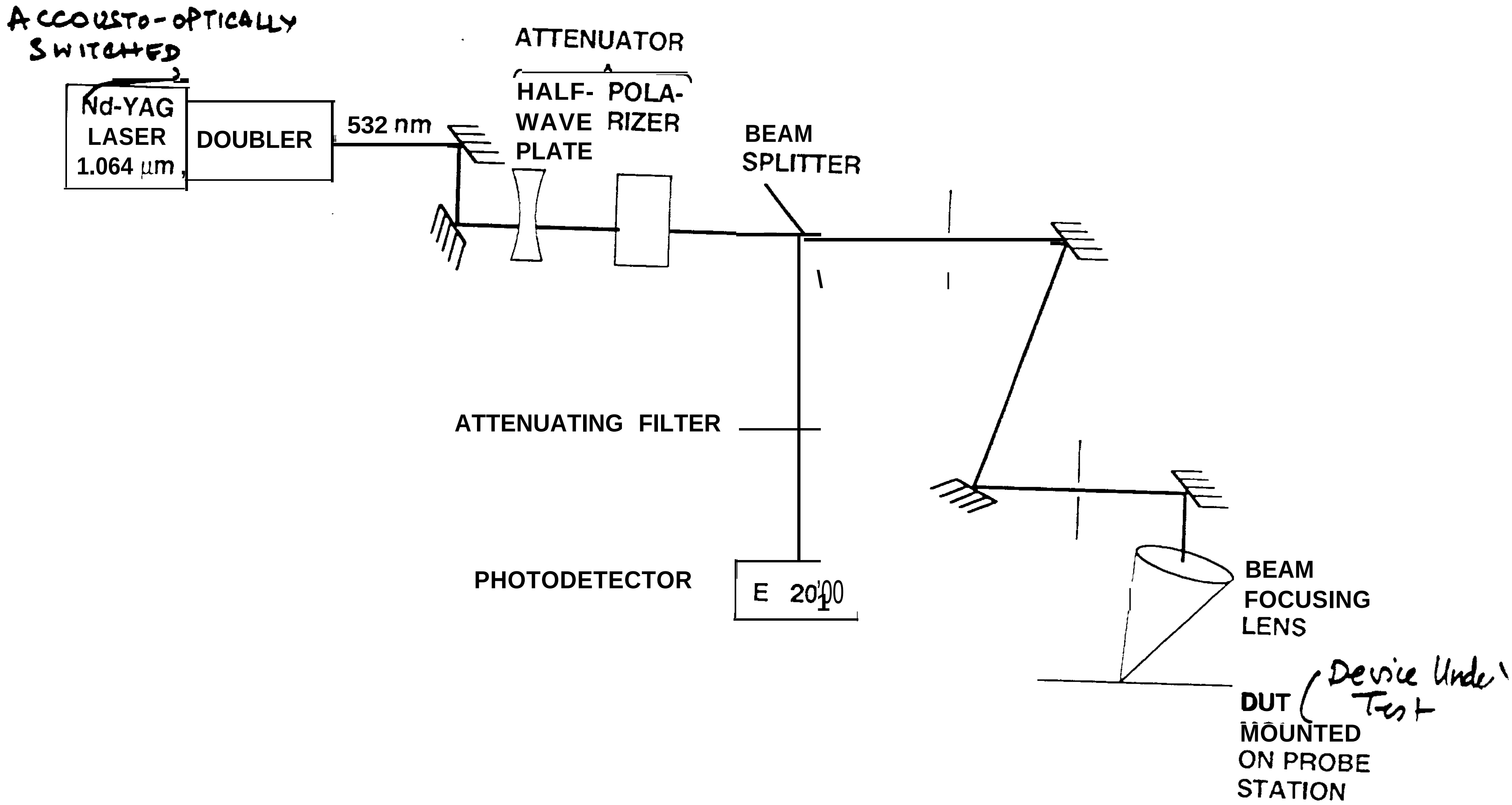
SCHEMATIC OPTICAL SET-UP



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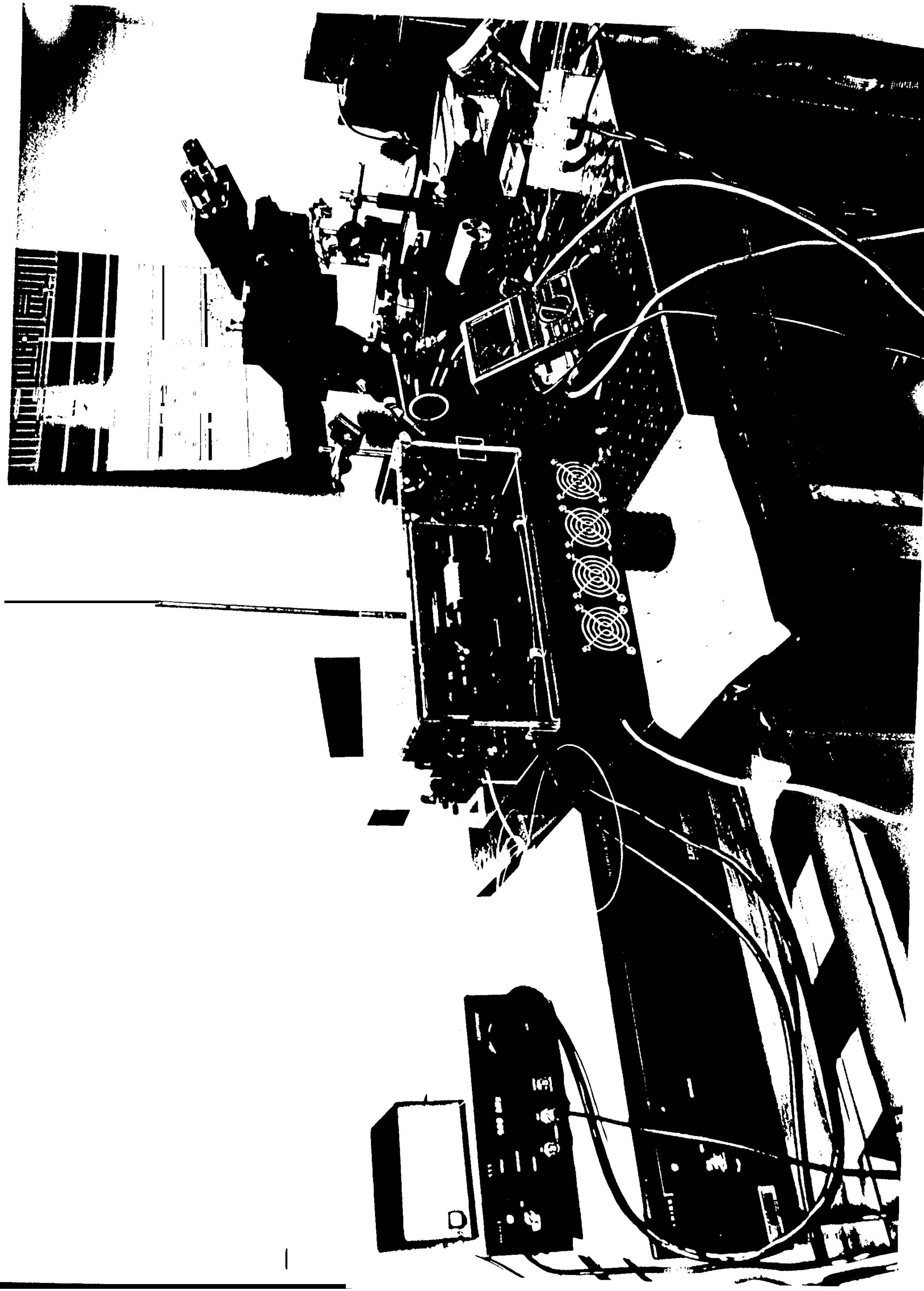
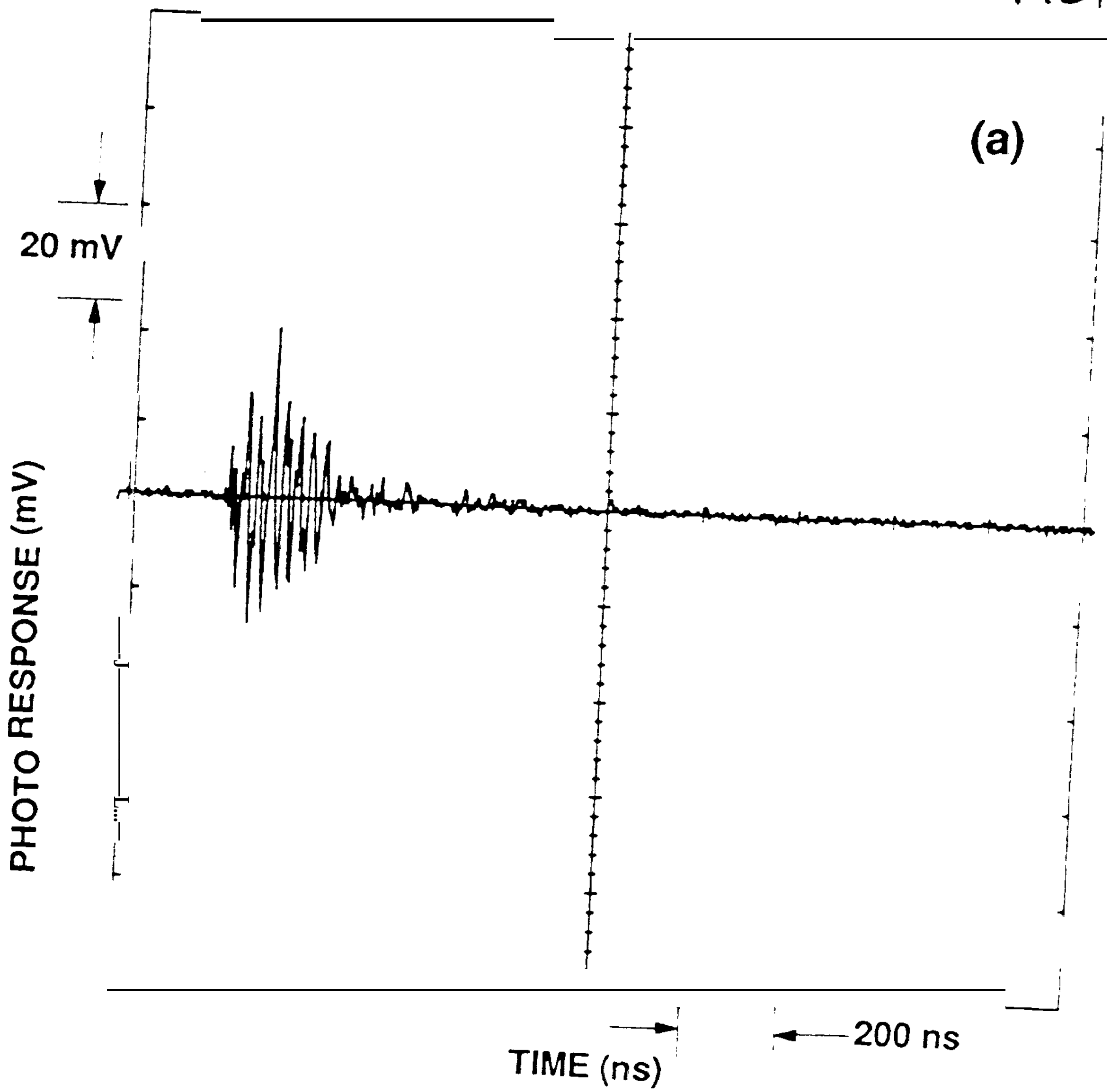


ELECTRO OPTICALLY SWITCHED LASER (LARGE NOISE PICK UP)



