Reactive Fusion Cutting

- Add gas stream (usually oxygen) that reacts with material
  burn reaction (oxidation) adds energy to laser cutting
- Steel typically 60% added energy
- Titanium 90% added energy
- However reaction can chemically change the work face
  eg titanium gets brittle from oxygen
- Cutting speed is increases with addition of oxygen

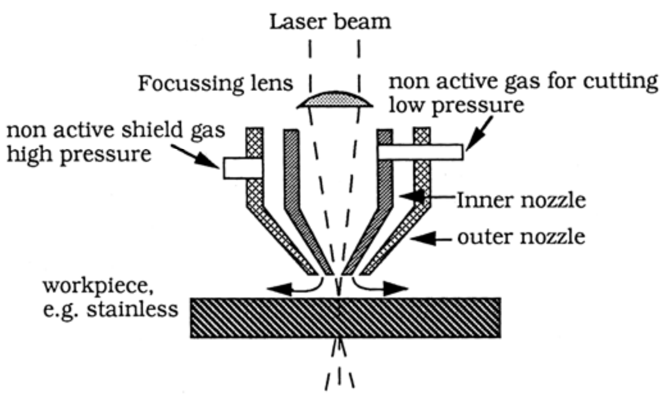
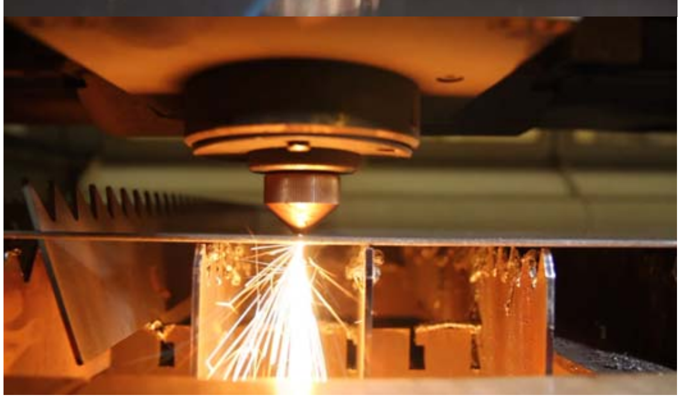


Fig. 3.22. A High Pressure Ring Nozzle used for "Clean Cut" Technique (27).



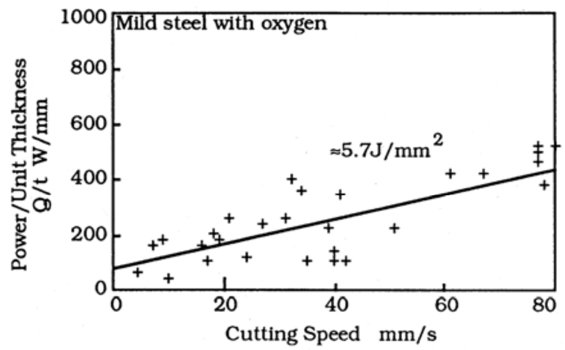


Fig. 3.4. P/t vs V for mild steel.

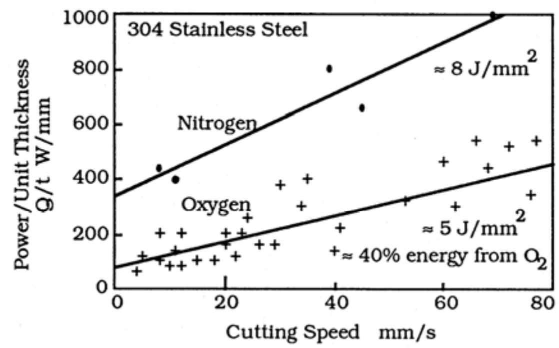


Fig. 3.5. P/t vs V for stainless steel.

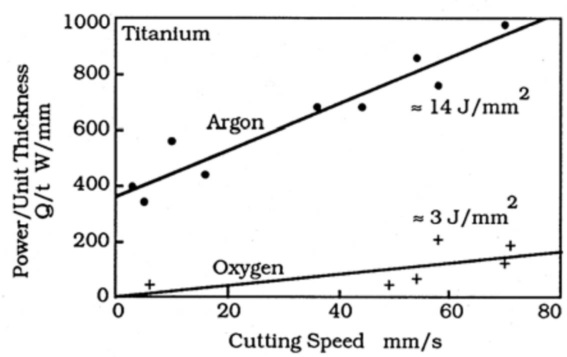


Fig. 3.6. P/t vs V for titanium.

Reactive Fusion Cutting Striations

- Reactions create a burn front
- Causes striations in material
- Seen if the cut is slow

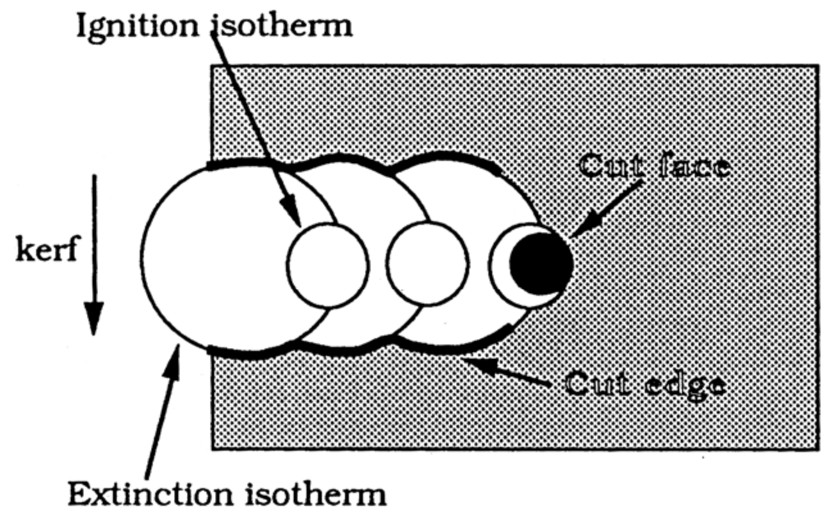


Fig. 3.9. Striation formation due to sideways burning.

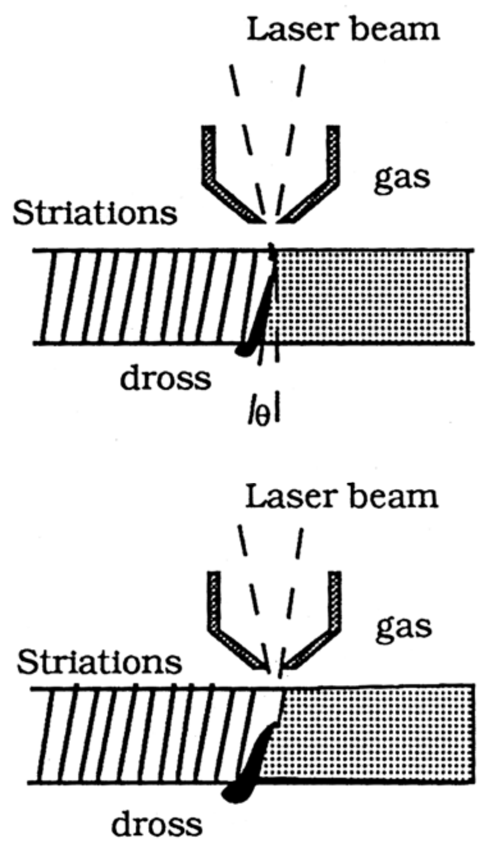


Fig. 3.8. The stepwise formation of striations.

Behavior of Materials for Laser Cutting

- Generally break down by reflectivity and organic/inorganic

Table 3.7	Behaviour of Different Materials to Laser Cutting
Property	Material
High Reflectivity (Need for Fine Focus)	Gold, Silver, Copper, Aluminium, Brass
Medium/High Reflectivity	Most metals
High Melting Point	W, Mo, Cr, Ta, Ti, Zr
Low Melting Point	Fe, Ni, .Sn, Pb
High Oxide Melting Point (Dross Problems)	Cr, Al, Zr
Low Reflectivity	Most non metals
Organics	
Tendency to char	PVC, Epoxy, Leather, Wood, Rubber, Wool, Cotton
Less tendency to char	Acrylics, Polythene, Polypropylene, Polycarbonate
Inorganics	
Tendency to crack	Glass, Natural Stones
Less tendency to crack	Quartz, Alumina, China, Asbestos, Mica
See also list of the cuttability of many materials in Industrial Laser Annual Handbook 1990 pp3-6, published Penwell Books, Tulsa, Oklahoma,USA.	

Controlled Fracture and Scribing

Controlled Fracture

- Brittle materials vulnerable to thermal stress fracture
- Heat volume: it expands, creates tensile stress
- On cooling may crack
- Crack continue in direction of hot spot
- Mostly applies to insulators eg Sapphire, glass

Scribing

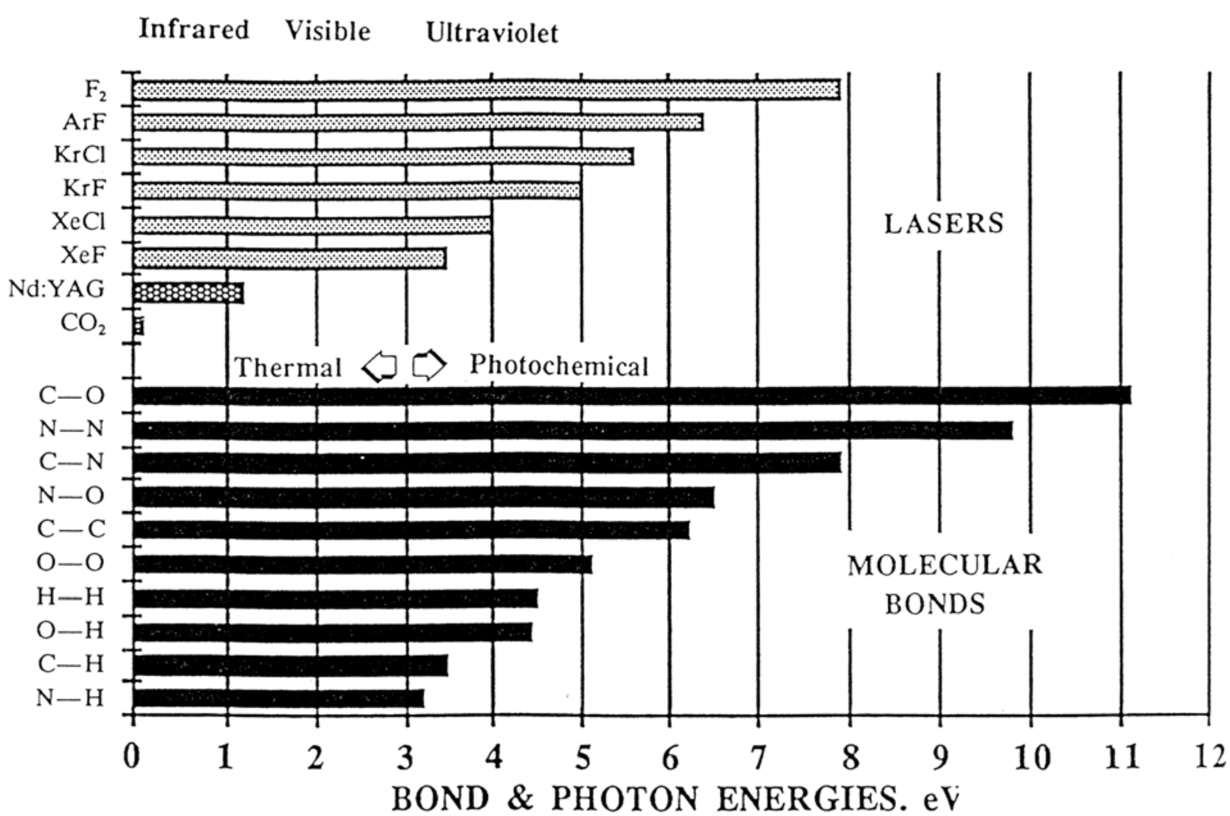
- Create a cut point in the material
- Forms a local point for stress breakage
- Use either a line of holes or grove

Table 3.5	Controlled Fracture Cutting Rates			
Material	Thickness mm	Spot Diameter mm	Incident Power W	Rate of separation m/s
99% Al2O3	0.7	0.38	7	0.3
	1.0	0.38	16	0.08
Soda Glass	1.0	0.5x12.7	10	0.3
Sapphire	1.2	0.38	12	0.08
Quartz (cryst)	0.8	0.38	3	0.61

Cold Cutting or Laser Dissociation

- Uses Eximer (UV) lasers to cut without melting
- UV photons 3.5 - 7.9 eV
- Enough energy to break organic molecular bonds
- eg C=H bond energy is 3.5 eV
- Breaking the bonds causes the material to fall apart: disintigrates
- Does not melt, chare or boil surface
- eg ArF laser will create Ozone in air
  which shows the molecular effects

Table 9.1 Strengths of some common molecular chemical bonds compared with excimer laser photon energies.



Eximer Laser Photo-ablation

- Done either with beam directly or by mask
- Short Laser pulse absorbed in 10 micron depth
- Breaks polymer bonds
- Rapid rise in local pressure as dissociation or photoablation
- Mini explosions eject material

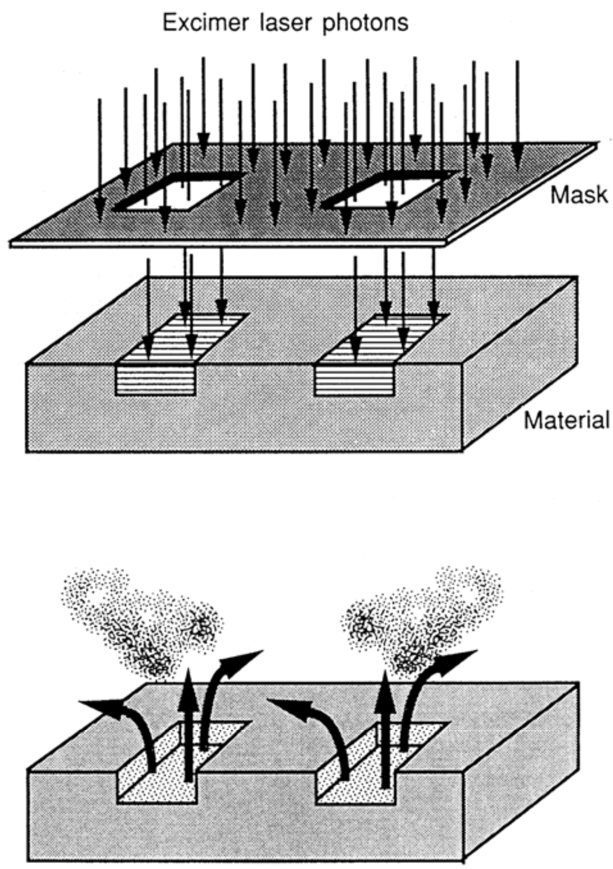
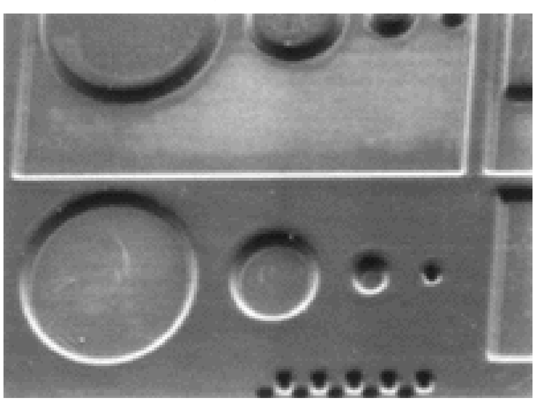
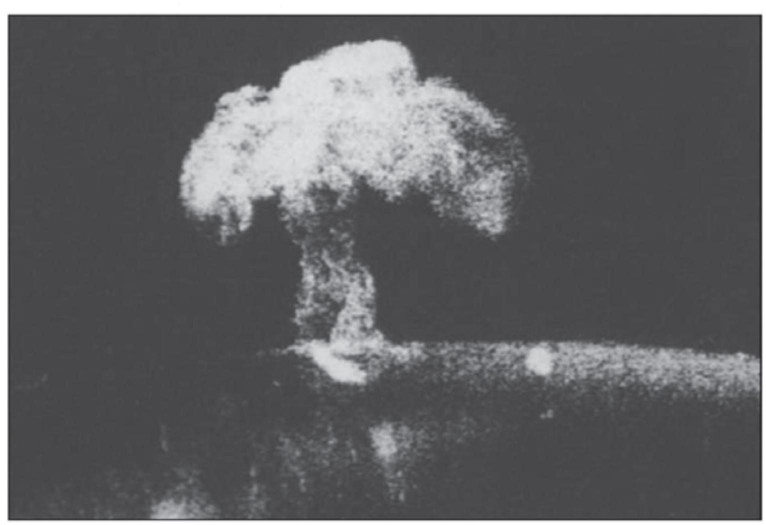


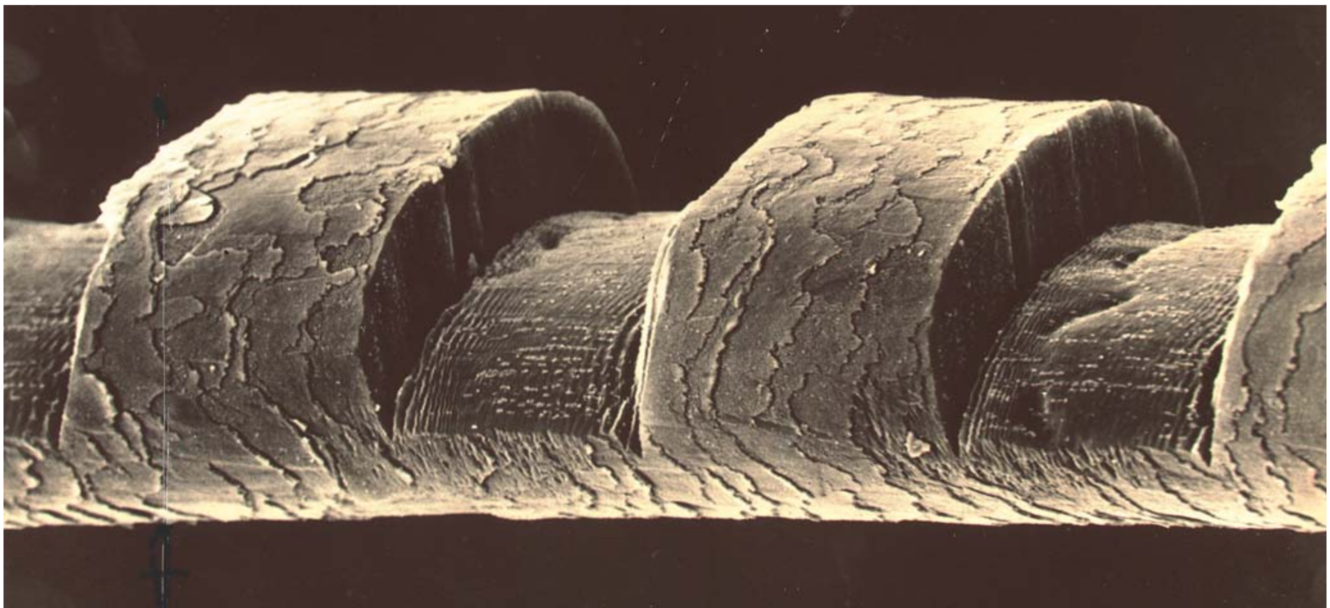
Fig. 9.1 The short-duration UV excimer laser pulse rapidly breaks chemical bonds in a polymer within a restricted volume to cause a mini-explosion that ejects material.

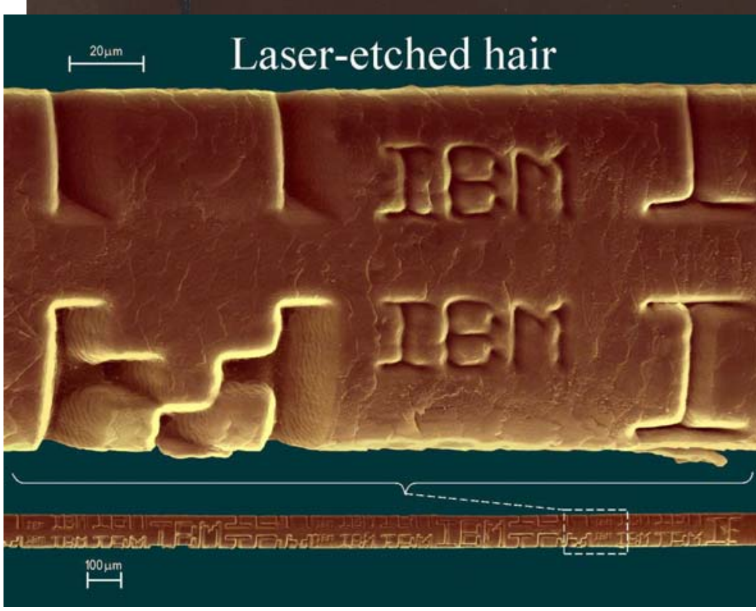


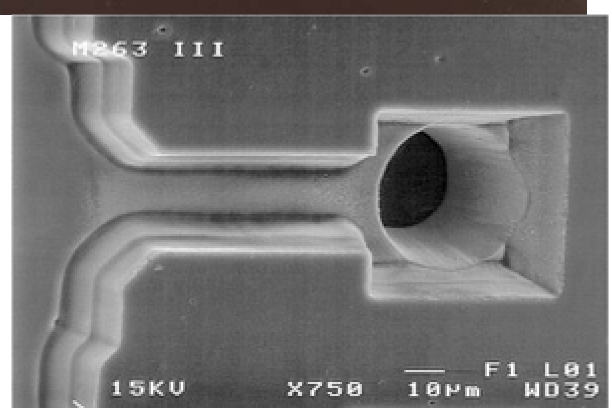


Eximer Micromachining

- Can carve complex structures into organics, plastics
- Called Photoablation
- Also shape inorganics glasses/crystals
  like Nd:Yag,
  quartz difficult (not absorbing)
- Composites: cuts the organic binders easily no wear like blades
- Eg Ink jet nozzles are cut using photoablation







Ink Jet Nozzle Eximer cut

Etching with Eximers

- Each pulse removes materials
- However definite threshold effect
- Also saturation,
  because beam does not penetrate
- Many organics just top microns absorbs

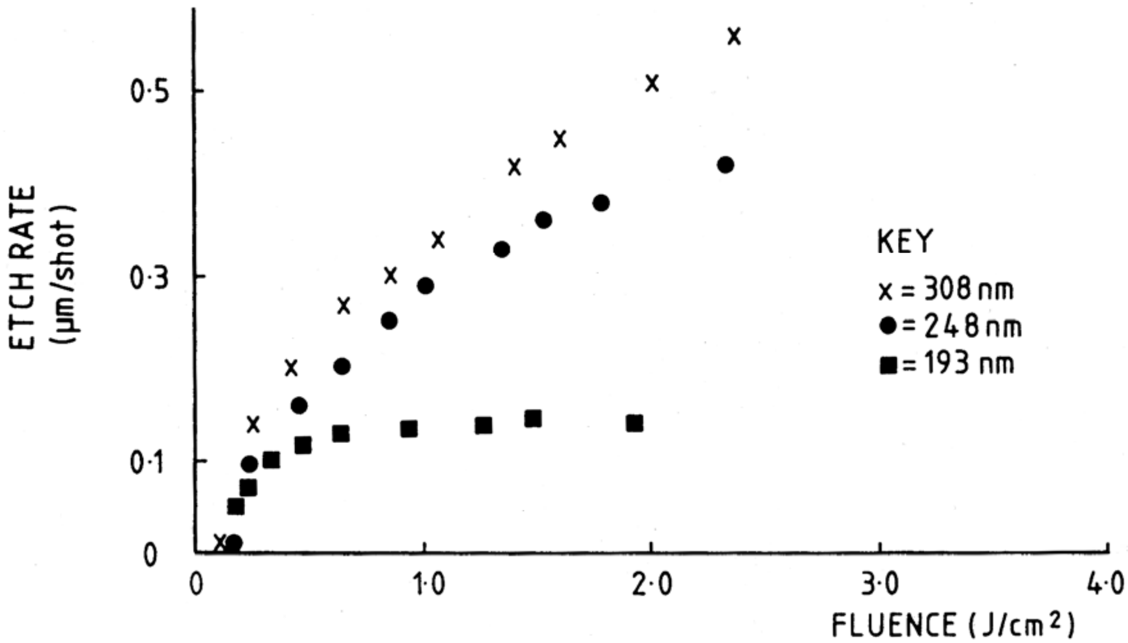


Fig. 9.7 Rate for etching polyimide per pulse versus fluence with the three principal excimer lasers.

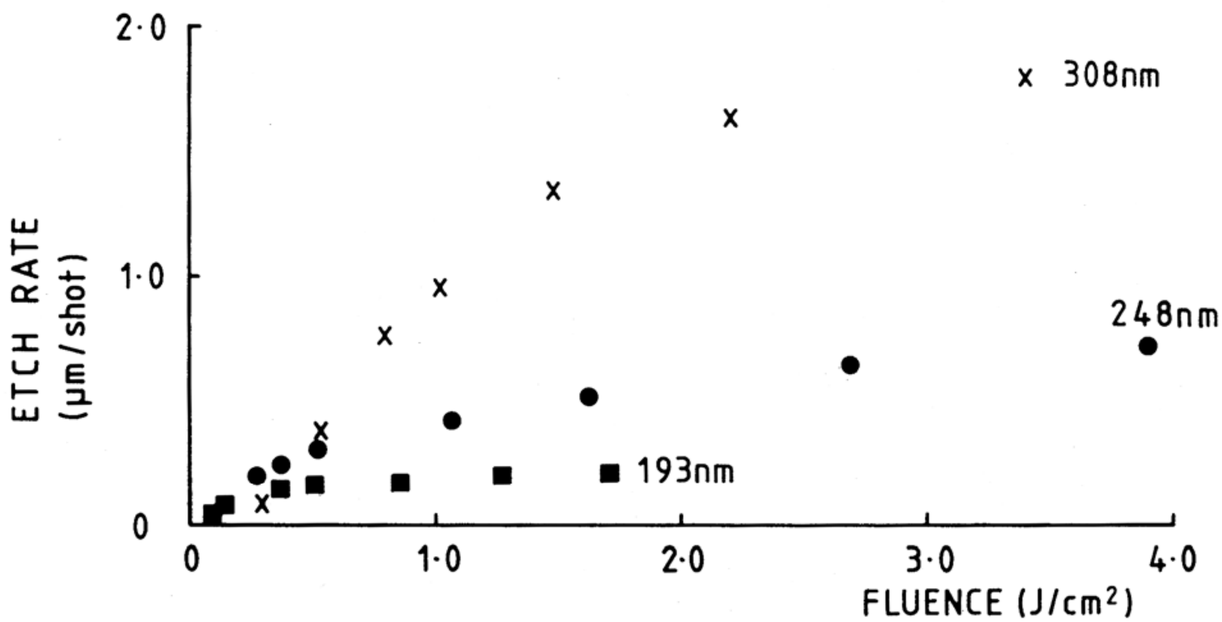
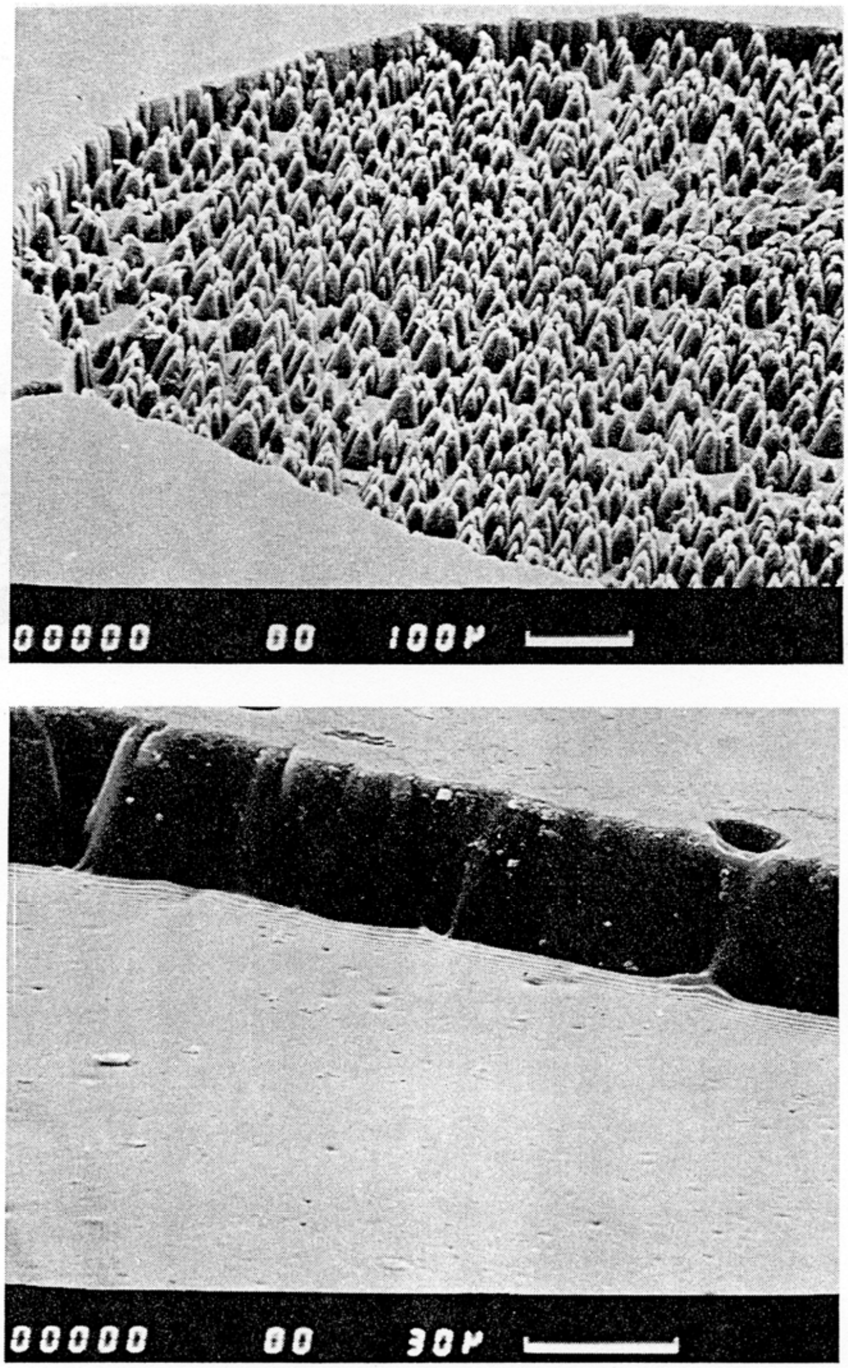


Fig. 9.8 Rate for etching PET per pulse versus fluence with the three principal excimer lasers.

Threshold Effect in Photoablation

- If too low get cone shaped structures
- Only local dissociations
- High power, smooth sidewalls



(a) 0.23 J/cm^2

(b) 2.33 J/cm^2

Fig. 9.14 Etches in polyimide with a KrF laser (a) just above the etching threshold, showing cone like structures, (b) smooth etching at a fluence ≈10 times the threshold for etching.

Corneal Sculpting

- Laser cold cutting used to shape the cornea to correct vision
- LASIK: Laser-Assisted In Situ Keratomileusis
- Cornea absorbed 193 nm in 4 microns
- Directly ablates cornea materials
- Use a computer controlled shaping pattern
- 50-100 microns cuts for up to 7 diopters change
- Cuts may require up to 90% reduction in areas with surgery
- Eximer leaves a very smooth surface
- Current price $1000-4000 per eye (depending on complexity)

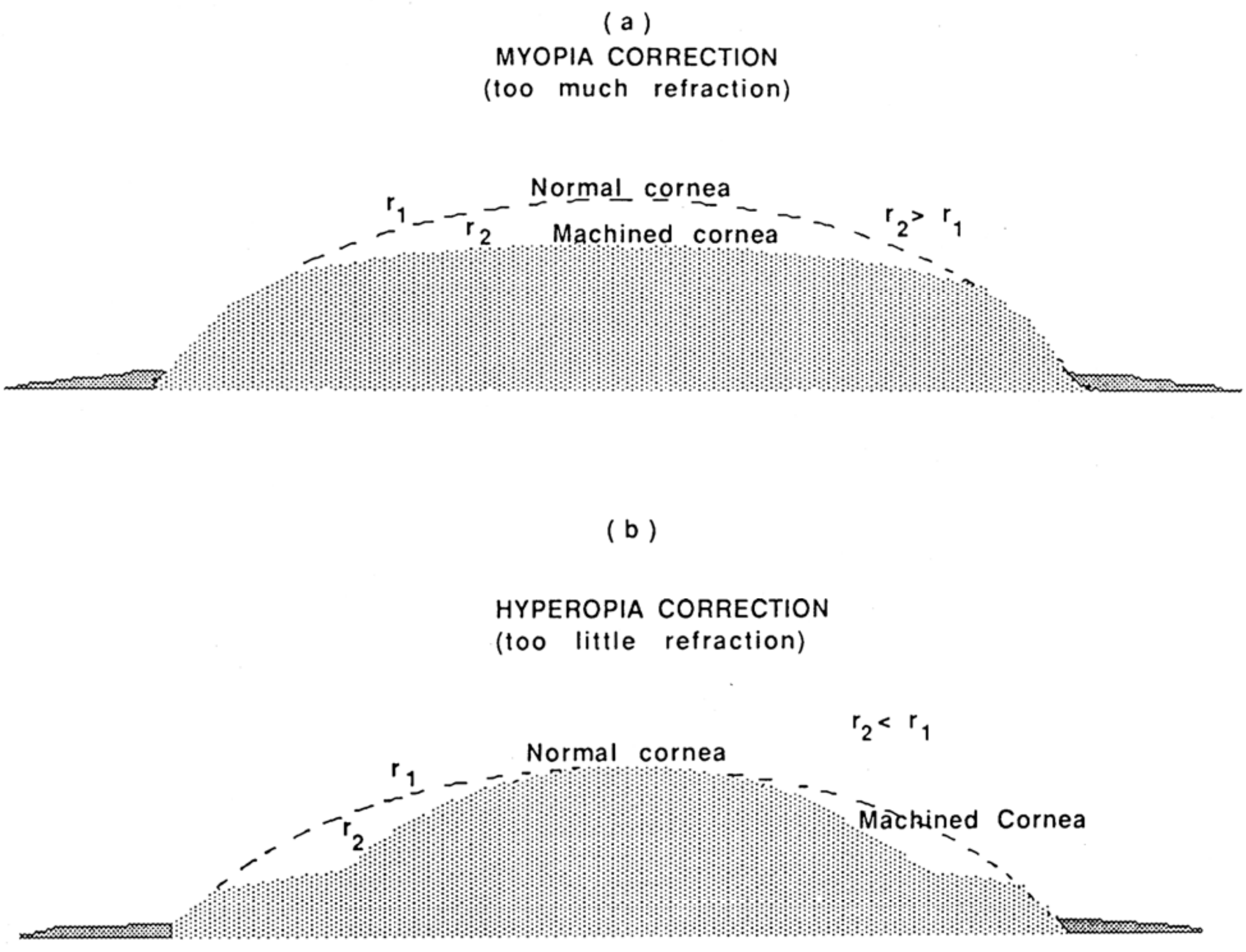


Fig. 9.53 Machining with an ArF laser and image projection on to the cornea a mask consisting of (a) a variable circular aperture producing a larger radius for myopia correction, (b) a variable annular aperture producing a smaller radius for hyperopia correction. Similar profiles can be obtained using rotating wedged slit aperture masks or sacrificial masks of variable thickness placed on to the cornea.

Comparison of Diamond Surgery & Laser Eye Surgery

- Older Diamond Eye Surgery is much rougher
- Laser photoablation is very smooth
- Problem is eye infections rates of up to 25% for laser systems

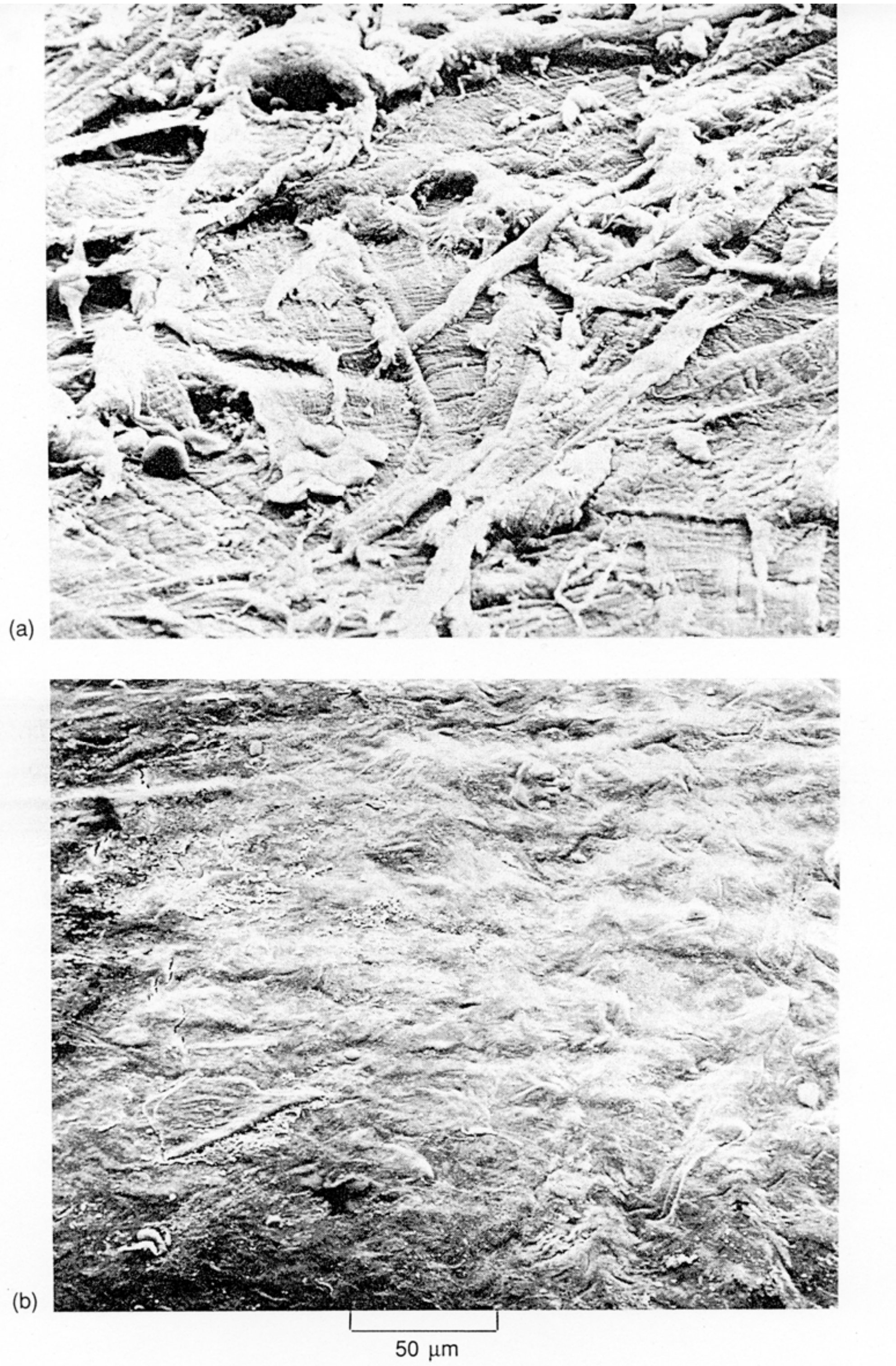
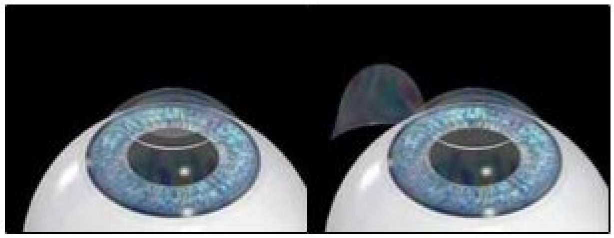


Fig. 9.52 Floor of corneal keratectomy cut in the stroma of a human eye with (a) a trephine diamond knife and (b) an ArF excimer laser. Photograph courtesy of Prof. J. Marshall, Institute of Ophthalmology, University of London, UK.

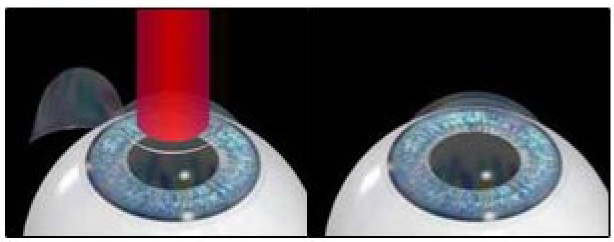
Laser Eye Surgery Systems

- LASIK starts with cutting back a corneal flap (~200-300 μm)
- Eximer shapes cornea, then flap put back
- Wavefront Lasik adds beam that measures cornea surface
- Adjusts cutting to get the better correction (~90% 20/20 vision)



Step 1: Corneal flap is created with a microkeratome.

Step 2: The corneal flap is folded back.



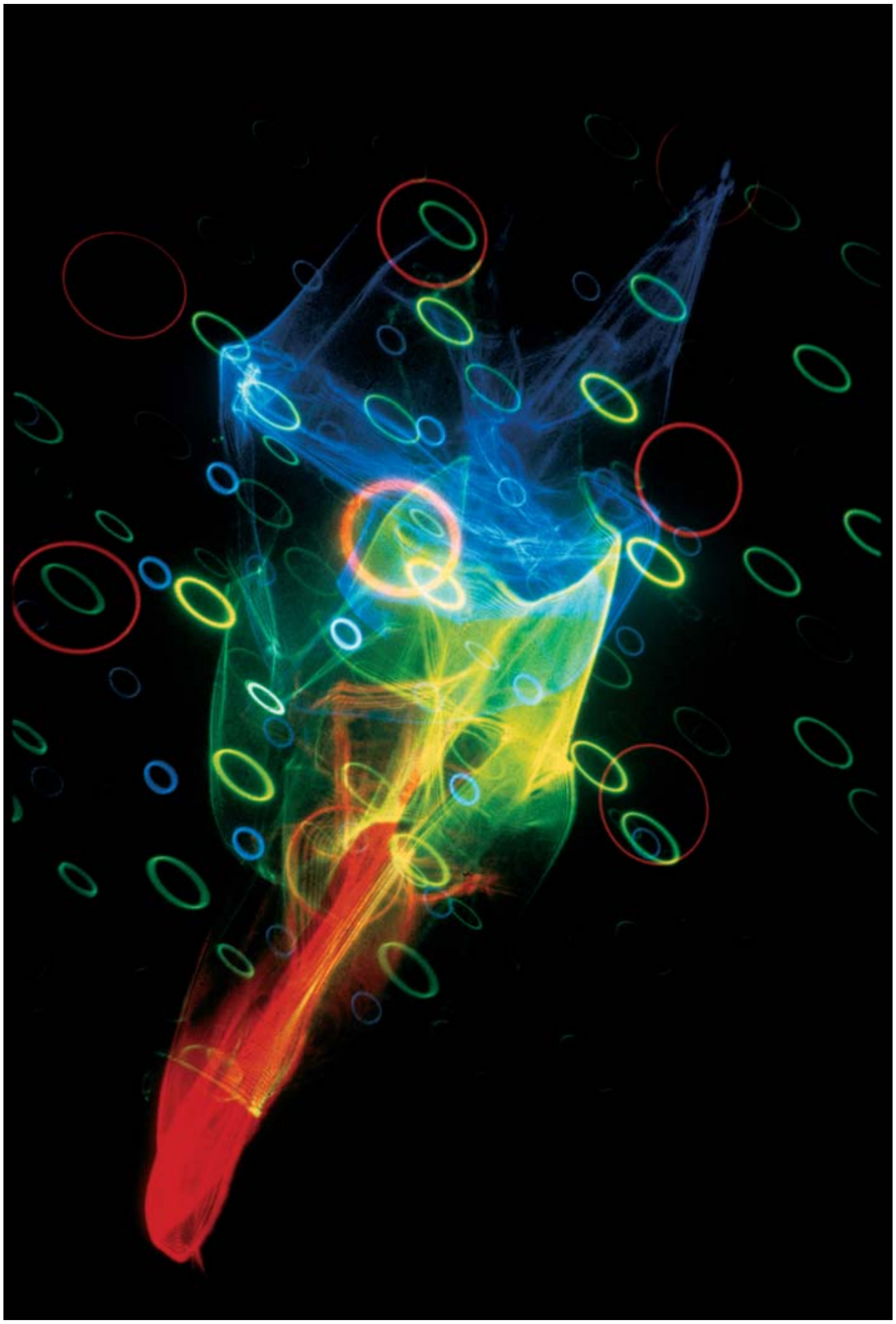
Step 3: Excimer laser beam reshapes the cornea.

Step 4: The corneal flap is folded back in place.

Air Force photo by Tech Sgt. Lance Cheung

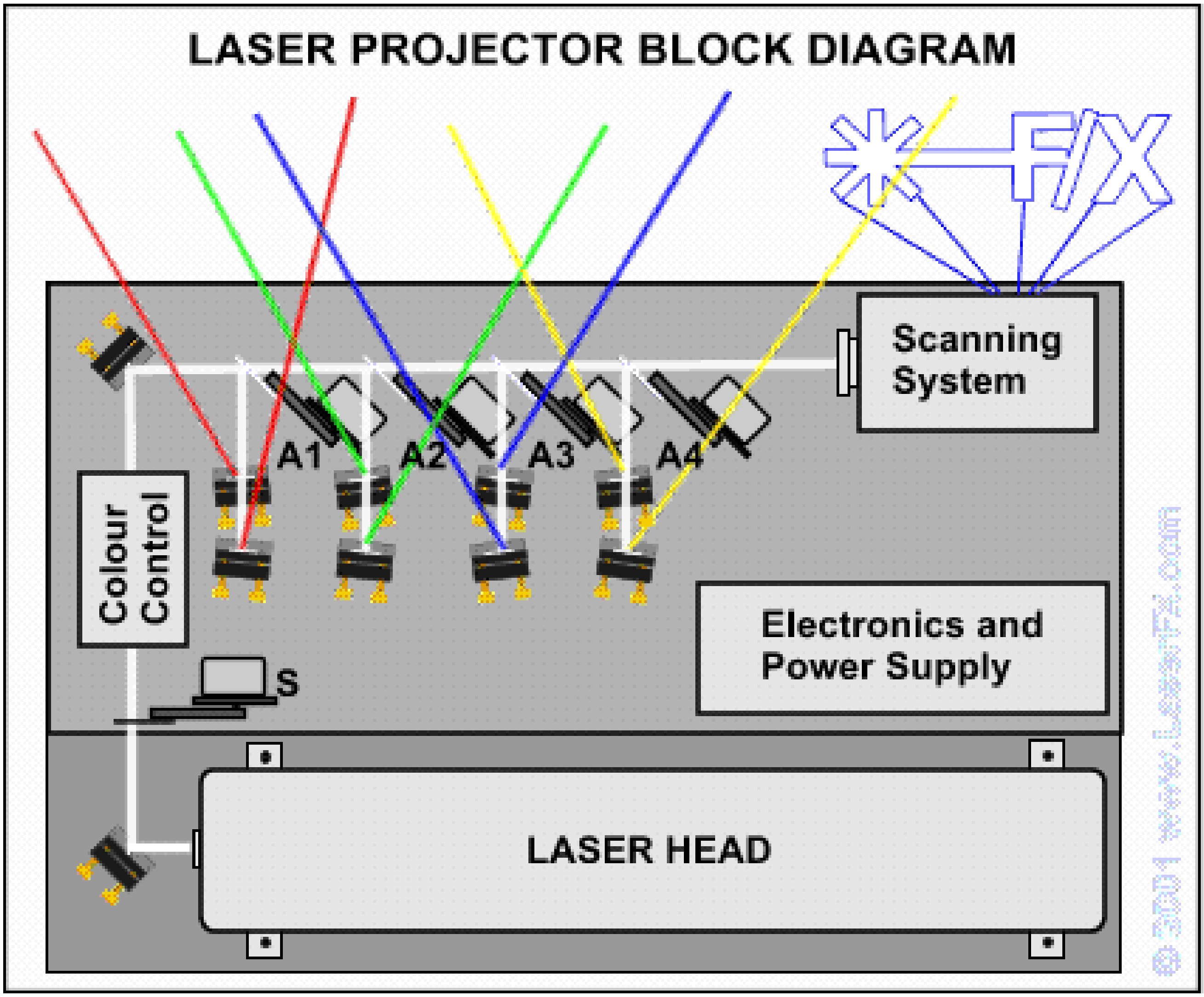
Lasers and Entertainment

- Lasers used extensively in Laser Light Shows
- Needs lasers with multicoloured lines (Red, Green, Blue, Yellow)
- Argon laser (greens, blues, violets)
  & Krypton (Red, orange, yellow)
- Argon/Krypton most common – 25-50% of market
- Combined with laser scanners



Laser Light Show Pattern Creation

- Run lasers all lines then split light
- Use either dichromatic mirrors, prisms, or diffraction grating
- Each beam goes to its own scanner,
- Computer control of each scanner creates colour pattern



Laser Scanners

- Need to direct beam using computer controlled system
- Most common moving mirror systems
- Wavelength independent
- Two types
- Galvanometric scanners & resonant scanners
- Both scan about + & - 30 degrees
- Current scanners 16 - 21 bit accuracy

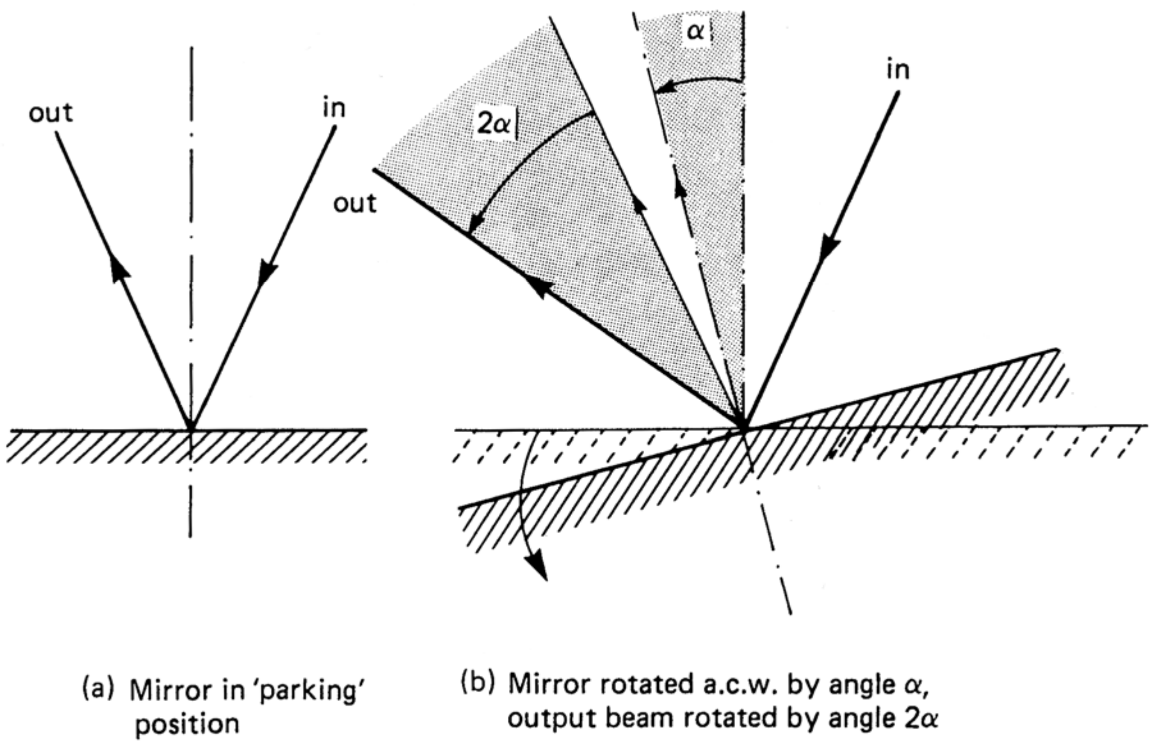


Figure 10.14 The incident laser beam is made to fall on to a rotating first surface mirror *M* which directs it to the wanted address by deflecting it by the angle 2α. Note the angle doubling

Galvanometric Scanners

- Work by interacting current in coil on mirror with powerful permanent magnets (rare earth)

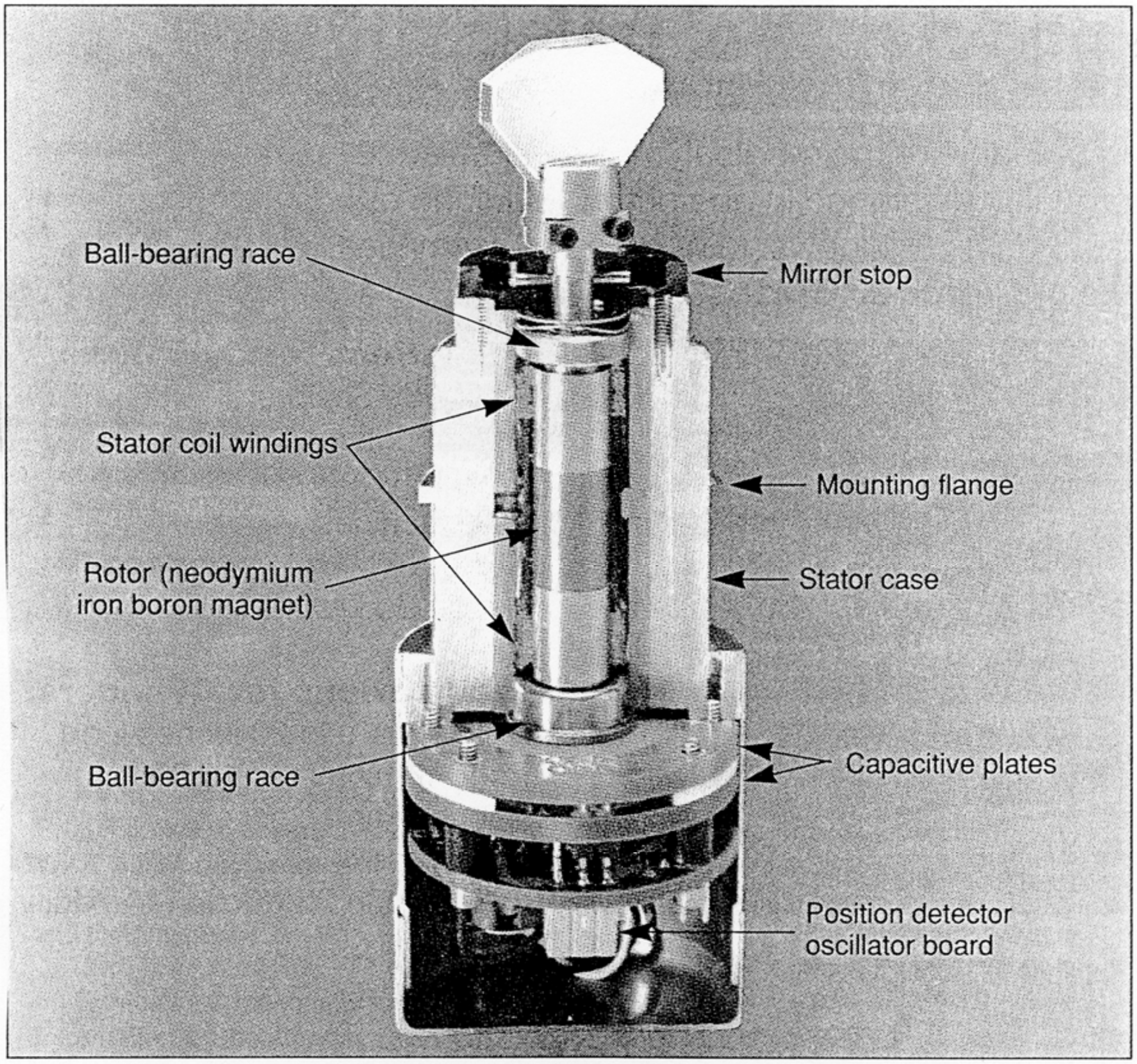


FIGURE 2. Cross section of a moving-magnet galvanometric scanner shows the magnet rotor driven by the stator coil.

Galvanometric Scanners types

- Iron core, Magnet & coil types
- Permanent Magnets lowest inertia, mass
- Coil type fastest but high mass & power

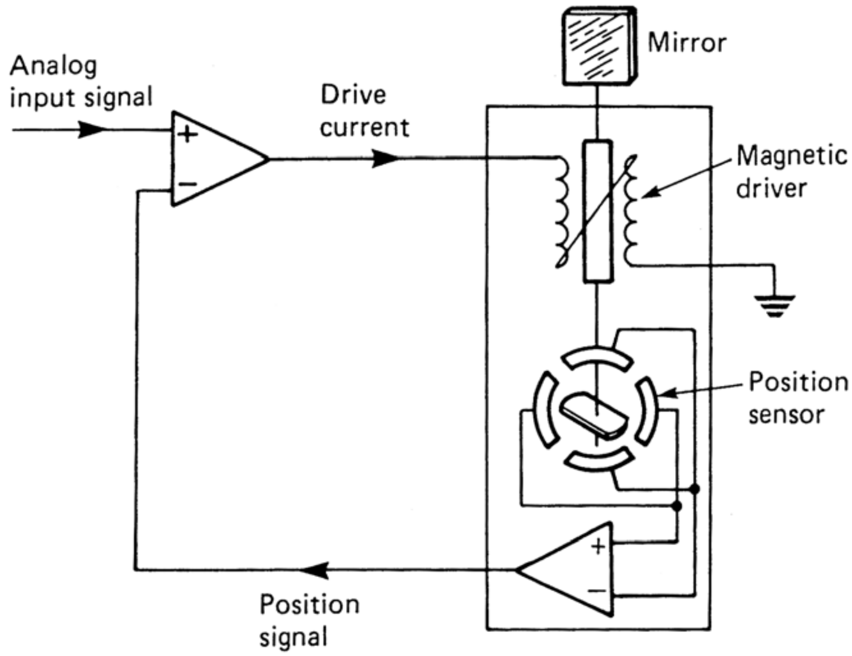


Figure 10.15 Galvo scanner with pick-up position sensor for feedback

Performance comparison of galvanometric scanners

Armature(1)	Iron(2)	Magnet(2)	Coil(3)
Inertia (g-cm^2)	6.0	5.0	9
Thermal conductivity, coil to base (°C/W)	–	1.4	2.8
Power (W)(4)	–	57.2	28.6
Torque 10% duty factor (g-cm)(5)	2500(6)	5600	6020
Acceleration, no load (rad/s^2)(5)	0.40×10^6	1.1×10^6	0.67×10^6
First resonance (kHz), 11 g-cm^2 load(7)	5	5	3
Resistance (Ω)	2	4.8	3.5
Time constant, L/R (ms)	3	0.27	0.23
Weight (g)	670	300	1000
Gain drift (ppm/°C)(8)	60	40	50
Null drift (μrad)(8)	10	5	10

(1) Butterfly moving dielectric capacitive encoders: output shaft diameter 0.250 in.; (2) Data sheets of General Scanning Inc. 1993 for products G3B and M3H; (3) Data Sheets of Cambridge Technology Inc. 1993 for product 6650; (4) 80°C temperature rise; (5) Derived from data for a maximum temp. of 150°C; (6) Torque limited by saturation; (7) Mirror and mirror mount; (8) Temp. range typically 10°C to 50°C

Moving Mirror Scanners

- All work by reflecting beam
- Resonant scanners for raster scan type operations
- Optical Scanning Microscopes
- Newest application HDTV projection systems
- Advantages: Very high light levels, High resolution
- Problems getting lasers of correct wavelength
  with same brightness & resolution
- Requires two scanner mirrors

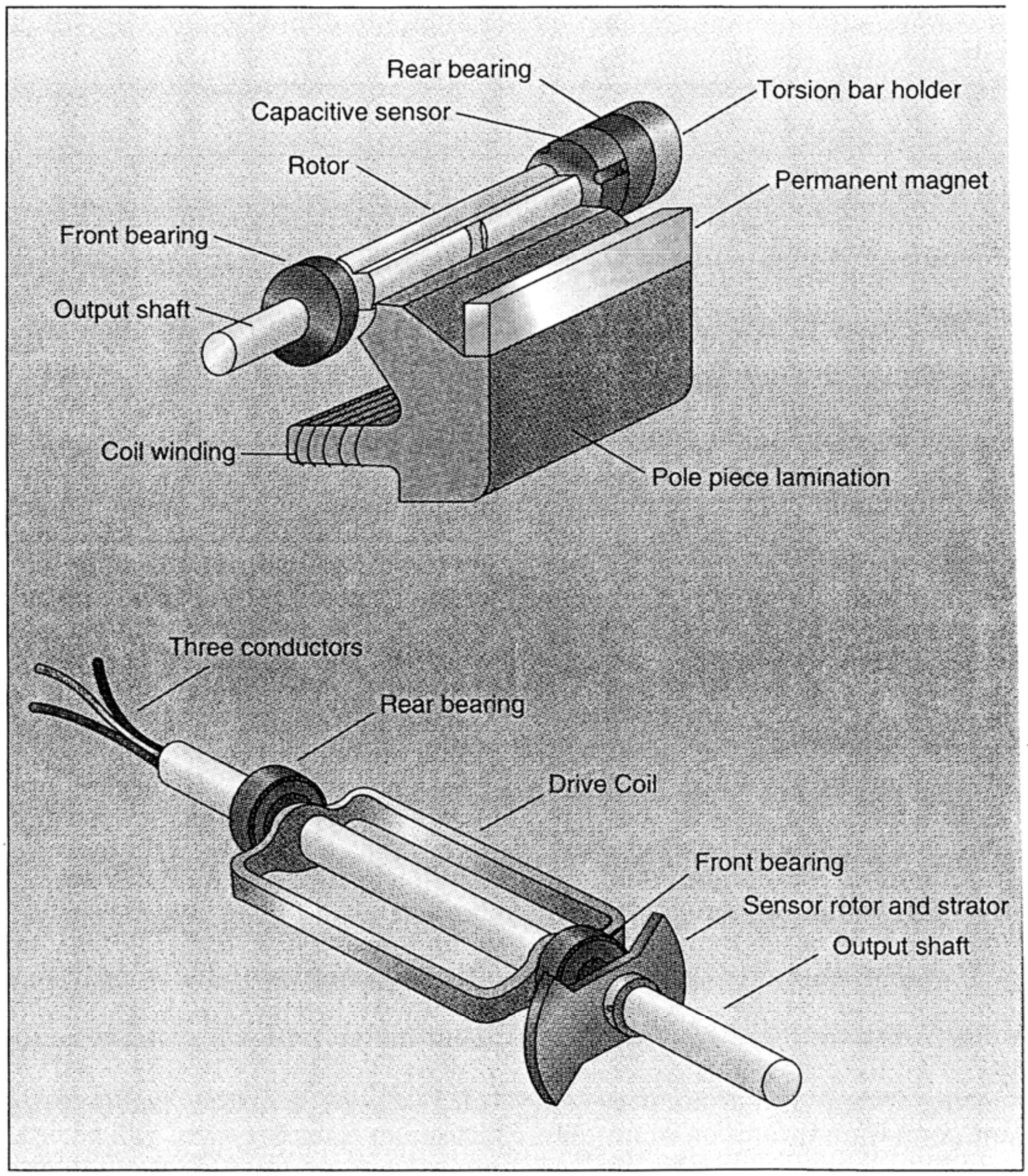


FIGURE 1. Armatures for galvanometric scanners include moving-iron galvanometer stator (top), moving coil (bottom), and a moving magnet (see Fig. 2). In each of these devices, a mirror is mounted on the output shaft.

Two Mirror Scanners

- Required for XY picture formation
- Also used for 3D systems

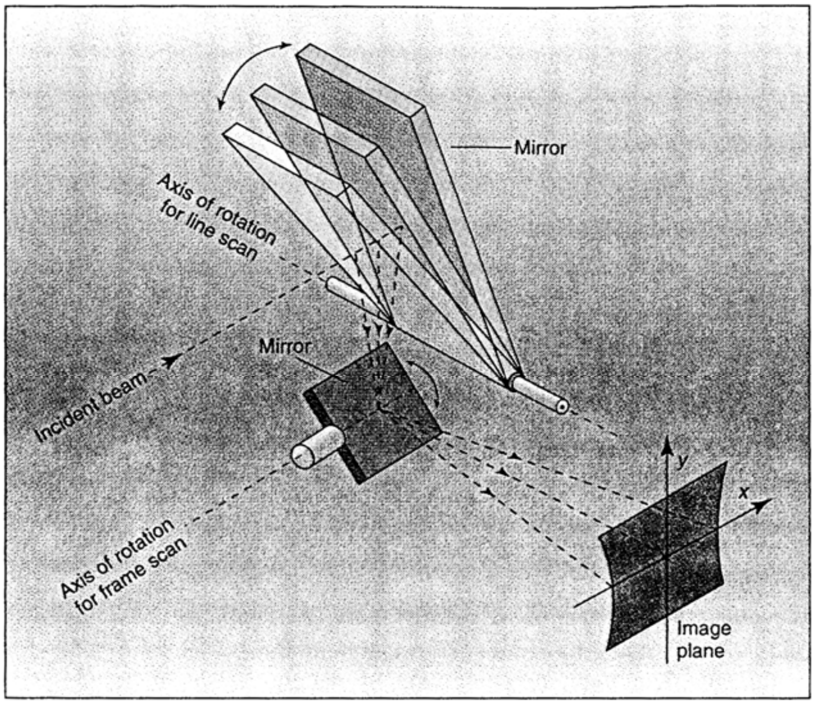
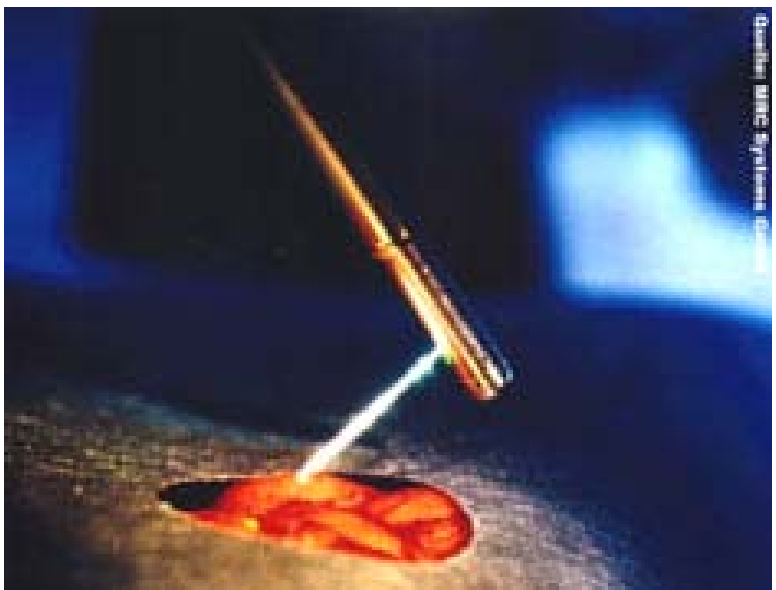


FIGURE 3. Dual-axis scanners with orthogonal axes can produce 2-D displays. These scanners are also the basis of 3-D projectors.

Lasers in Medicine

- Medical applications one of fastest growing laser fields
- $US958 million (2016), 8% of laser sales
- Growing at ~10%/year, but more slowly than overall laser market
- Three main Areas:
- Surgery, as a cutting tool
- Ophthalmology (eye operations)
- Dermatology (Skin Operations)

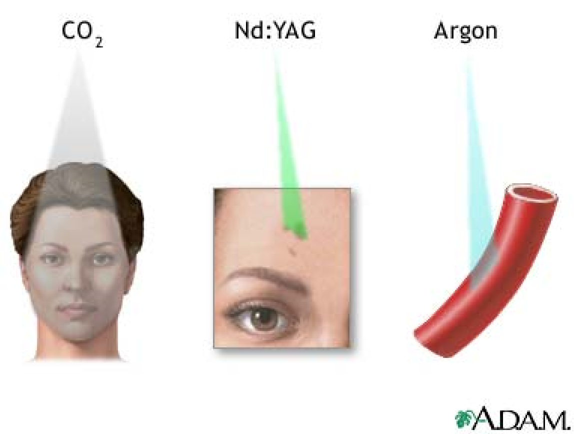


Lasers for Medicine

- CO_2 laser widely used for cutting but is shallow depth cutting
  10.6 μm heavily absorbed by water in tissue
  Evaporation of water leads to destruction of tissue
- Nd:Yag penetrates deeper, but widely used
- Argon laser: skin blemishes, Ophthalmology (eye)
- Eximer: Cornea shaping & