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

JPL
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AUGUST 10, 1994

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Presented at the International Symposium of Applied Ferroelectrics held August 7-10, 1994 at Penn State Scanticon, State College, Pennsylvania
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
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

SCHEMATIC OPTICAL SET-UP

Nd-YAG Laser 1.064 μm

Atenuator

Beam Splitter

Attenuating Filter

Photodetector

Beam Focusing Lens

DUT (Device Under Test) Mounted on Probe Station
ELECTRO OPTICALLY SWITCHED LASER (LARGE NOISE PICK UP)
ACOUSTO OPTICALLY SWITCHED LASER

LOW NOISE SIGNAL FOR HIGH SPEED PHOTORESPONSE MEASUREMENT
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 SPUTTERDEPOSIT: 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/cm²
    • ILLUMINATION PULSE LENGTH VARIABLE FROM 1-99 sec
    • HYSTERESIS LOOPS OBSERVED AS FUNCTION OF ILLUMINATION

● HIGH SPEED EFFECTS: 532 nm Nd.YAG PULSED LASER
  • PULSE WIDTH ~ 10 ns, POWER .6 mW/µm²
    • PHOTORESPOONSE MEASURED DIFFERENTIALLY ACROSS 50 Ω INPUT IMPEDENCE OF A DSA 602A TEKTRONIX DIGITIZING SIGNAL ANALYZER
PZT FILMS
SOL-GEL DEPOSITED FILMS*

• BASE ELECTRODE: Ti/Pt (1000 Å)
• PZT COMPOSITION (Zr:52, Ti:48)
  18% EXCESS LEAD
• TOP ELECTRODE: DC SPUTTER-DEPOSITED
  SEMITRANSPARENT Pt (~150 Å)
  OPTICAL TRANSMISSION ~30%

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 ~1\mu m

PZT: GOOD OPTICAL TRANSMITTANCE
SURFACE ROUGHNESS ~ 0.2\mu m
EFFECT OF BANDGAP ILLUMINATION COMPARISON UNFATIGUED AND FATIGUED STATE

DOTTED LINE - WITHOUT 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.
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
HIGH SPEED PHOTORESPONSE:
UNFATIGUED INITIAL STATE

PHOTORESPONSE (mV)

10 mV

TIME (ns)

200 ns

HIGH SPEED PHOTORESPONSE:
FATIGUED STATE

PHOTORESPONSE

5 mV

TIME (ns)

200 ns
HYSTERESIS LOOPS (1 kHz)
FATIGUED AND UNFATIGUED STATES COMPARISON

UNFATIGUED INITIAL STATE

FATIGUED STATE ($10^{10}$ CYCLES)
HIGH SPEED PHOTORESPONSE: EFFECT OF CAPACITANCE.
High Speed Photoresponse Analysis

<table>
<thead>
<tr>
<th>Poling Polarity</th>
<th>Ratio: Unfatigued Polarization</th>
<th>Fatigued Polarization</th>
<th>Ratio: Area under peak, unfatigued</th>
<th>Area under peak, fatigued</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>determined by hysteresis loop</td>
<td></td>
<td>determined by photoresponse</td>
<td></td>
</tr>
<tr>
<td>positive</td>
<td>2.57</td>
<td></td>
<td></td>
<td>2.57</td>
</tr>
<tr>
<td>negative</td>
<td>2.62</td>
<td></td>
<td></td>
<td>2.65</td>
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HIGH SPEED PHOTOEFFECT

\[ \text{AREA UNDER THE PHOTORESPONSE PEAK, } A_R \]

\[ A_R \propto \Delta P_R, \text{ CHANGE OF POLARIZATION ASSOCIATED WITH INCIDENCE OF ILLUMINATION PULSE} \]

- ALSO, \( \Delta P_R \propto P_R, \) POLARIZATION OF THE FERRO-CAPACITOR

\[ \text{SO } A_R \propto P_R \]

- SPEED OF PHOTO RESPONSE \( \propto \) CAPACITANCE

- THE ILLUMINATION PULSE IS NON-INVASIVE. THE CHANGE \( \Delta P_R \) 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.
PHOTORESPONSE: PROBING FOR "HISTORY" OF THE FERROELECTRIC CAPACITORS

<table>
<thead>
<tr>
<th>HISTORY</th>
<th>READOUT</th>
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<tbody>
<tr>
<td>±4 V, 1 msec, BIPOLAR</td>
<td>POLING</td>
</tr>
<tr>
<td>-5 V, 10 sec</td>
<td>+4 V, 1 msec</td>
</tr>
<tr>
<td>+5 V, 10 sec</td>
<td>+4 V, 1 msec</td>
</tr>
</tbody>
</table>
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)
ACKNOWLEDGEMENTS

- DR. JANE ALEXANDER, ARPA
- DR. STEVE BERNACKI, RAYTHEON
- PROF. ERIC CROSS, PENN STATE
- DR. P. LARSEN, PHILLIPS, NETHERLANDS
- DR. R. RAMESH, BELLCORE

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