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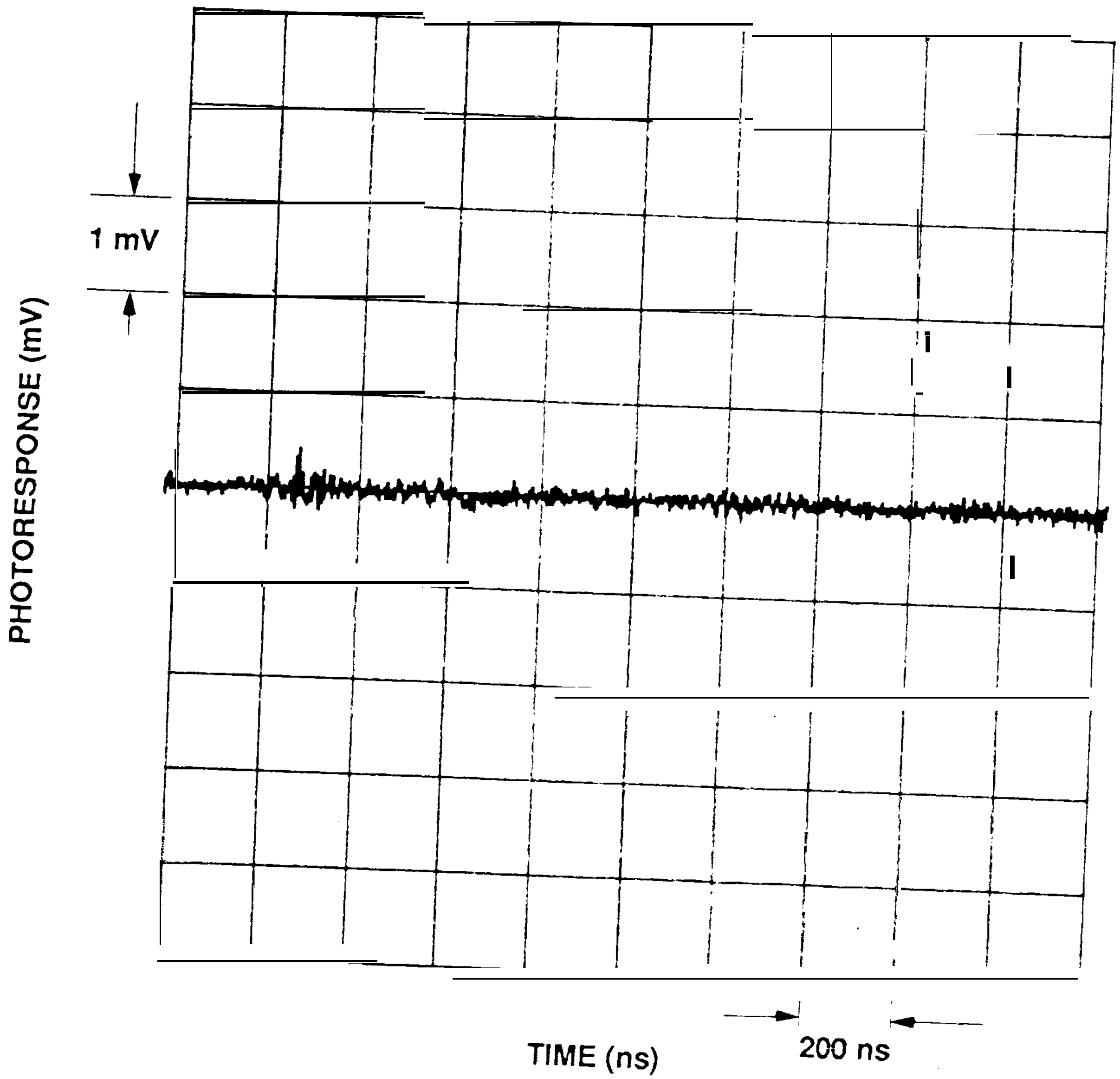
ACCOUSTO OPTICALLY ~~AS~~ SWITCHED LASER

LOW NOISE SIGNAL FOR HIGH SPEED PHOTORESPONSE MEASUREMENT



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EXPERIMENTAL DETAILS

- TRANSMISSION RESPONSE 200 nm-800 nm USING CAREY MODEL 5A SPECTROPHOTOMETER
  - DC, MULTIMAGNETRON SPUTTERED PZT (S. THAKOOR, U.S. PATENT #5196101 (23 MARCH 1993))
    ANGLE OF INCIDENCE OF SPUTTER DESPOSIT: CONTROL PARAMETER
    FILM A: DEPOSITED USING ALL ANGLES OF DEPOSITION
    FILM B: DEPOSITION ANGLE RESTRICTED TO PERPENDICULAR INCIDENCE
  - SURFACE TOPOGRAPHY INSPECTED USING CAMBRIDGE S250 SEM
- BANDGAP LIGHT ILLUMINATION:
  - SHORT ARC MERCURY LAMP: UV VISIBLE ILLUMINATION SOURCE (300-600 nm)
    365 nm FILTER USED TO OBTAIN ~100 mW/cm^2
    ILLUMINATION PULSE LENGTH VARIABLE FROM 1-99 sec
    HYSTERISIS LOOPS OBSERVED AS FUNCTION OF ILLUMINATION
- HIGH SPEED EFFECTS: 532 nm Nd.YAG PULSED LASER
  - PULSE WIDTH ~ 10 ns, POWER .6 $mW/\mu m^2$
    PHOTORESPONSE MEASURED DIFFERENTIALLY ACROSS 50 Ω INPUT IMPEDENCE OF A DSA 602A TEKTRONIX DIGITIZING SIGNAL ANALYZER

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PZT FILMS
SOL-GEL DEPOSITED FILMS*:

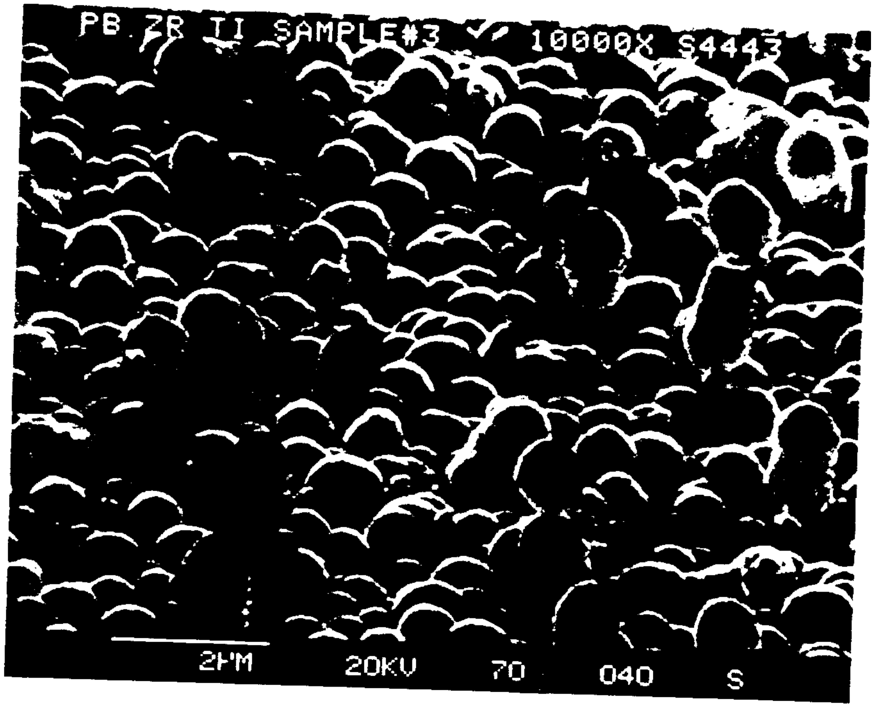
- BASE ELECTRODE: Ti/Pt (1000&l 000 Å)

- PZT COMPOSITION (Zr:52, Ti:48)
  18% EXCESS LEAD

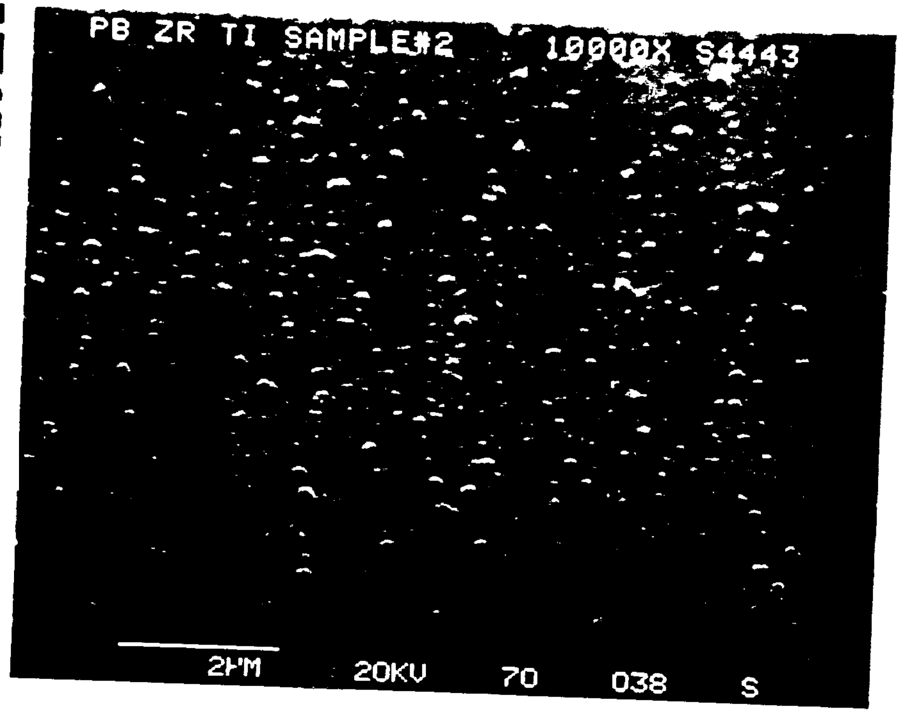
- TOP ELECTRODE: DC SPUTTER-DEPOSITED
  SEMITRANSPARENT Pt (~150 Å)
  OPTICAL TRANSMISSION ~30%

* 1. G. YI, Z. WU AND M. SAYER, JAP 64, 2717 (1988)
2. S.E. BERNSTEIN et al, FERROELECTRIC THIN FILMS II
MRS PROC. VOL. 243, P. 343

SURFACE TOPOGRAPHY OF SEQUENTIAL, REACTIVE, MAGNETRON, SPUTTER DEPOSITED PZT

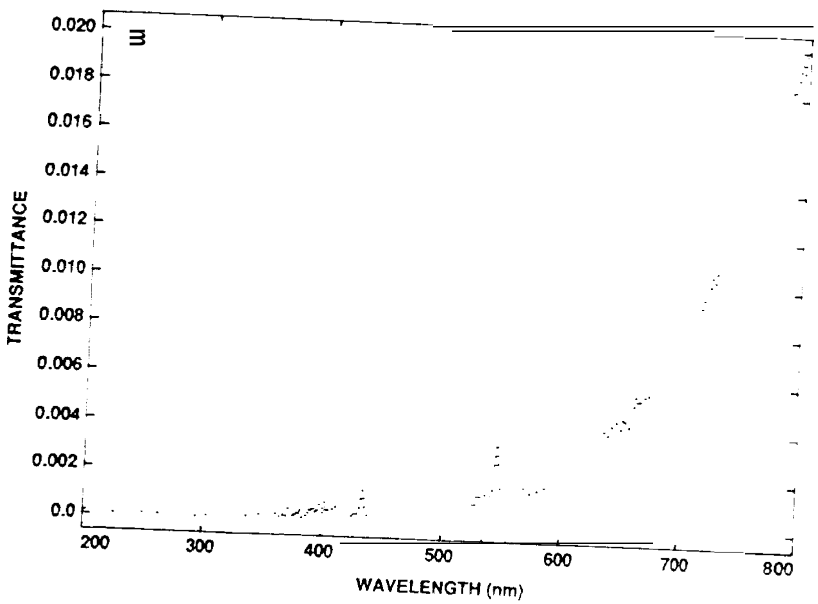


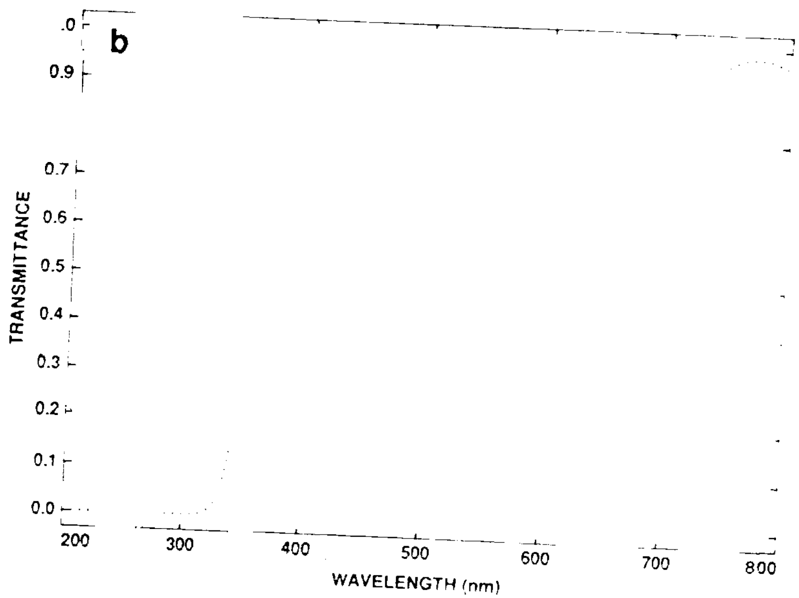
PZT: HIGH OPTICAL SCATTERING
SURFACE ROUGHNESS ~1μm



PZT: GOOD OPTICAL TRANSMITTANCE
SURFACE ROUGHNESS ~0.2μm

COMPARISON OF TRANSMISSION SPECTRA MULTIMAGNETRON DC SPUTTERED PZT





PZT: HIGH OPTICAL SCATTERING
SURFACE ROUGHNESS ~1μm

PZT: GOOD OPTICAL TRANSMITTANCE
SURFACE ROUGHNESS ~ 0.2μm

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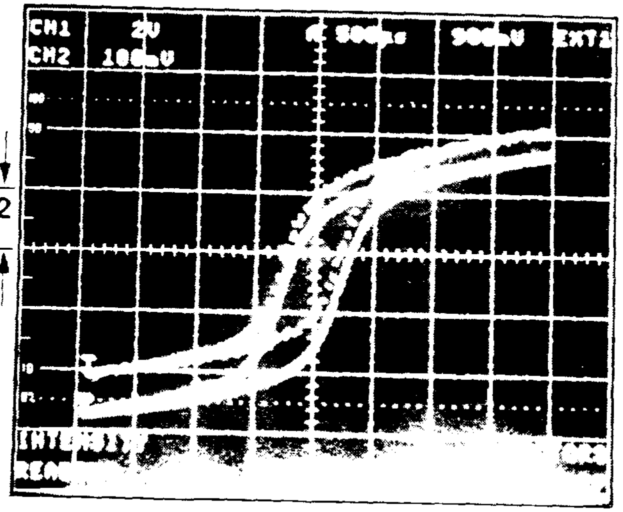
EFFECT OF BANDGAP ILLUMINATION COMPARISON UNFATIGUED AND FATIGUED STATE

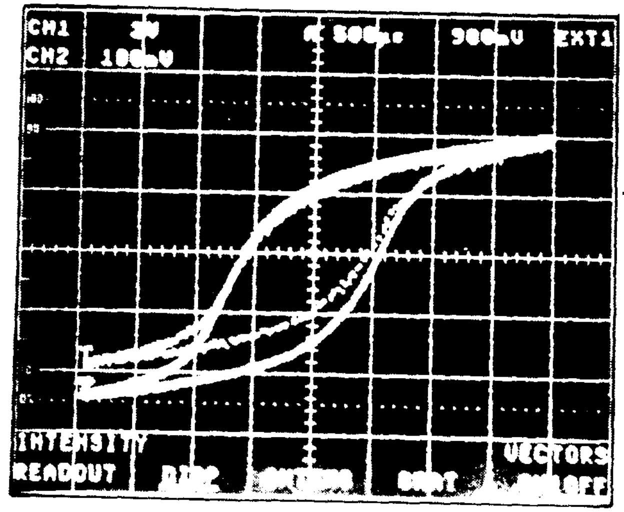
a

20 µC/cm2



UNFATIGUED

b

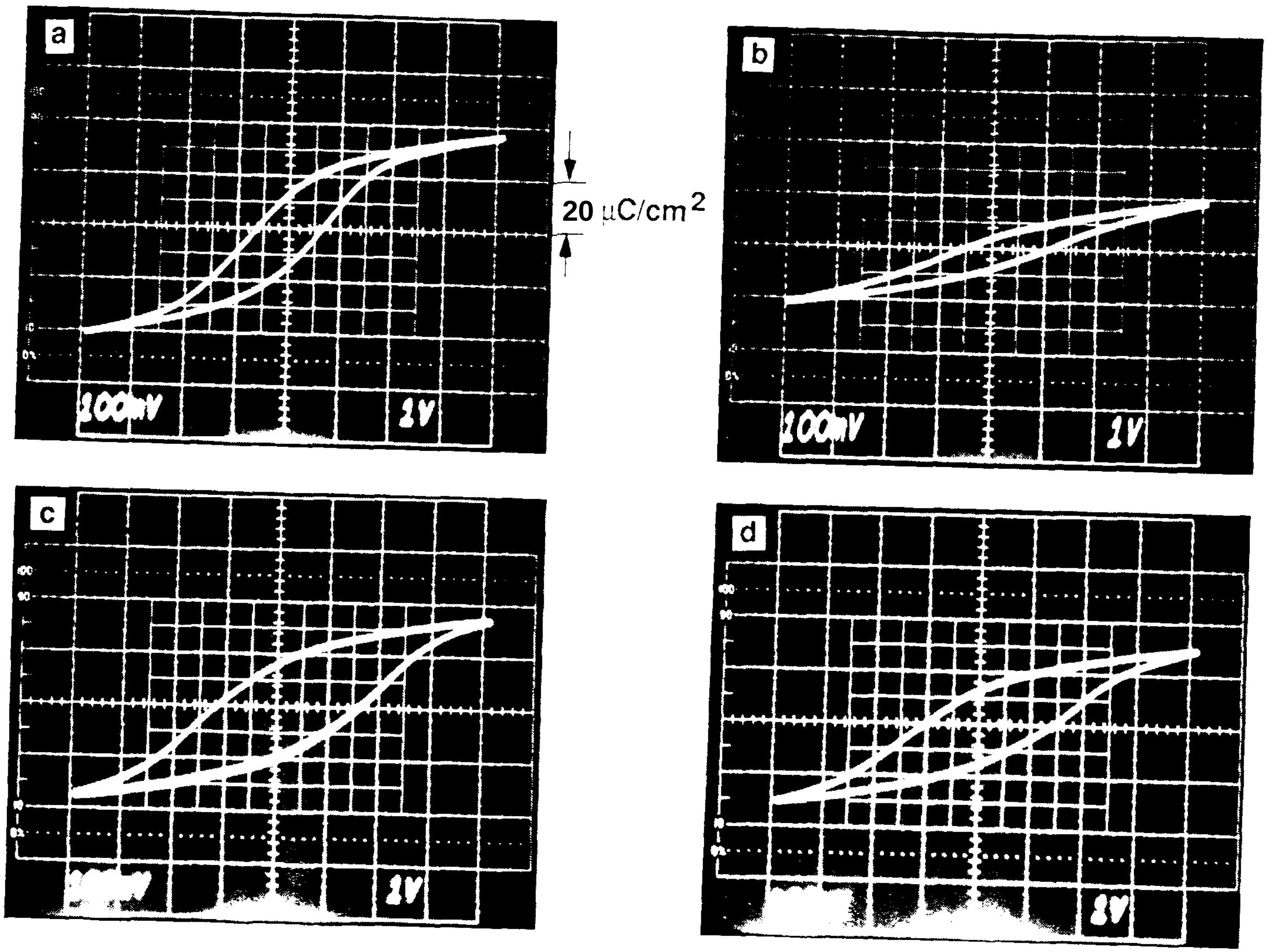


20 µC/cm2

FATIGUED, 10^8 CYCLES

DOTTED LINE - W; THOUT ILLUMINATION
FULL LINE - WITH ILLUMINATION

EFFECT OF BANDGAP ILLUMINATION ON FATIGUED CAPACITOR



HYSTERESIS LOOPS AT 500 Hz: (a) : INITIAL STATE· (b) : FATIGUED STATE
(C) : ILLUMINATION REJUVENATED STATE, 1st LOOP AFTER ILLUMINATION TURN-OFF
(d) : ILLUMINATION OF REJUVENATED STATE, STEADY STATE LOOP AFTER ILLUMINATION TURN-OFF.

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BANDGAP ILLUMINATION EFFECTS

- 365 nm ILLUMINATION CAUSES THE HYSTERESIS LOOP TO SHIFT AS WELL AS BLOOM

- UNFATIGUED CAPACITORS AND MILDLY FATIGUED CAPACITORS PRIMARILY SHOW ONLY A PHOTOINDUCED CONDUCTIVITY CHANGE AS INDICATED BY HYSTERESIS LOOP REVERTING BACK TO VIRTUALLY ORIGINAL STATE ON TURN-OFF OF ILLUMINATION

- FATIGUED SAMPLES (~10^{10} CYCLES) CAN BE CONDITIONED USING BANDGAP LIGHT
  - IMPROVED REMANENT POLARIZATION SUGGESTS DE-PINNING OF PINNED DOMAINS/REMOVAL OF SCREENING FIELDS
  - INCREASED COERCIVE VOLTAGE SUGGESTS INCREASE IN THE NON-FERROELECTRIC (RESISTIVE) INTERFACE/SURFACE LAYER IN THE FERROELECTRIC DEVICE STRUCTURE

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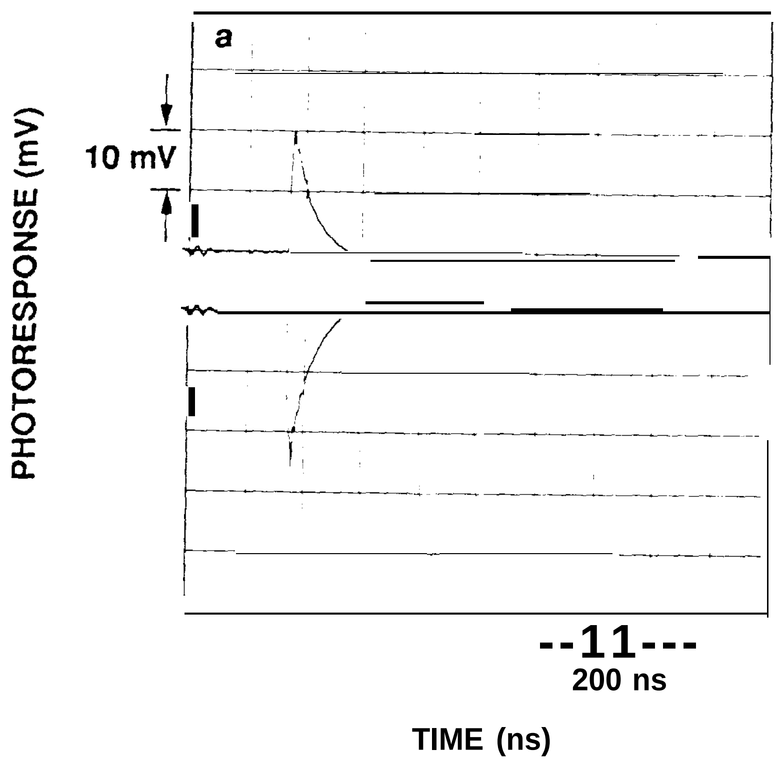
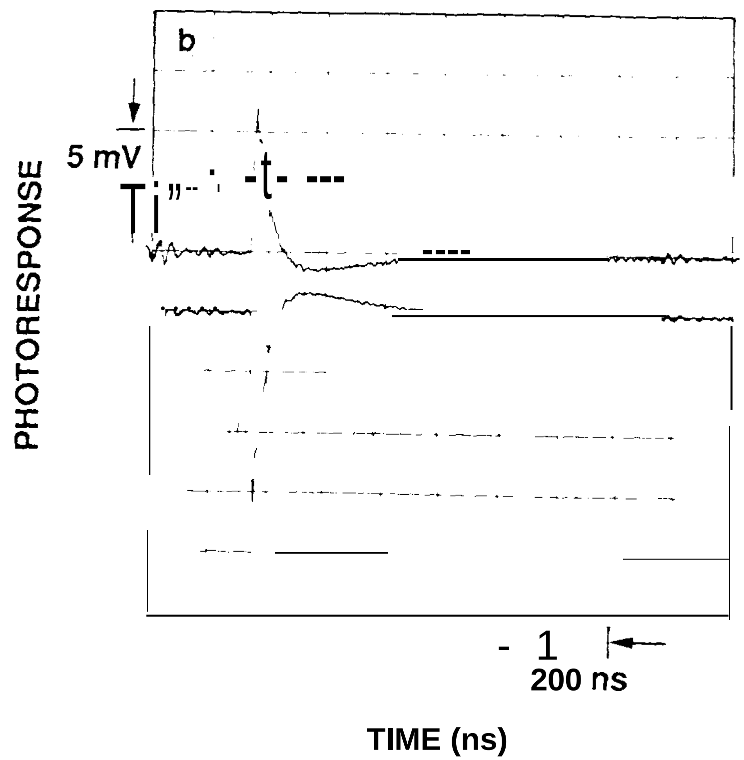
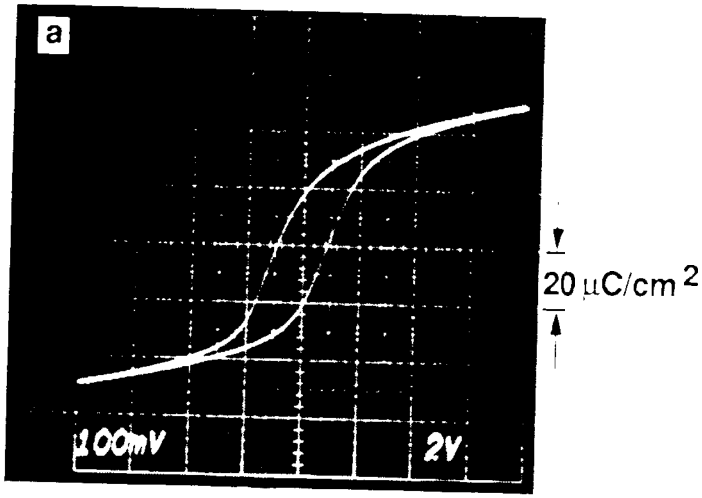
HIGH SPEED PHOTORESPONSE: UNFATIGUED INITIAL STATE



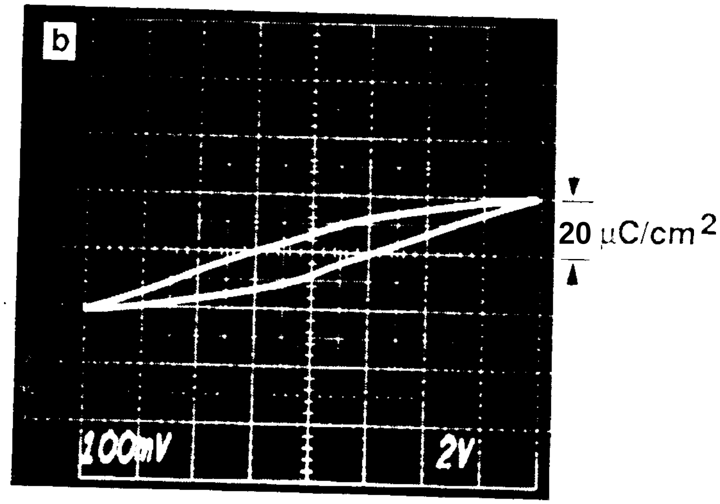
HIGH SPEED PHOTORESPONSE: FATIGUED STATE



HYSTERESIS LOOPS (1 kHz) FATIGUED AND UNFATIGUED STATES COMPARISON



UNFATIGUED INITIAL STATE



FATIGUED STATE (10^{10} CYCLES)

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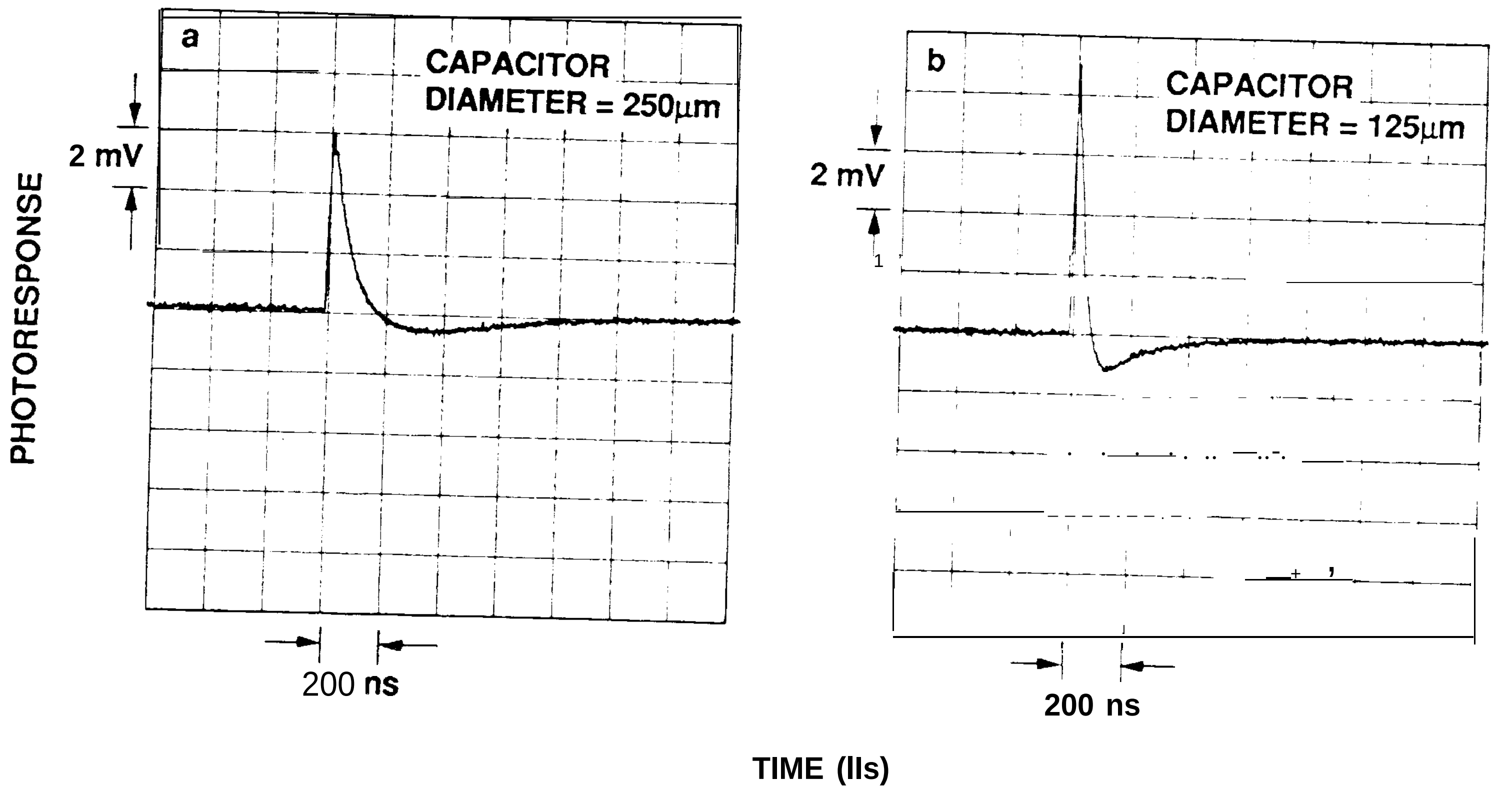
HIGH SPEED PHOTORESPONSE: EFFECT OF CAPACITANCE.



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High Speed Photoresponse Analysis

Poling Polarity	Ratio: $\frac{\textit{Unfatigued Polarization}}{\textit{Fatigued Polarization}}$ determined by hysteresis loop	Ratio: $\frac{\textit{Area under peak, unfatigued}}{\textit{Area under peak, fatigued}}$ determined by photoresponse
positive	2.57	2.57
negative	2.62	2.65

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HIGH SPEED PHOTOEFFECT

- **AREA** UNDER THE PHOTORESPONSE PEAK, A_R
  - $A_R \propto \Delta P_R$, CHANGE OF POLARIZATION ASSOCIATED WITH INCIDENCE OF ILLUMINATION PULSE

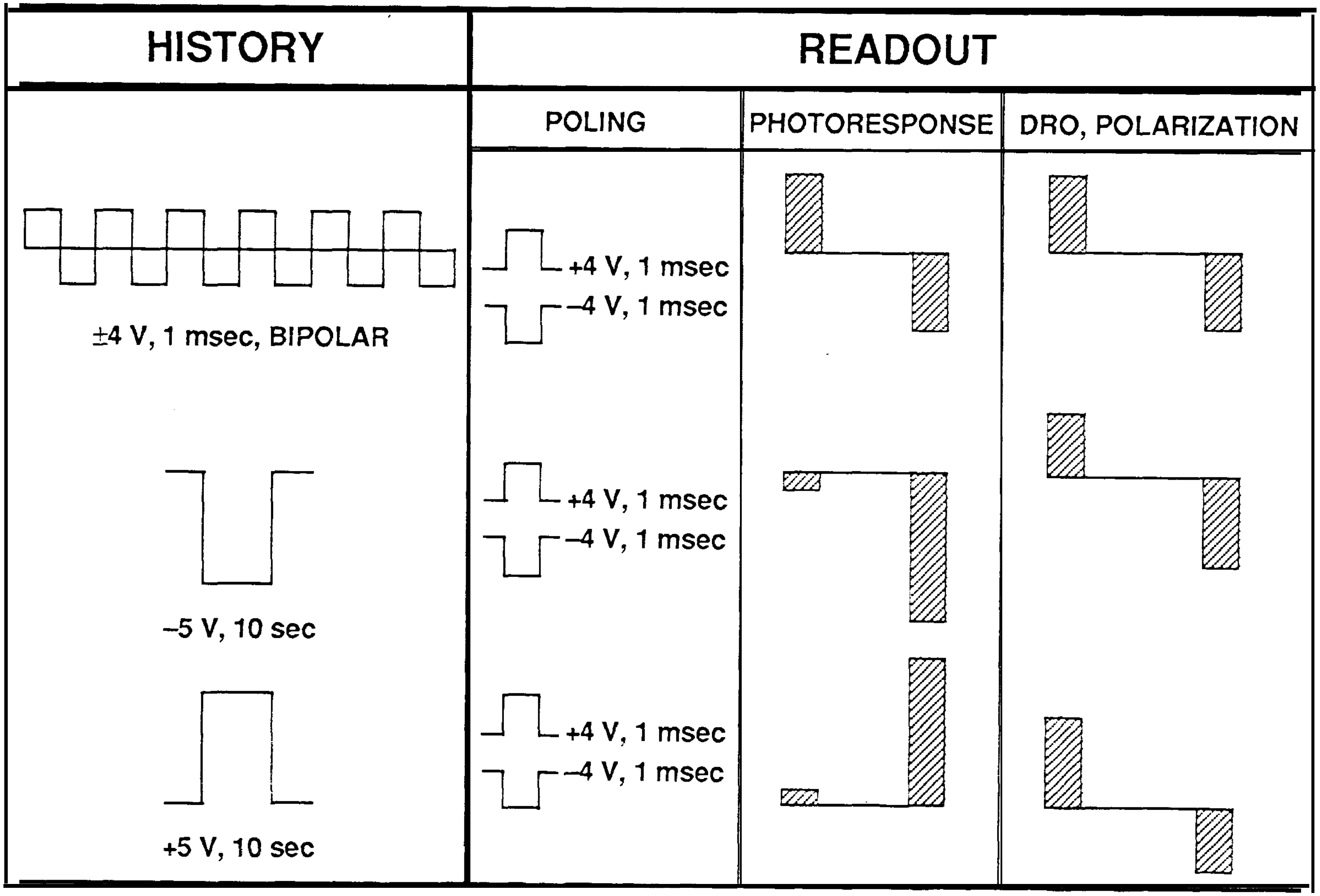
- **ALSO**, $\Delta P_R \propto P_R$, POLARIZATION OF THE **FERRO-**CAPACITOR

  SO $A_R \propto P_R$

- SPEED OF PHOTO RESPONSE α CAPACITANCE

- THE ILLUMINATION PULSE IS NON-INVASIVE .
  THE CHANGE ΔP_R IS FOLLOWED BY AN EQUIVALENT $-\Delta P_R$
  SO THERE IS NO NET CHANGE IN P_R AS VERIFIED INDEPENDENTLY BY USING DRO WITH AND WITHOUT ILLUMINATION

JPL PHOTORESPONSE: PROBING FOR "HISTORY" OF THE FERROELECTRIC CAPACITORS



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CONCLUSIONS:

- **HIGH** SPEED PHOTOEFFECT
  - **AREA** UNDER THE PHOTORESPONSE PEAK, (A_R), PROVIDES AN EXCELLENT NON-INVASIVE, QUANTITATIVE MEASURE OF REMANENT POLARIZATION **(P_R)**
  - SPEED OF PHOTORESPONSE IS DIRECTLY DICTATED BY THE DEVICE CAPACITANCE, THEREFORE, WITH REDUCING **FERROELECTRIC** PIXEL SIZE, THE RESPONSE SPEED BECOMES PROPORTIONALLY FASTER
  - **HIGH** SPEED PHOTOEFFECT REFLECTS SENSITIVELY THE POLARIZATION HISTORY OF THE FERROELECTRIC CAPACITOR
- BANDGAP ILLUMINATION EFFECTS
  - FATIGUED SAMPLES CAN **BE CONDITIONED USING BANDGAP LIGHT**
  - **STEADY PHOTOCURRENT CAN SERVE AS INDICATOR OF CAPACITOR INTERFACE STATUS (S. Thakoor, JAP 75 (10), p. 5409, May 1994)**

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