Laser Diagnostics

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Laser Diagnostics in a Nutshell

• Shine a laser beam on a subject
• Modulate/manipulate beam to produce useful patterns
• Detect light from reflected subject, and extract meaningful info from patterns
Laser Inspection

- Miniaturization of circuits and need for precise measurements drives laser-based inspection market
- Laser is well suited:
  - High resolution
  - Various wavelengths can be selected in accordance with material under investigation
- Can be divided into two segments
Laser Inspection

1. Defect and contamination location in semiconductor field
   • Scattering, absorption and ultrasonic techniques
   • sizes detectable depend on the wavelength used

2. Macroscopic quality determination
   • interferometry, shearography and holography using visible wavelengths
Scattering

- Inspection Area scanned by laser light
- Contaminants scatter light
- Scattered light polarization characteristics differ according to the contaminant
Scattering

a) Silicon crystalline planes are slipped very close to each other
b) And c) show typical scratches
Scattering

- Detectable Particle Size
  - from .35\(\mu\)m to .20\(\mu\)m

- Detectability
  - Will catch between 90-95% of particles in particle size range
  - Can increase number of passes for slightly better detection

- Speed
  - Around 7 minutes to scan 1m\(^2\) area

HORIBA : Reticle/Mask Particle Detection System/PR-PD2
Scattering

• Today’s Si fabrication processes need even higher resolution
• Defects too small show up as fuzzy dot. Ambiguity as to specifics of defect
• Modern defects are getting smaller and more critical
• 488 nm Argon lasers are being used, and work is under way to extend this technology to .13\(\mu\)m design rules
• Industry is reluctant to take painful ($$) step towards SEM and TEM-based inspection
• Many full-wafer SEM’s in use and under review
Scattering

• TEM image of GaAs-Si interface (8x10^6 X). Lattice mismatch at interface shows as V-shaped defects
• Laser scattering will not disappear. Its high speeds are good for tool monitoring applications.
Ultrasonic

- Generation and detection of ultrasound with lasers
- Easy to inspect complex shapes
- Popular in Aerospace to determine stress on parts
- Very generic and can be applied to metals, polymers and composites
- Detects porosity, delaminations or foreign matter
- Traditional ultrasonic testing is transducer based
  - Slow, requires water coupling
  - Very complex
Ultrasonic

- Generating laser produces ultrasonic wave normal to surface
- Mirror scans lasers across surface
- Ultrasonic echoes do not require laser beam to be normal to surface
- CO$_2$ laser generates ultrasonic pulse in sample
- CW laser interferometer detects the small displacements generated where the ultrasonic pulse reaches the surface
Laser Ultrasound

- Lasers are effective at generating ultrasound
- Laser ultrasonic receivers have some problems
  - Most ultrasonic receivers are interferometers
  - Can not process speckled beams from rough surfaces
  - require exact path length matching for linear signal detection
Laser Ultrasound

• Solutions:
• Two wave mixing
  – the photorefractive medium acts as an adaptive beamsplitter:

no path-length stabilization is required to maintain this condition
• Reference beam interferometer with photo-emf detector
• the speckled signal beam interferes with the reference beam in a photorefractive material, producing a spatially modulated conductivity pattern
• Small modulation of surface motion from signal causes vibration of free-carrier grating, inducing AC current
• GaAs lasers can use a bandwidth of 100KHz, and can measure samples moving faster than 20m/s
• The upper limit on the ultrasonic signal processing bandwidth is determined by the recombination rate, which is about 80 MHz in conventional semi-insulating GaAs
Ultrasound Examples

- mid-fuselage section for the F-22 Raptor
- Made of composite materials
- Structures made of these materials are preferred because of their high strength-to-weight ratio, durability, stiffness, and overall suitability for high-performance weapon systems.
- They require an unprecedented level of testing due to the high performance of the aircraft
Examples

- http://www.ultrasonics.ktu.lt/interfr.htm
Moire Interferometry

- A grating is deposited on the surface of the specimen using photolithography
  - Pitch of 5?
- Can obtain sub-micron accuracy
- Laser beams illuminate surface
- Two of the diffracted beams from the gratings are collected and interfered producing a fringe pattern
Moire Interferometry

http://www.packaging.buffalo.edu/moire0.html
Moire Interferometry

• based on four-beam arrangement
• three adjustable mirrors, a light source (10 mW Helium Neon laser), beam collimating and imaging optics.
• After passing through a spatial filter, light from the laser is expanded and collimated using a lens
• half the incident beam B1 impinges directly on the specimen surface while the other half B2 impinges on the mirror M3 and then reflects to the specimen in a symmetrical direction to form a virtual (reference) grating
• This virtual grating interacts with the vertical set of lines of the specimen grating to form a moiré fringe pattern which is recorded using a CCD camera (u-displacement field)
• virtual grating formed by the mirrors M1 and M2 interacts with the horizontal set of lines of specimen (v-displacement field)
Overview of the optical system for moire interferometry (a), and optical arrangement for $u$ and $v$ displacement measurement (b).
Moire Interferometry

- Strain analysis
Moire Interferometry

Displacement fringe pattern produced after a crack is formed in a laminated composite

After software analysis:

Distribution of shear strain in laminated composite (peak-valley value = 1.35%)
Twyman-Green interferometer

- Monochromatic point source S shines on principal focus of lens L1
- Divided by glass plate P1
- Reflected from plane mirrors M1 and M2, focused on S2 by lens L2
- Adjusted until images reflected by two mirrors coincide
- Recombined waves are exactly parallel, with constant phase difference across the entire field of view
• Any surface irregularity will cause a fringe pattern
• The mirror in a) will produce the fringe pattern in b)
• The intensity is maximum when the path difference is zero or differs by an integral number of wavelengths (bright fringes)
• Dark lines where the troughs of the waves from one beam coincide with the peaks of the waves from the other beam
• Since mirror $M_2$ is assumed to have a slightly irregular surface, the emerging wavefront $W_2$ is slightly deformed. With the eye at $S'$, the observer will see fringes which arise because of the interference between the plane reference wave $W_1$ reflecting from the plane mirror $M_1$ and the slightly deformed wave $W_2$ reflecting from mirror $M_2$.

• Fringes show contour map of $M_2$'s surface.
Twyman-Green Interferometry

• Good for testing optical equipment
  – Glass flatness
  – Lens aberrations

To test lenses, M2 is replaced by lens and convex mirror
Twyman-Green Interferometry

- Typical fringe patterns
References

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