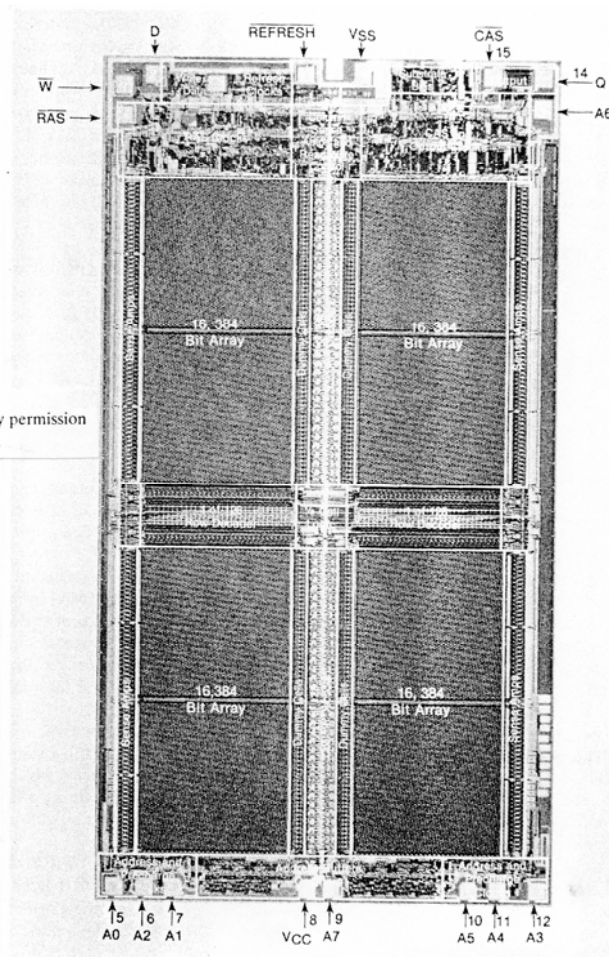


Lasers Defect Correction in DRAM's

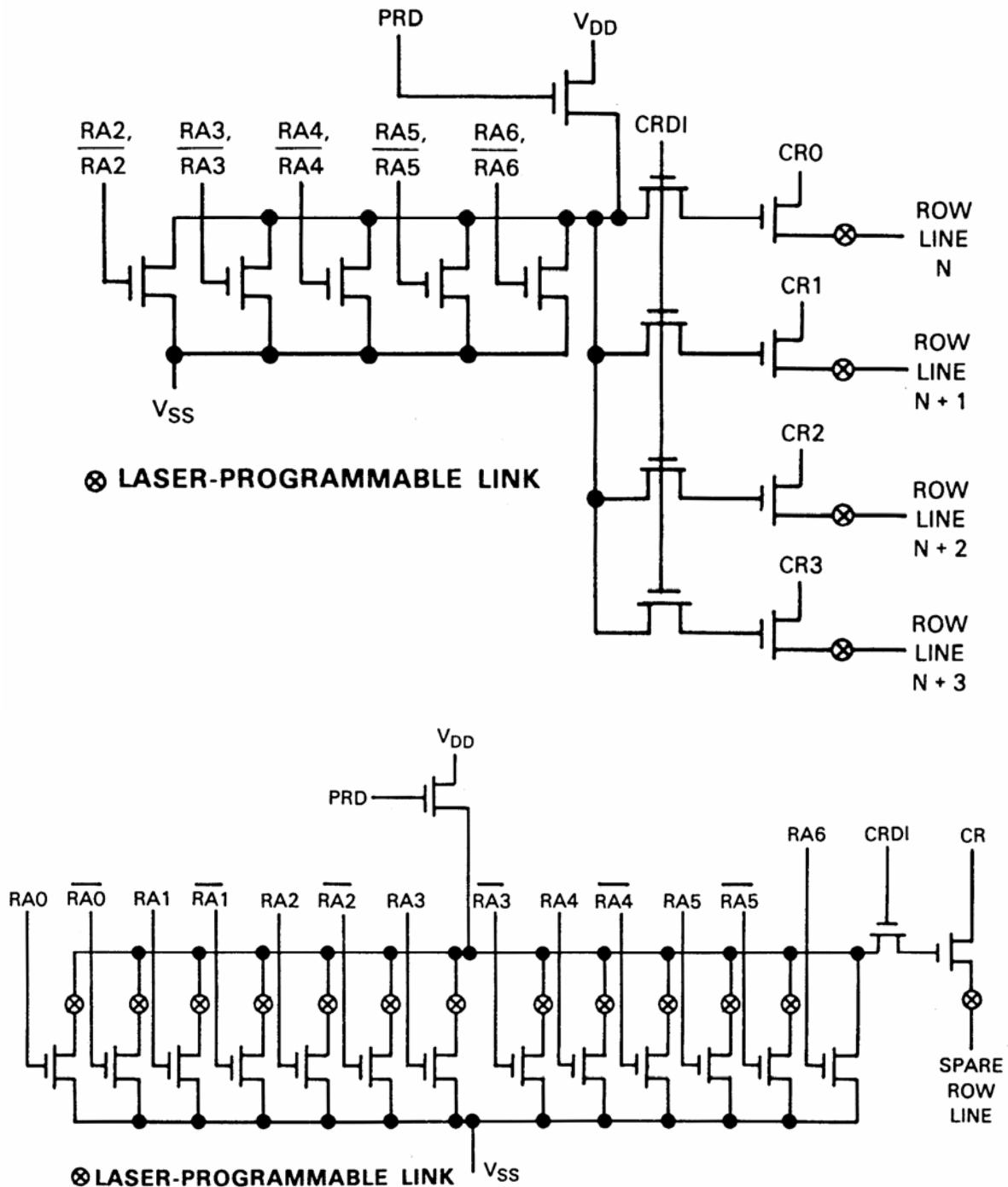
- Problem: very hard to make memory chips with no defects
- Memory chips have maximum density of devices
- Repeated structures all substitutable
- Create spare rows and columns of memory
- Substitute in working column/row for defects
- Use laser cutting to do this
- Started with 64K DRAM's in 1979
- Difficult to build DRAM's without this
- Now also important for embedded SRAM/DRAM
- Embedded rams typically $> 256K$
Note typical SRAM has 6 transistors/DRAM only 1
- Very Important for Systems on a Chip (SoC)

64K Dynamic RAM die photograph. (Reproduced by permission of Motorola Inc.)



Laser Defect Corrections in DRAM's

- DRAM's have spare rows & columns
- After testing locates defective bit cut off that column
- With cuts program in that column address in spare
- Typically have 4 spares in each half a DRAM



Poly Silicon Cuts (Fuses)

- Use laser to cut polysilicon lines
- Melts back the poly
- Some damage to coverglass
- Each die test, defects determined, and laser cut
- Commercial machines >\$750- 2,000K do this (e.g. ESI)

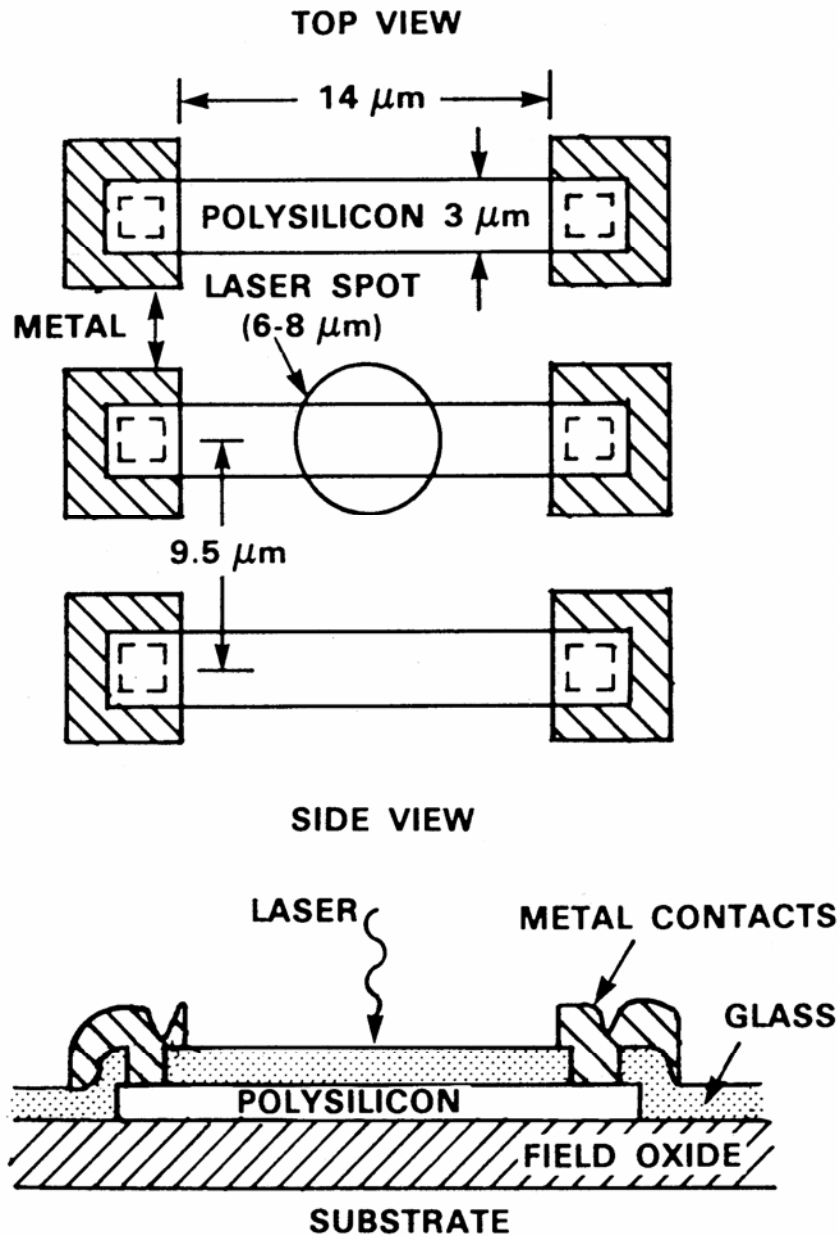
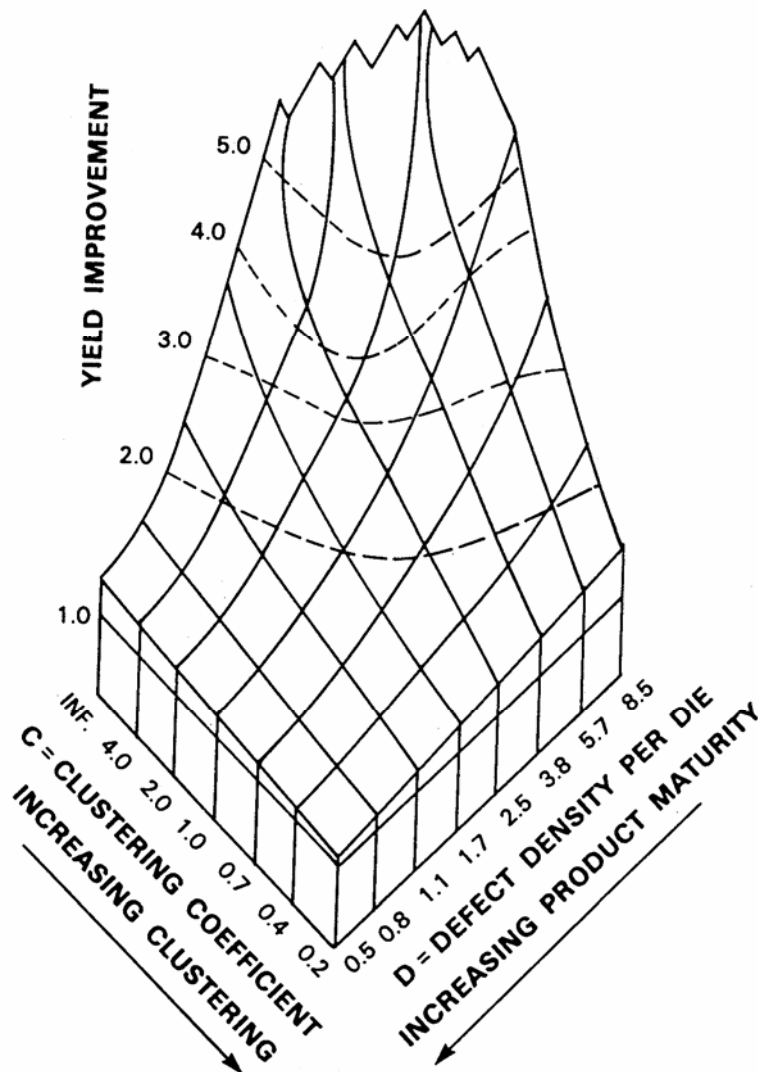


Fig. 27. Polysilicon laser cut point (fuse). (After Wells and Stewart [70].)

Yield Improvement on DRAM's With Laser Repair

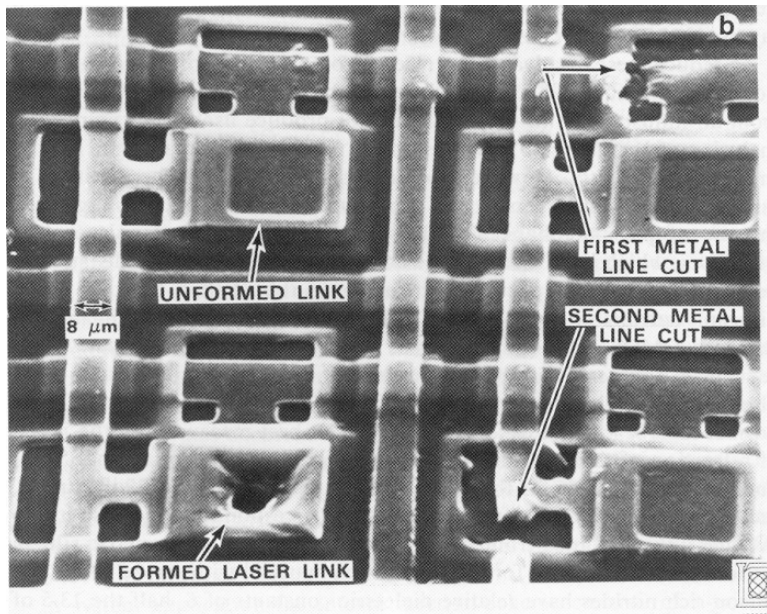
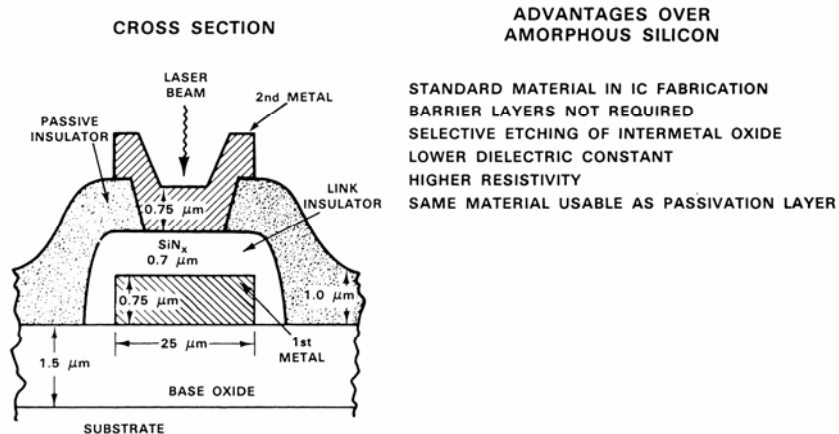
- New DRAM's uses highest density Microfab process available
- Currently generation using 0.13 micron 5/6 level metal
- Typical new DRAM design has low yield ~ 1-3%
- Cost of production independent of yield
- Hence if can increase yield by 100% drastically cut costs
- Yield follows Negative Binomial Statistics (defects cluster) has a "Culster Coefficient" that measures this
- Average defects may be 2-5 per chip but a few have only 0-1
- Can get 2-4 times improved yield



Vertical Laser Silicon Nitride Links

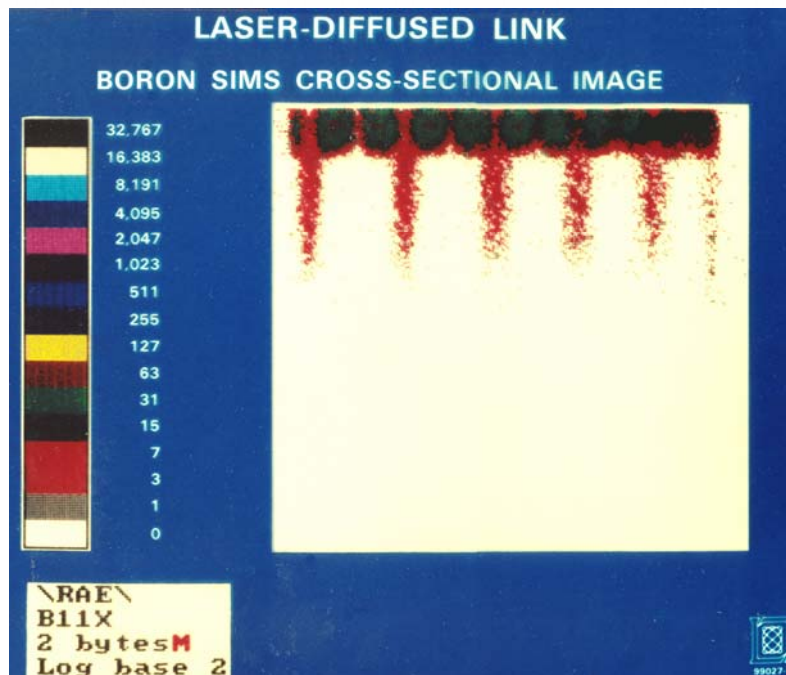
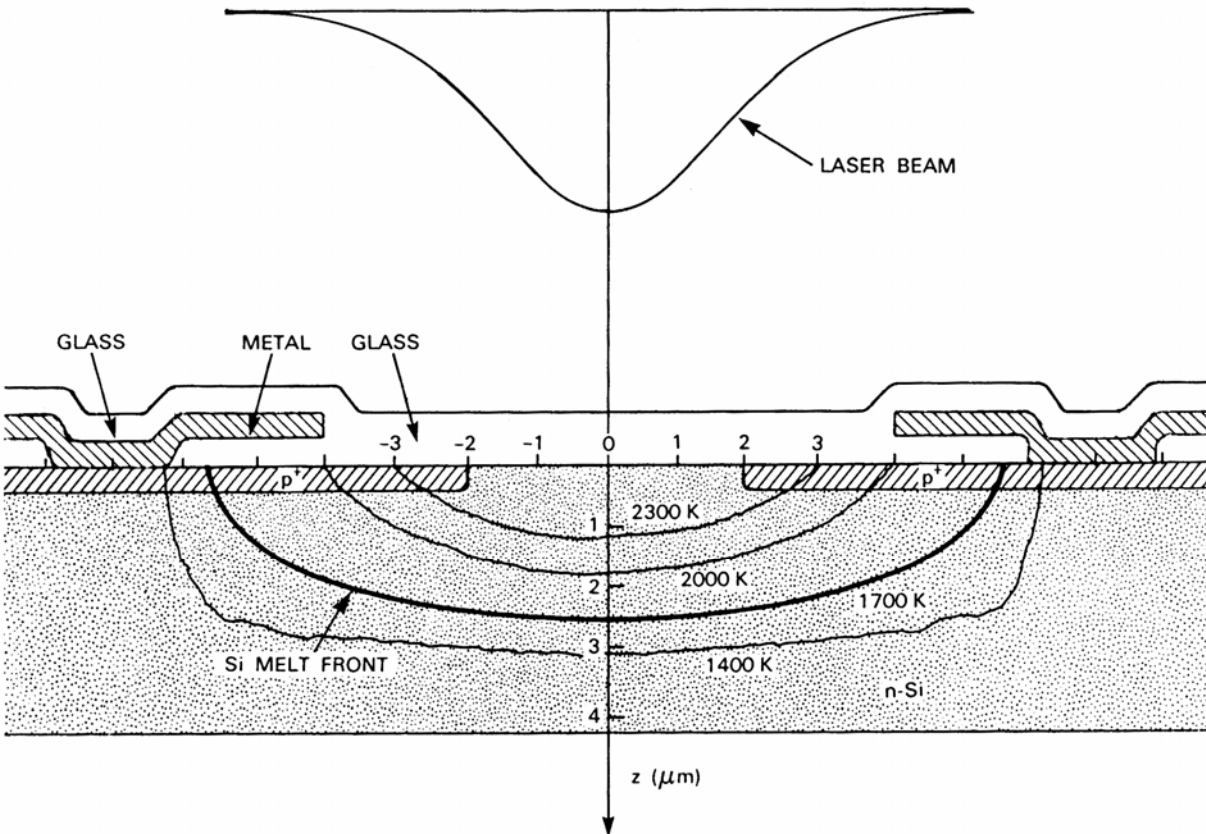
- Vertical laser links used to make permanent connections
- Metal 1 over metal 2 with silicon rich Silicon Nitride SiN_x between
- Laser melts top metal creates Al Si short 1st to 2nd metal
- Unconnected $R > 1G\Omega$, Laser Linked $\sim 1-2\Omega$
- Argon laser focused on pad top $\sim 1 \mu m$ spot, 1 msec at 1 W
- Structure allows cutting of lines & removal of the link if needed
- Could carry > 1 mA current to power cells
- Designed to route signal interconnecting circuit blocks
- Developed MIT Lincoln Lab 1981: Chapman, Raphael, Herdon
- Used to create worlds first wafer scale device
DSP integrator on 5x5 cm substrate 1983

SILICON NITRIDE LASER LINK



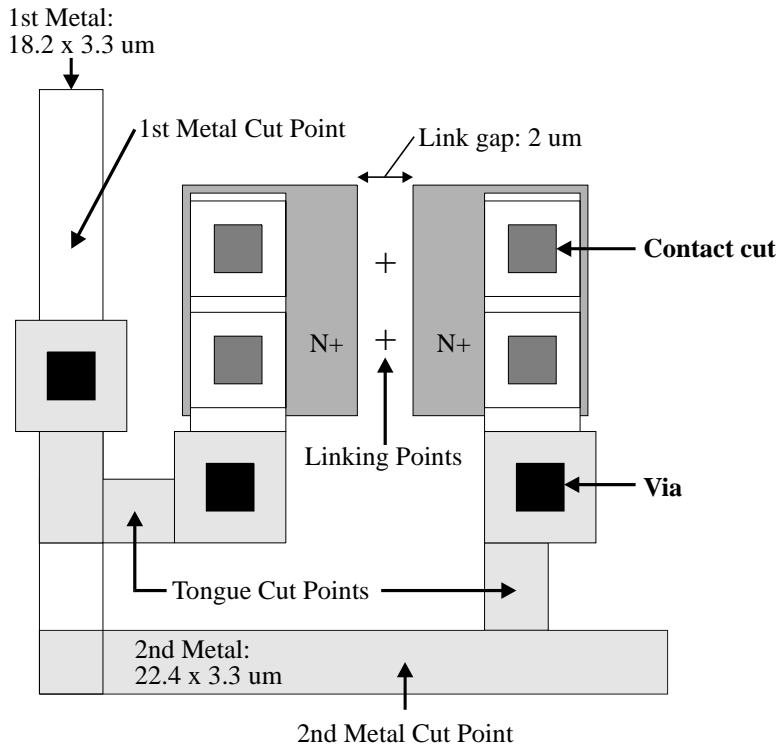
Lateral Laser Diffused Link

- Designed to use Standard CMOS process
- Two doped areas separate by min allowed gap
- Laser pulse melts silicon, causes dopant to cross gap
- Creates permanent connections
- Can see dopant across gap using Scanning Ion Microscopy

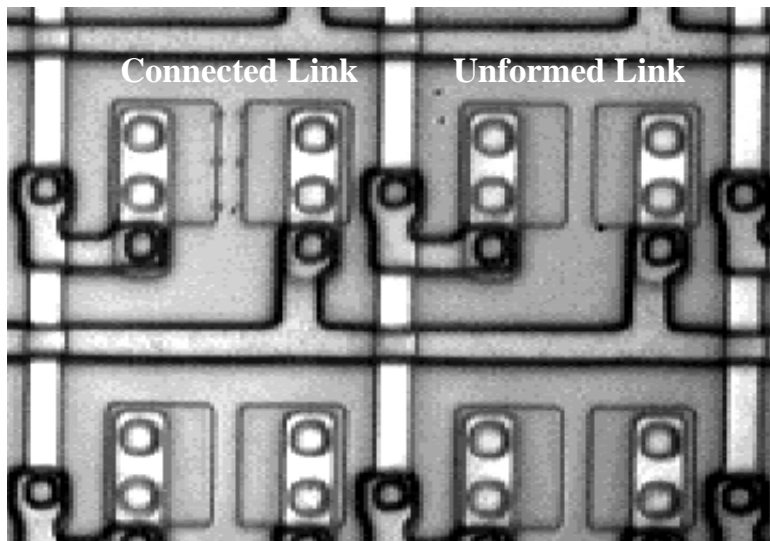


Laser Diffused Link

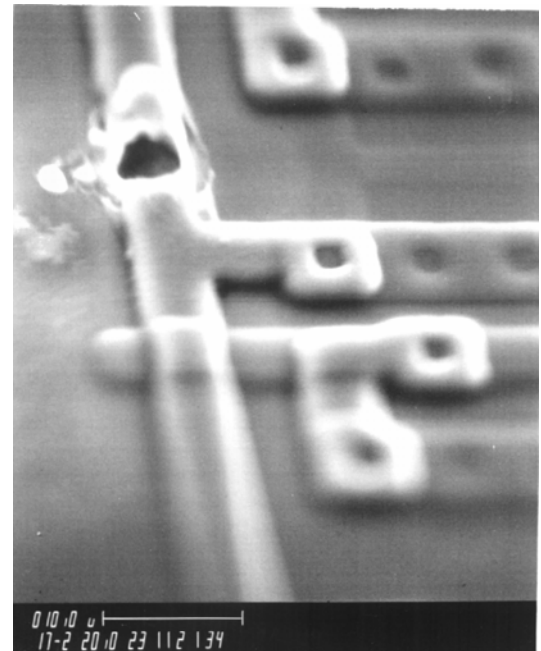
- Made in structures from 5 micron to 0.5 micron CMOS
- Developed at MIT Lincoln Lab 1986 by G. Chapman, R. Raphael, J. Canter
- Makes ~50-100 ohm resistance connection
- Implemented in wafer scale projects at Lincoln Lab and SFU



Laser Diode Link Layout
2 micron CMOS



Laser Linked Structures



SEM of Link and Cut

Other Laser Microsurgery Tools

Metal short to P Tub

- Laser pulse hits metal to diffusion via
- Melts Al and spikes through n+ to P tub
- Makes ~30 Kohm resistance connection

Laser Assisted Deposition

- Can write metal/Poly Si lines
- Using laser as localized energy source
- Must also have local etching/dielectric removal

Metal Laser vertical links: MakeLink

- Creates metal connections between two metal layers
- Create by Joe Bernstein at MIT Lincoln Lab
- Melts metal: breaks connections between insulators
- Resistance ~ 10 ohms

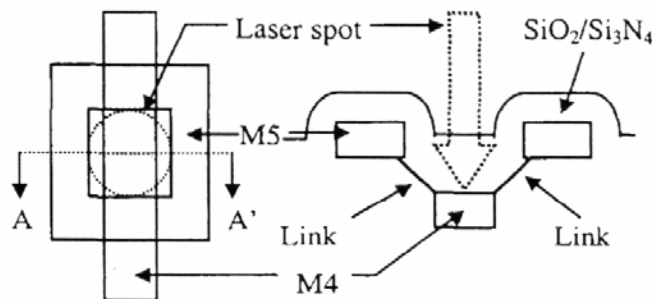


Fig. 1. Schematics of laser-induced vertical metal link, (a) top view and (b) cross section A-A'.

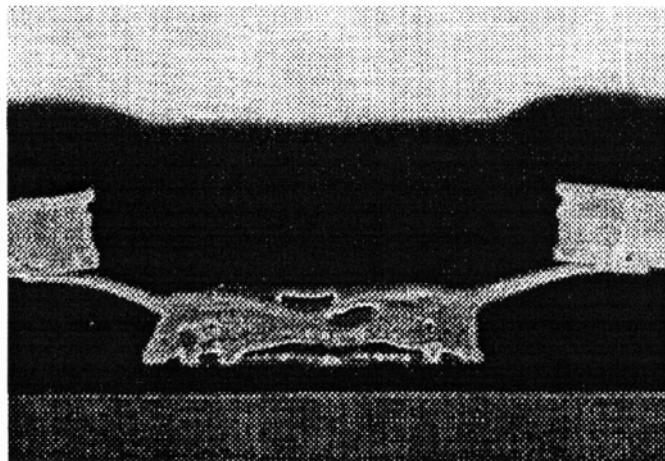
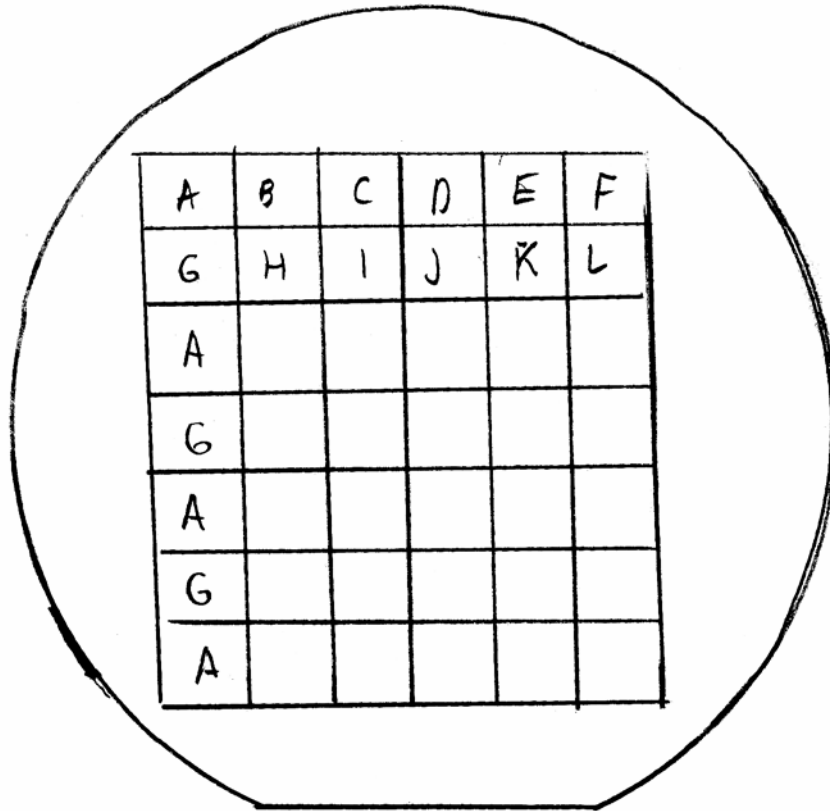


Fig. 3. FIB cross-section of a vertical link between the lower metal and two sides of the hole in upper level metal.

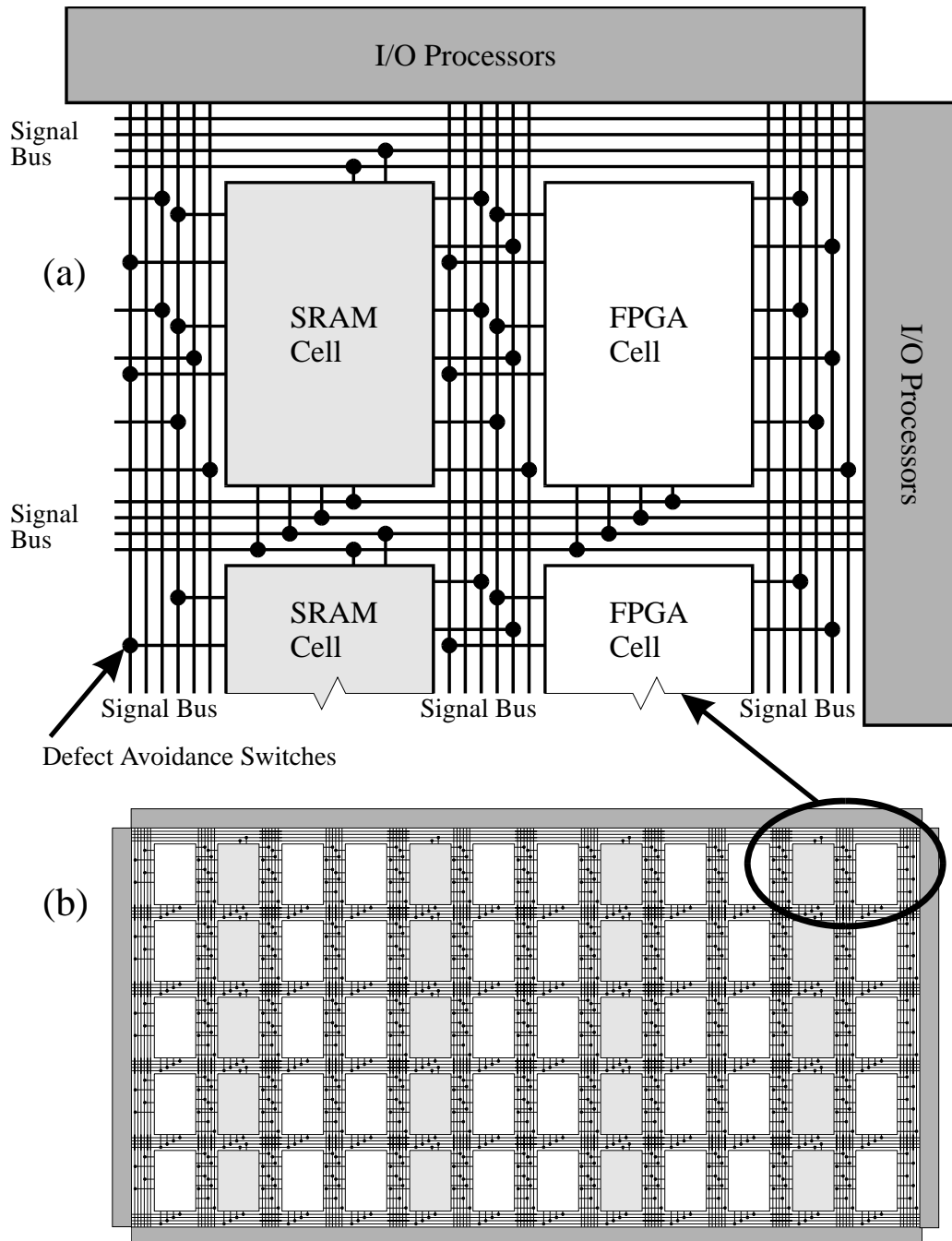
Large Area/Wafer Scale Silicon Systems

- Large area structures: problem is yield declines with square of area
Hence 10x area reduces yield by 100 times
- Break system into repeated circuit blocks cells
- Want many cells because some are defective
but design those for relatively high yield



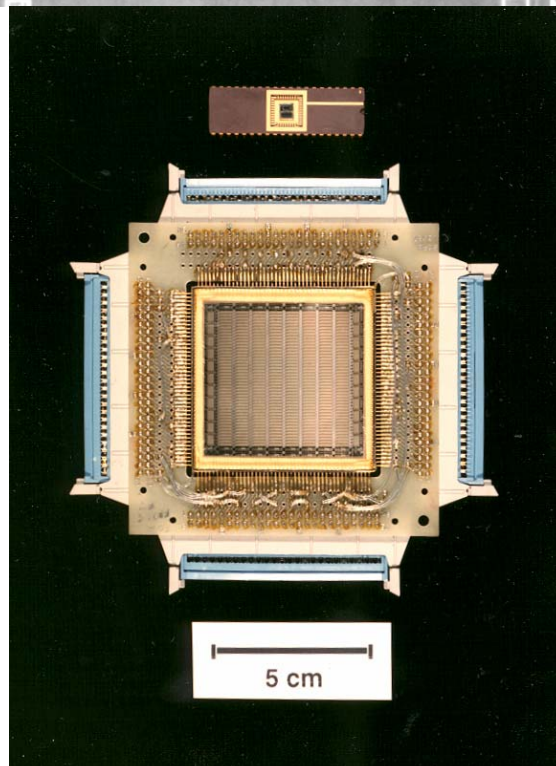
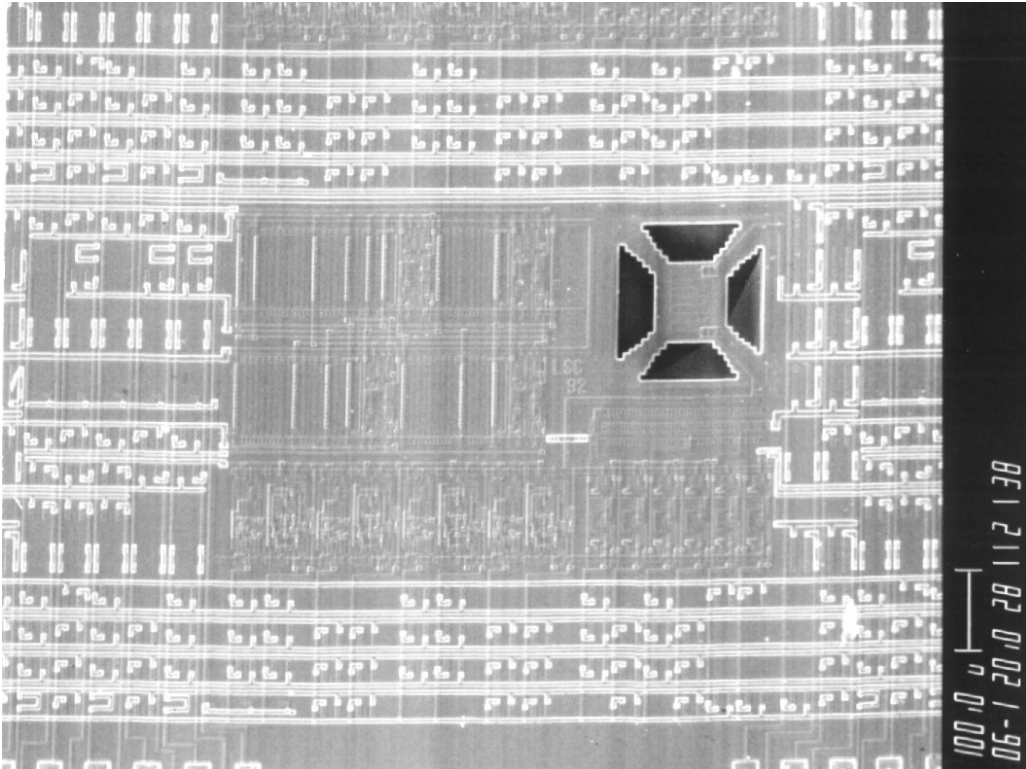
Large Area/Wafer Scale Silicon Systems

- Surround with a bus structure
- Use switches (laser links) to make connections
- Laser links make permanent connections – very fast
- Important for combinations of Transducers & links



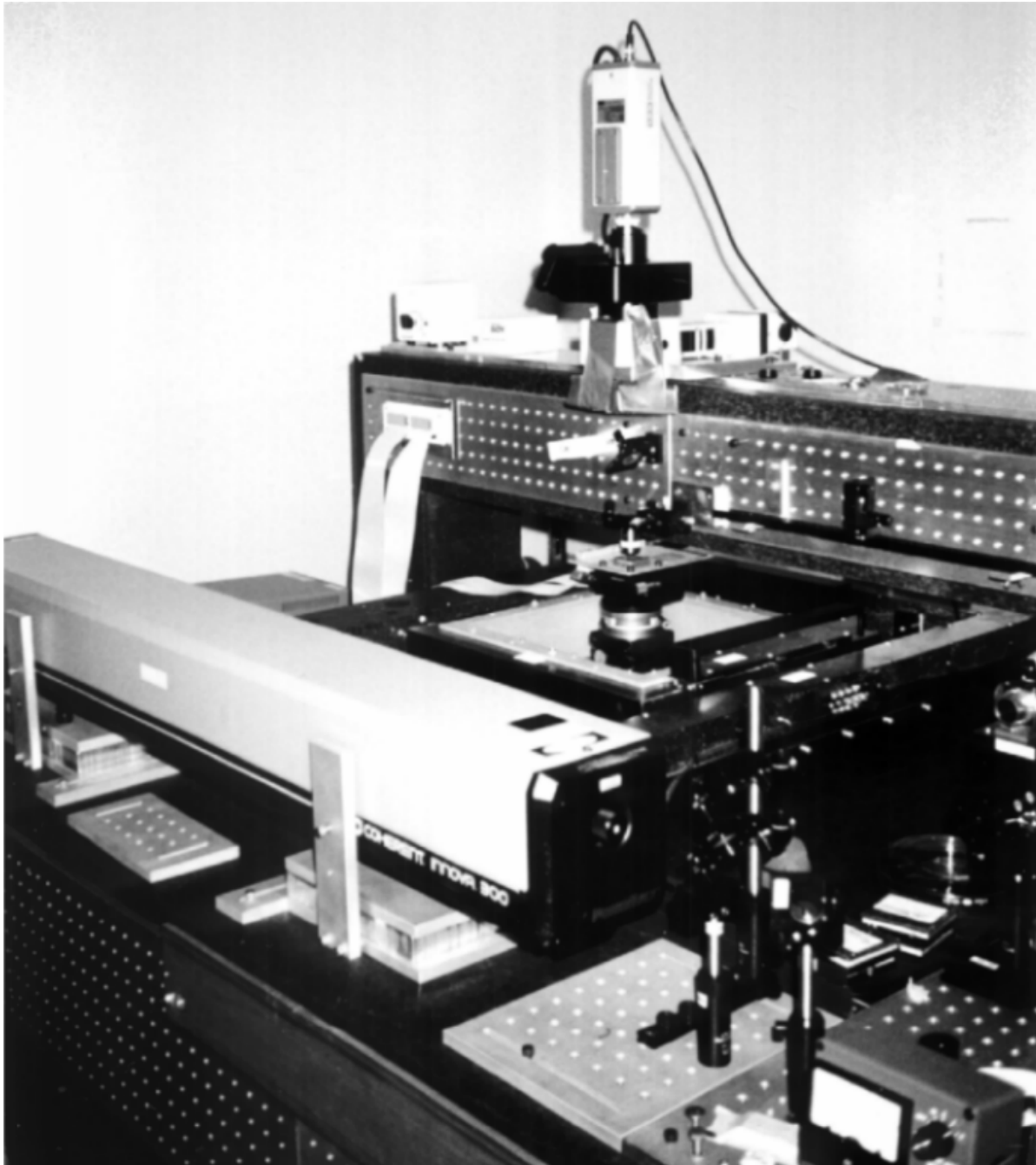
Large Area/Wafer Scale Silicon Systems

- Several Designs of Wafer Scale Devices at MIT Lincoln Labs
- At SFU made Laser area Transducer Arrays
- Combine micromachining and WSI techniques



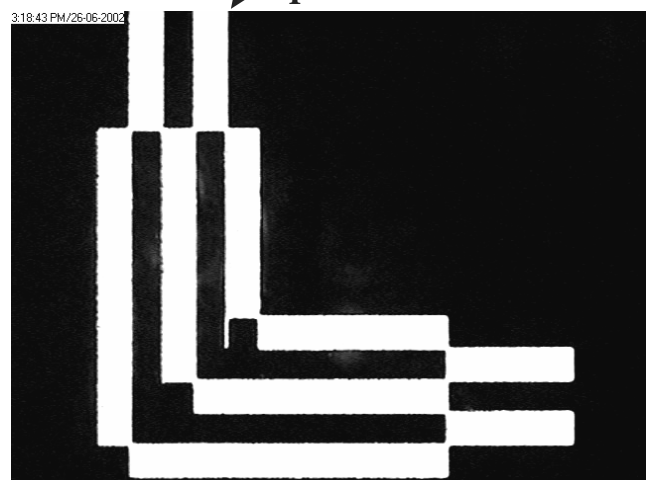
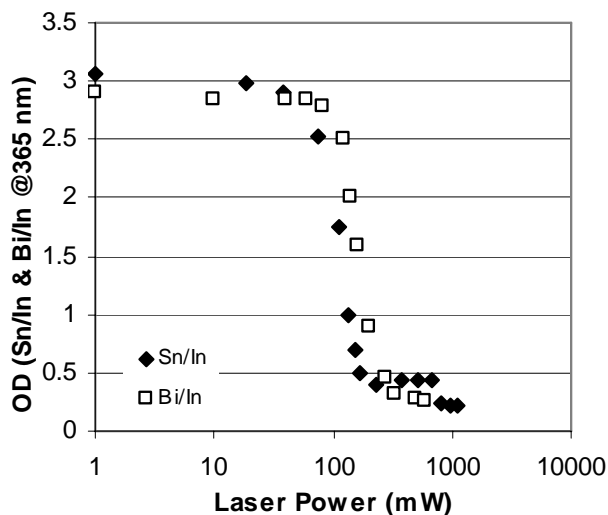
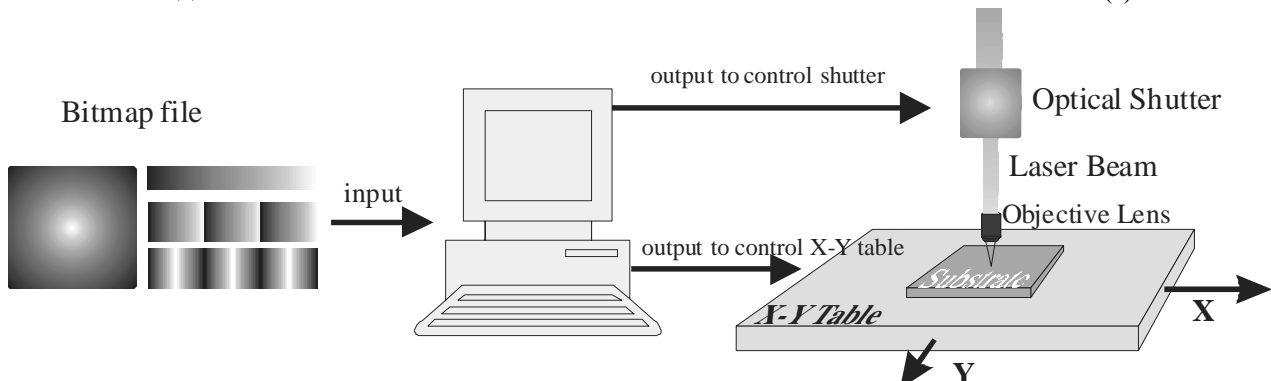
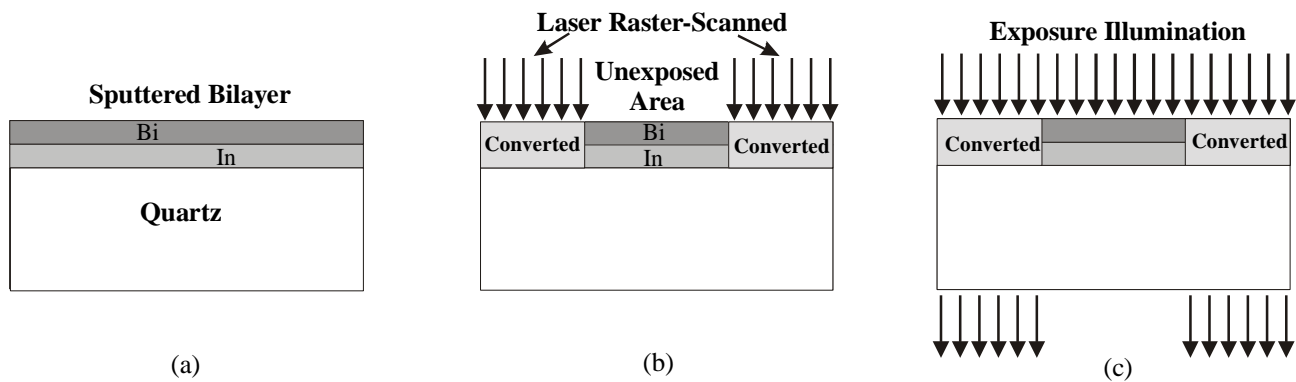
Laser Linking/Microsurgery Table

- Table moves circuit under focused laser spot
- Position done by laser interferometry: 0.02 micron positing
- Microscope/TV system shows circuit
- Electro-optical shutter gives control of laser pulse duration



Laser Direct Write Photomasks

- Photomasks create the patterns used in microfabrication (IC's)
- Patterns projected on wafer to make circuits
- Creation of regular masks expensive
- Requires several exposure, development and etching steps
- Created a direct laser write photomask
- Put down ~15-100 nm film of Bismuth & Indium
- When hit with laser turns transparent: change from 3OD to 0.2 OD
- When laser hits Bi/In or Sn/In film creates transparent oxide



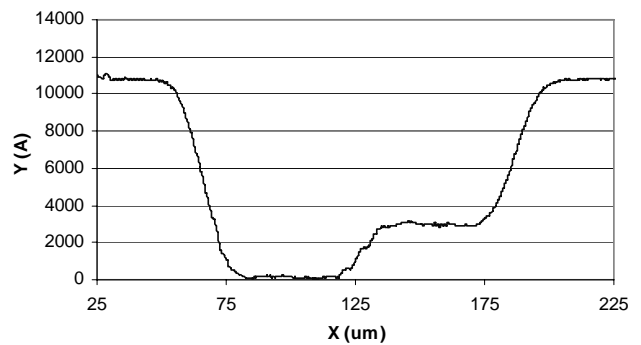
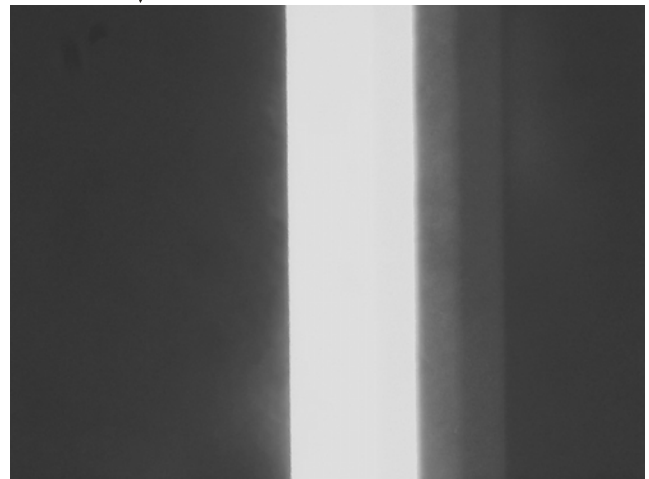
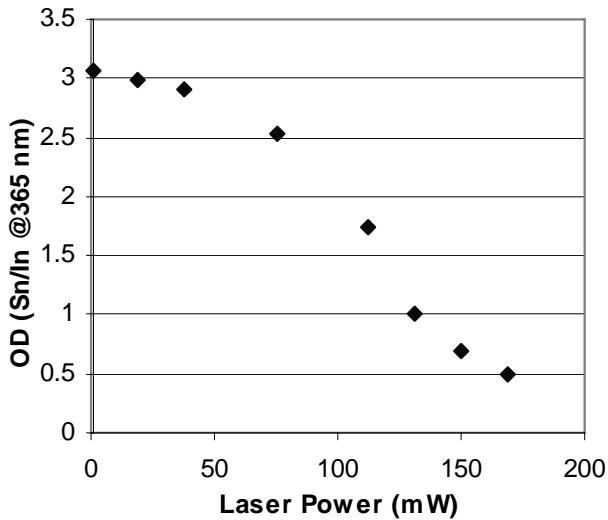
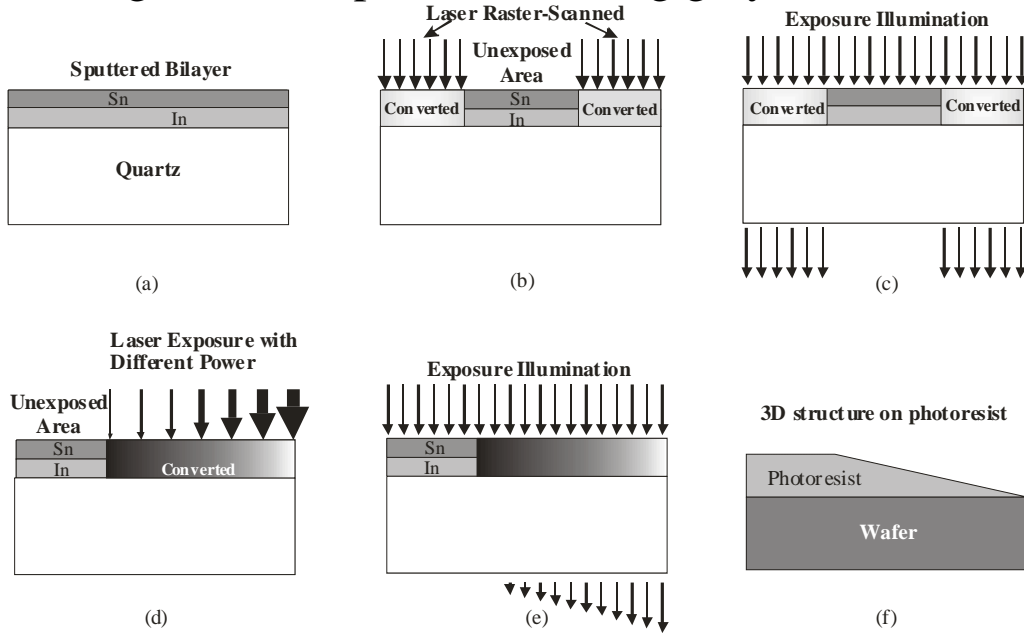
Bimetallic Grayscale Photomasks

Grayscale masks contain many gray levels

When hits photoresist developed thickness function of exposure

Can create 3D microfabricated devices (eg. Microoptics, MEMS)

Better OD range and cheaper than existing grayscales



Low Power Laser Applications: Alignment & Measurement Circularizing Laser Diodes

- Laser diodes are important for low power applications
- But laser diodes have high divergence & asymmetric beams
- Get 5-30° beam divergence
- Start with collimator: high power converging lens: stops expansion
- Then compensate for asymmetry
- Use cylindrical lens beam expander
- Cylindrical lenses: curved in one axis only unlike circular lenses
- Expands/focuses light in one direction only (along curved axis)
- Results in circular collimating beam

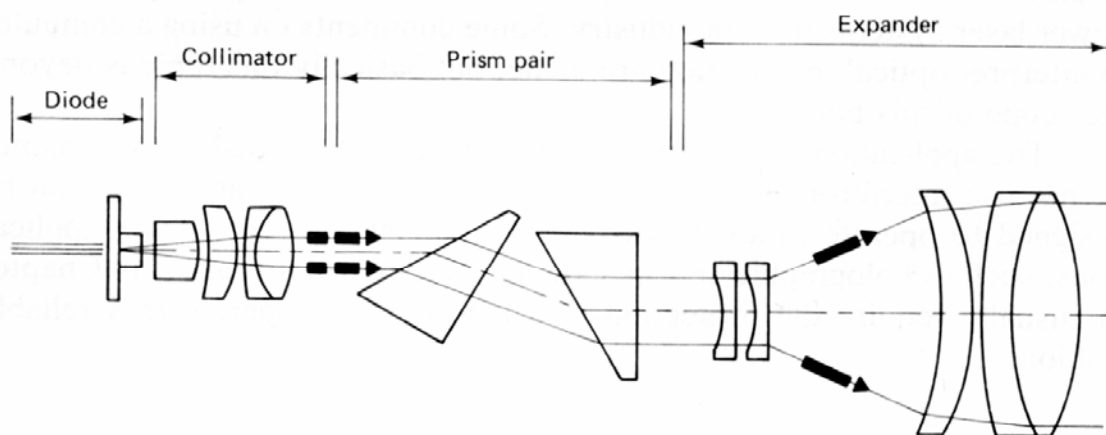
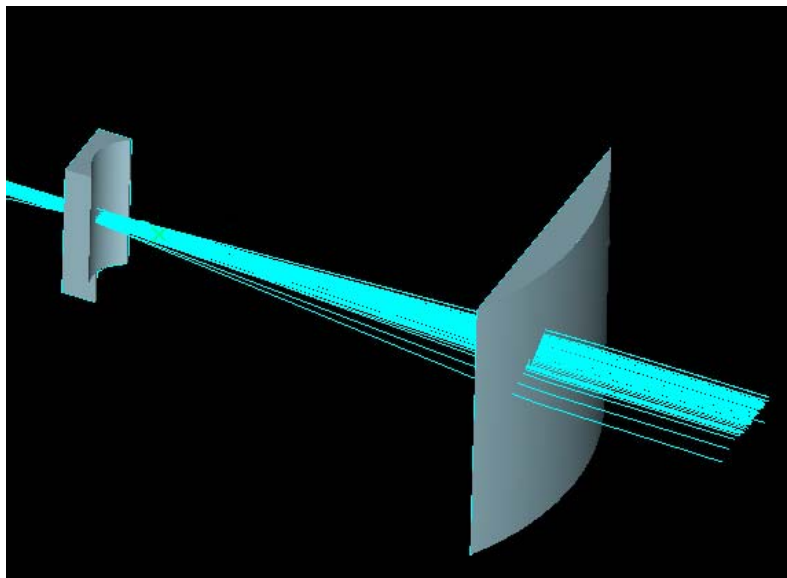


Figure 9-1 Optics used to circularize and collimate beam from diode laser. (Courtesy of Melle Griot.)



Quadrature Detectors for Alignment

- Often put detector on object being aligned to laser
- Use 4 quadrant detector Silicon photodiode detector
- Expand beam so some light in each quadrant
- Amount of photocurrent in each quadrant proportional to light
- Detect current difference of right/left & top bottom
- Higher current side has more beam
- Perfect alignment null current for both sides

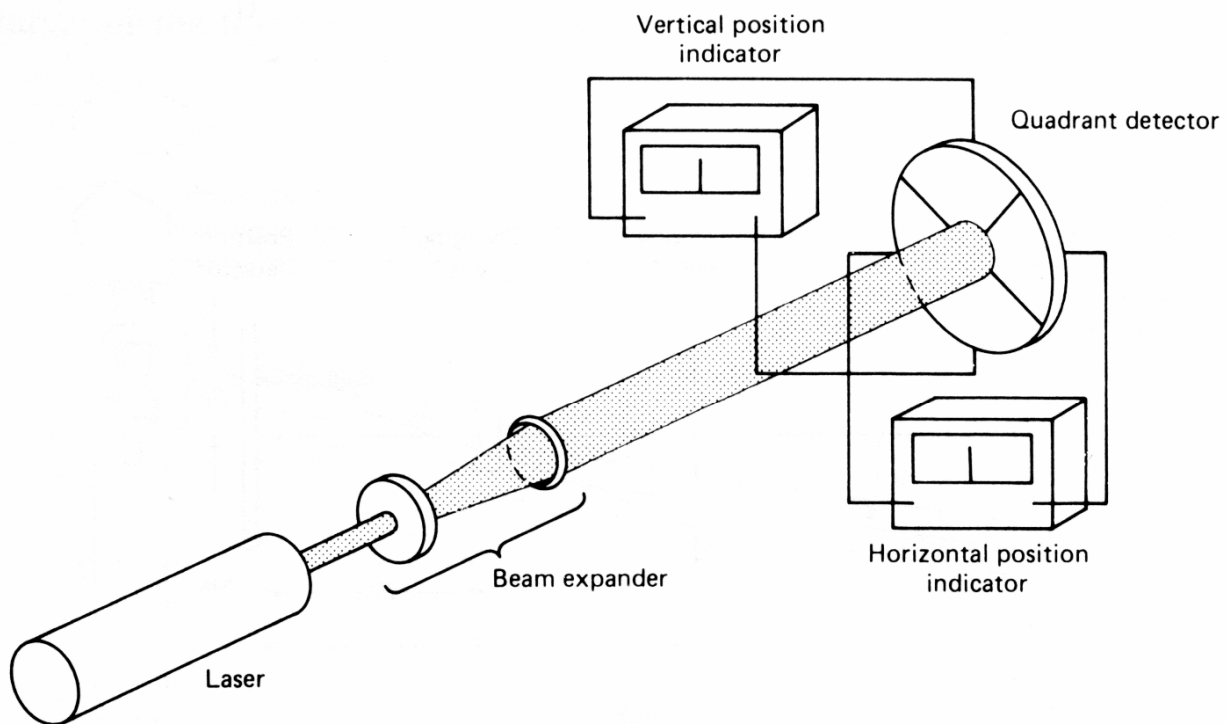


Figure 9-2 Simplified diagram of a laser alignment system.

Laser Leveling

- Lasers used to project lines of light
- Accuracy is set by the level of the beam source
- Used in construction projects: lines and cross lines
- Get vertical and horizontal
- Laser diodes give low cost levels now
- More complex: reflect light back from object
- Make certain light is reflected along the same path
- Called Autocolation

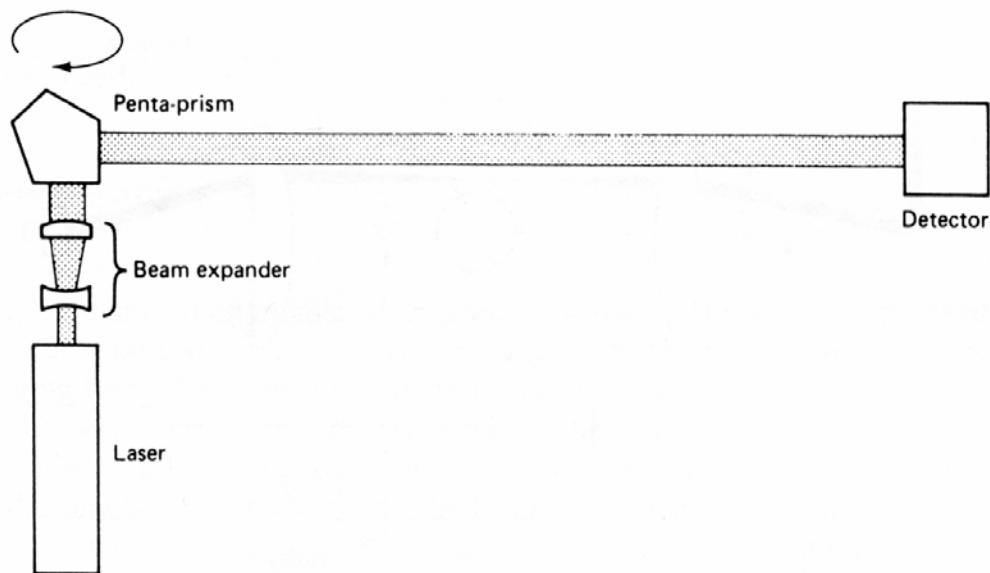


Figure 9-4 Diagram of a laser scanner system used for leveling.

Laser Size Gauging

- Gauging is measuring the size of objects in the beam
- Simplest expand beam the refocus
- Object (eg sphere) in beam reduces power
- Estimate size based on power reduction
- More accurate: scanning systems
- Scan beam with moving mirror (focused to point)
- Then measure time beam is blocked by object
- Knowing scan range then measure size of object

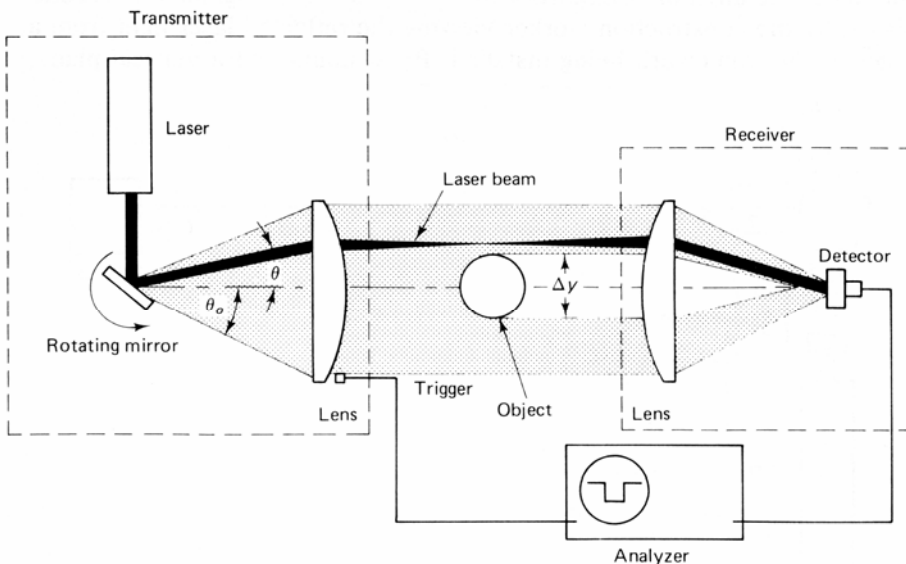


Figure 9-5 Simplified diagram of laser scanner gage.

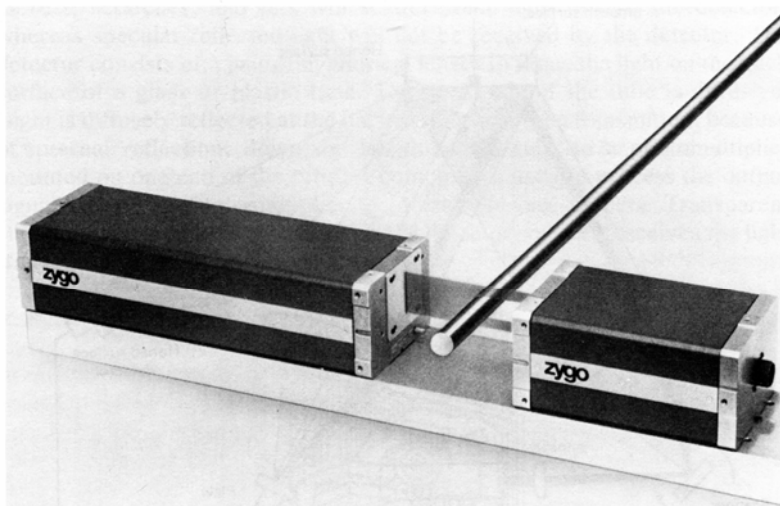


Figure 9-7 Laser scanner and detector being used to measure the diameter of a round bar. (Courtesy of Zygo.)

Laser & Linear Detector Array

- Use laser diode to illuminate a linear or 2D detector array
- Laser diode because creates collimated beam
- Expand beam to fill area
- Image is magnified or shrunk by lens
- Use pixel positions to determine object profile
- Low cost pixel arrays makes this less costly to gage scanners

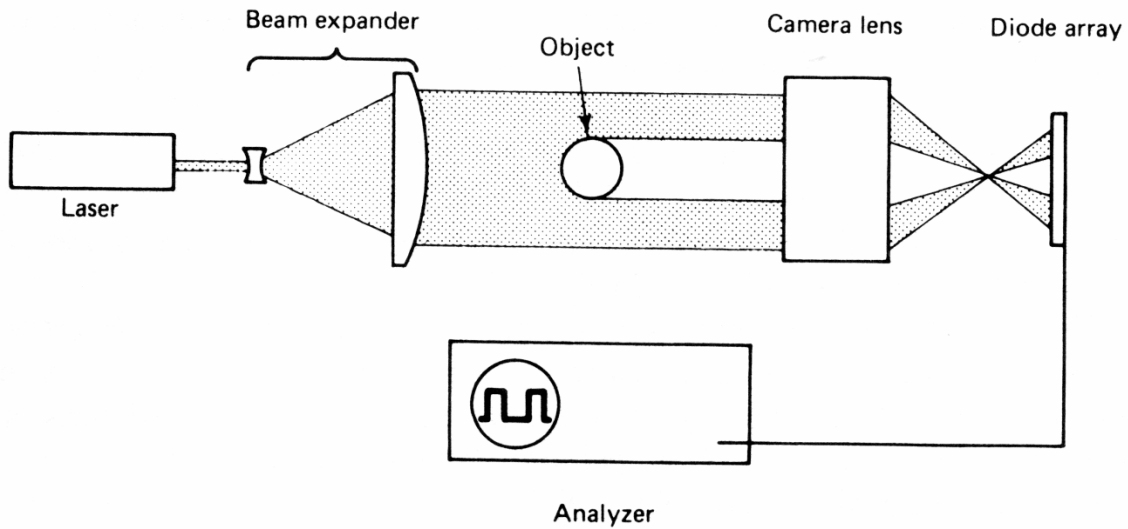


Figure 9-16 Typical linear photodiode array camera system.

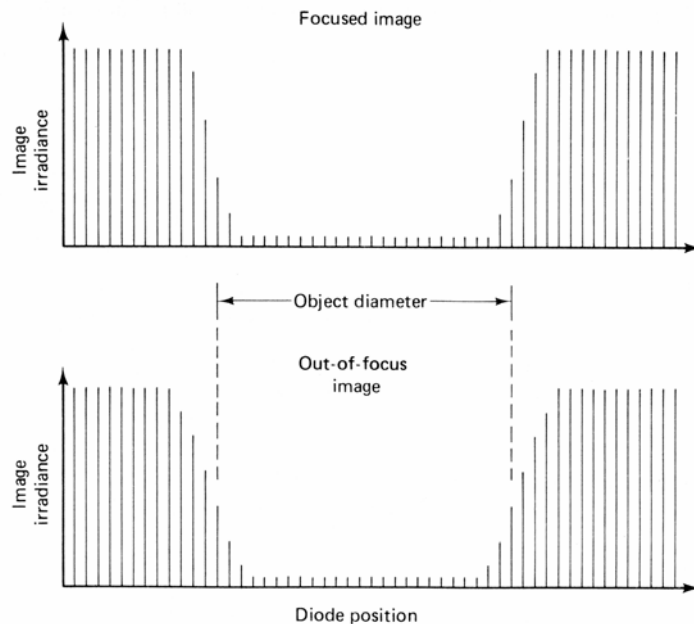


Figure 9-18 Focused and out-of-focus digitized images produced using a linear photodiode array, collimated light, and a constant image distance.

Laser Scanner to Detect Surface Defects

- Laser beam scanned across surface of reflective (eg metal) sheets
- Detect reflected light
- Flaws result in reduce or increase light
- Timing (when scanning) determines defect size
- Instead of spot use cylindrical expander to beam line of light
- Moving sheet (eg metal, glass, paper) crosses beam
- Use line or 2D images to detect changes
- Use both reflection and transmission depending on material
- Transmission can detect changes in thickness or quality

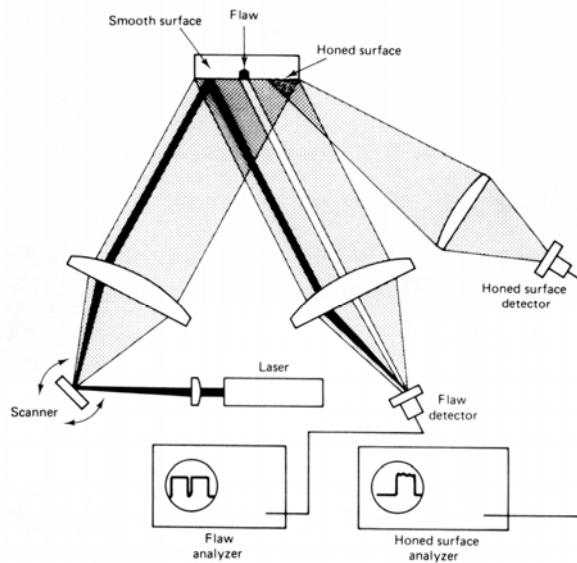


Figure 9-8 Laser scanner system designed to detect surface defects.

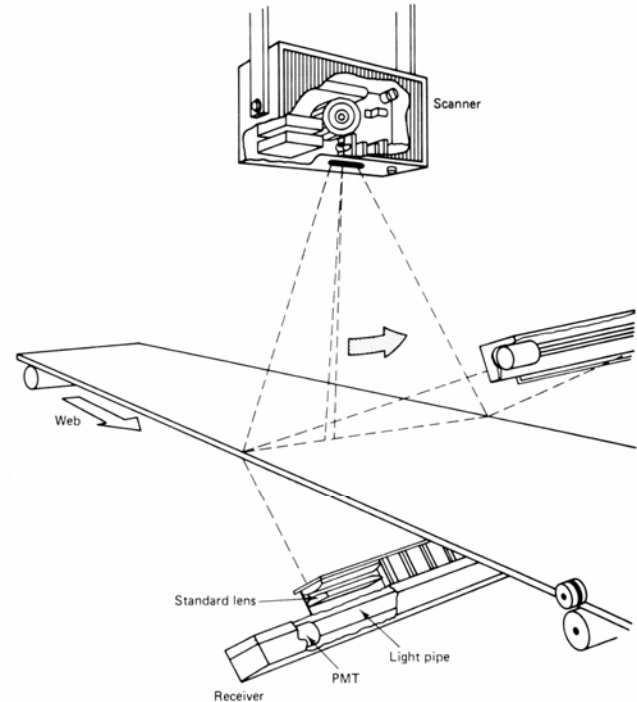


Figure 9-9 Laser scanner inspection system. (Courtesy of Intec Corp.)

Bar Code Scanners

- Diode laser now widely used in Bar code scanners
- Typically use two axis scanner
- Laser beam reflected from mirror on detector lens
- Bar code reflected light comes back along same path
- Detect rising and falling edge of the pattern
- Note: have the laser beam & return light on same path
- Use small mirror or beam splitter to put beam in path

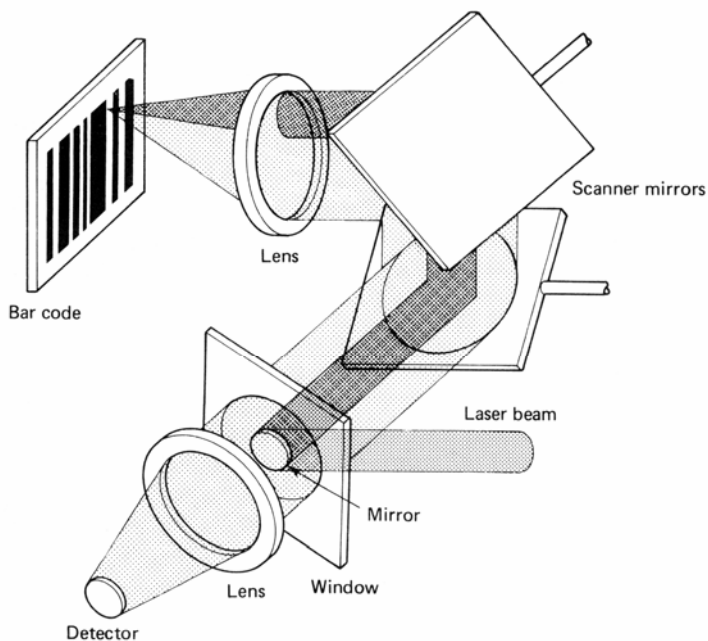


Figure 9-10 Bar-code scanner/reader.

Laser Triangulation

- Lasers aimed at precise angles depth/profiles using triangulation
- Single spot for depth measurement
- Laser spot focused by lens onto detector array
- Change in laser spot depth position Δz
- Gives change in position $\Delta z'$ at detector
- Change set by magnification caused by lens
- θ laser to lens angle
- ϕ angle between detector and lens axis
- Resulting equations

$$\Delta z' = m \left(\frac{\sin \theta}{\sin \phi} \right) \Delta z$$

- Get real time measurement of distance changes

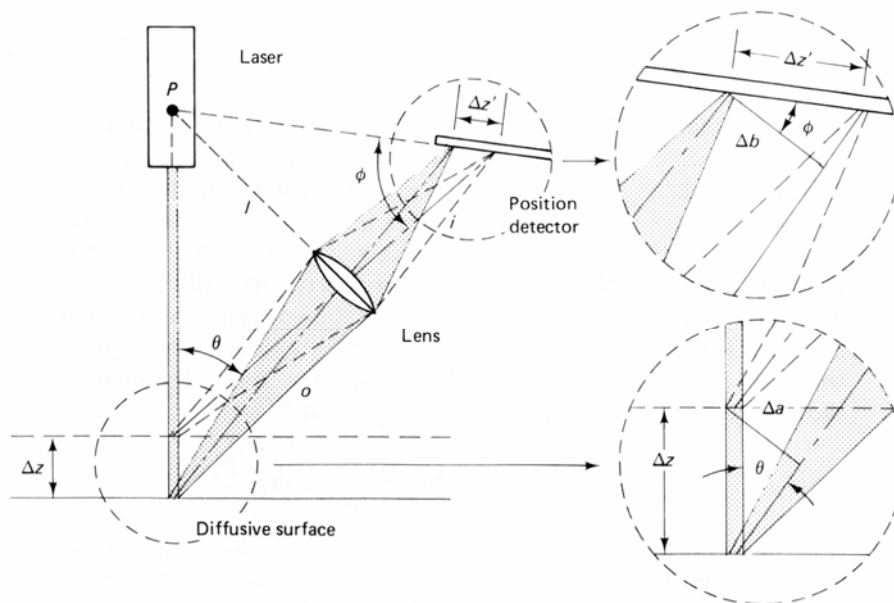


Figure 9-11 Diagram of optical triangulation system.

Laser Profileometry

- Use cylindrical lens to create line of laser light
- Use 2D detector array (imager) & lens to observe line
- If object is moving get continuous scan of profile
- Problems: Background light eg sunlight
- Changes in surface reflectance makes signal noisy
- Eg log profileometry for precise cutting of logs
- Problem is log surface changes eg dark knots, holes

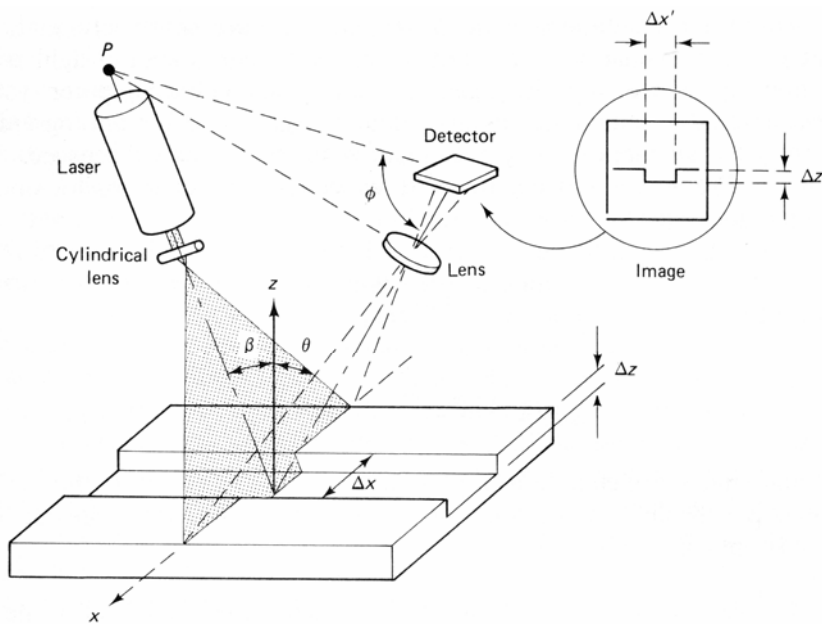


Figure 9-13 Line-of-sight optical triangulation unit.

Lidar

- Laser equivalent of Radar (RADIo Detection And Ranging)
- LIDAR: LIght Detection And Ranging
- Can use pulses & measure time of flight (like radar)
- But only hard to measure $<10^{-10}$ sec or 3 cm
- Better phase method
- Modulate the laser diode current with frequency f_m
- Then detector compares phase of laser to detector signal
- Phase shift for distance R is

$$\phi = \frac{2\pi}{\lambda_m}(2R) \quad \text{and} \quad c = \lambda_m f_m$$

- Then the distance is

$$R = \frac{c}{4\pi f_m} \phi$$

- If $>$ modulation wavelength λ_m need to get number of cycles
- In extreme phase changes in the laser light
- That requires a very stable (coherent) laser: HeNe not diode

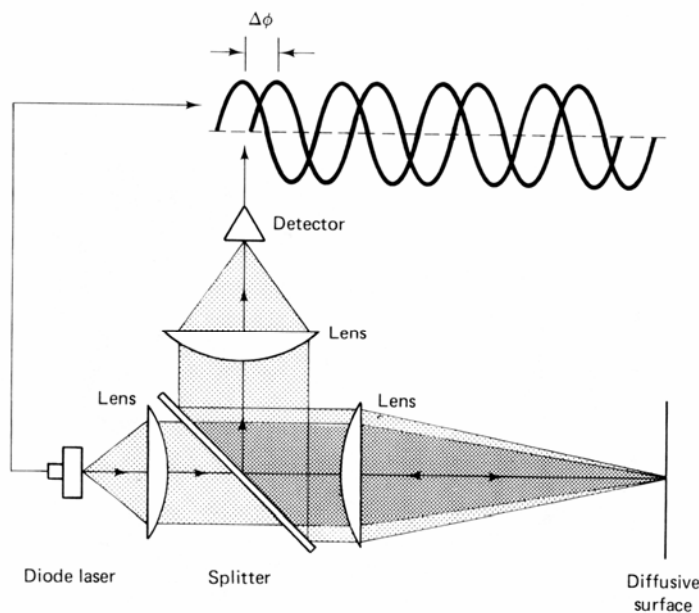


Figure 9-14 Diagram of laser range finder that uses an amplitude-modulated laser beam.