Thermoacoustic Imaging Using Heavy Ion Beams

T. N. Claytor, J. R. Tesmer
Los Alamos National Laboratory
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B. C. Deemer and J. C. Murphy
The Johns Hopkins University
Applied Physics Laboratory

SUMMARY

Ion beams have been used for surface modification, semiconductor device fabrication and for material analysis, which makes ion-material interactions of significant importance. Ion implantation will produce new compositions near the surface by ion mixing or directly by implanting desired ions. Ions exchange their energy to the host material as they travel into the material by several different processes. High energy ions ionize the host atoms before atomic collisions transfer the remaining momentum and stop the incident ion. As they penetrate the surface, the low energy ions ionize the host atoms, but also have a significantly large momentum transfer mechanism near the surface of the material. This leads to atoms, groups of atoms and electrons being ejected from the surface, which is the momentum transfer process of sputtering. This talk addresses the acoustic waves generated during ion implantation using modulated heavy ion beams. The mechanisms for elastic wave generation during ion implantation, in the regimes where sputtering is significant and where implantation is dominant and sputtering is negligible, has been studied. The role of momentum transfer and thermal energy production during ion implantation was compared to laser generated elastic waves in an opaque solid as a reference, since laser generated ultrasound has been extensively studied and is fairly well understood. We found no longitudinal wave at epicenter due to the momentum of the ion beam and sputtered material as is the case with laser ablation. The thermoelastic response dominated in both high and low ion energy regimes since, apparently, more energy is lost to thermal heat producing mechanisms than momentum transfer processes. The signal magnitude was found to vary almost linearly with incident energy as in the laser thermoelastic regime. The time delays for longitudinal and shear waves were characteristic of those expected for a purely thermal heating source. Ion beams appear to offer no significant advantage over lasers as a thermoacoustic source for NDE other than the fact that the ion beams are intrinsically less sensitive to the albedo of the surface.

MASTER

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TIME RESOLVED ELASTIC WAVES GENERATED BY MODULATED ION BEAMS

BRUCE C. DEEMER JOHNS HOPKINS UNIVERSITY
JOHN C. MURPHY JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LAB
TOM CLAYTOR LOS ALAMOS NATIONAL LAB
JOE TESMER LOS ALAMOS NATIONAL LAB

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OBJECTIVE:

- UNDERSTAND THE MECHANISMS OF ACOUSTIC WAVE GENERATION BY MODULATED ION BEAMS
- STUDY ION ENERGY LOSS MECHANISMS
- CHARACTERIZATION OF ION IMPLANTATION PROCESS

OUTLINE

- BACKGROUND
- MATERIAL/BEAM INTERACTIONS
- EXPERIMENTAL
- RESULTS/DISCUSSION
- SUMMARY

LASER GENERATED ULTRASOUND FOR OPAQUE SOLIDS

• ENERGY DEPENDANCE

THERMOELASTIC

- SIGNAL $\propto$ ENERGY
- LOW POWER DENSITY
- SURFACE HEATING

ABLATION

- SIGNAL $\propto$ ENERGY
- HIGH POWER DENSITY
- SURFACE HEATING
- MOMENTUM TRANSFER
- OTHERS

• ANGULAR DEPENDANCE

LONGITUDINAL WAVES

SHEAR WAVES

THEORETICAL PATTERN FOR
LASER THERMOELASTIC REGIME

THEORETICAL PATTERN FOR
LASER ABLATION REGIME

ION PENETRATION AND ENERGY LOSS PROFILES

THEORETICAL RANGE DISTRIBUTION OF BORON IN SILICON

DEPTH DISTRIBUTION OF ENERGY DEPOSITED INTO ATOMIC PROCESSES FOR BORON IN SILICON

REF. H. RYSEL AND I. RUGE, ION IMPLANTATION

ION BEAM FACILITIES

LOS ALAMOS

ENERGY RANGE 1-15MeV

APPLIED PHYSICS LAB

ENERGY RANGE 1-10KeV

DETECTOR/SAMPLE ASSEMBLIES

PZT TRANSDUCER

ADVANTAGES:
HIGH SENSITIVITY

DISADVANTAGES:
SLOW TIME RESPONSE
BULKY

PVDF TRANSDUCER

ADVANTAGES:
FAST TIME RESPONSE
EASY TO WORK WITH

DISADVANTAGES:
LOW SENSITIVITY

RESULTS

- Al (12.7mm THICK)
- PVDF TRANSDUCER

TIME RESOLVED DATA

- SILICON ION SOURCE
 - SIGNAL VERSUS ANGLE
 - SHEAR VELOCITIES
 - CALCULATED** VERSUS ION
GENERATED WAVEFORMS
- GOLD ION SOURCE
 - SIGNAL VERSUS ANGLE
 - CALCULATED** VERSUS ION
GENERATED WAVEFORMS

** PROVIDED BY DR. JIM SPICER FROM HIS PHD THESIS, JOHNS HOPKINS
UNIVERSITY 1991

ENERGY DEPENDANCE OF SIGNAL

LOG ENERGY VERSUS LOG SIGNAL MAGNITUDE

OFF EPICENTER WAVEFORMS

ANGULAR DEPENDANCE OF SIGNAL

SHEAR VELOCITIES VERSUS DISTANCE FROM EPICENTER

OBSERVED VERSUS CALCULATED WAVEFORMS

PULSE SHAPE

ANGLE MEASUREMENT

OBSERVED VERSUS CALCULATED WAVEFORMS

HIGH ENERGY SILICON IONS

$\theta = 0^\circ$

CALCULATED*

$\theta = 25^\circ$

$\theta = 45^\circ$

* FROM JIM SPICERS PHD THESIS JOHNS HOPKINS UNIVERSITY 1991

OBSERVED VERSUS CALCULATED WAVEFORMS

HIGH ENERGY GOLD IONS

$\theta = 0^\circ$

CALCULATED*

$\theta = 25^\circ$

$\theta = 45^\circ$

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ANGULAR DEPENDANCE OF SIGNAL

12MeV GOLD IONS

1uS PULSE

12.7mm Al SAMPLE

PVDF TRANSDUCER

RESULTS

- Cu (.8mm THICK)
- PZT TRANSDUCER

TIME RESOLVED DATA

- ION (LOW ENERGY 1-10KeV)
- ION (HIGH ENERGY 1-15MeV)
- LASER (THERMOELASTIC REGIME)
- SIGNAL MAGNITUDE VERSUS ENERGY
- OFF EPICENTER

SUMMARY

- ACOUSTIC SIGNALS WITH CHARACTERISTIC TIME DELAYS HAVE BEEN OBSERVED
- THERE IS A STRONG SIMILARITY BETWEEN THE ION ACOUSTIC DATA AND LASER GENERATED ULTRASOUND
- LARGE LONGITUDINAL SIGNAL AT EPICENTER HAS NOT BEEN DETECTED

FUTURE WORK

- COMPLETE LOW ENERGY ION MEASUREMENTS WITH PVDF TRANSDUCER
- DIFFERENT TYPES OF MATERIALS
- FLAW DETECTION
 - GRAIN BOUNDARIES
 - CRACKS, HOLES
 - IMPURITIES
 - LAYERS OR FILMS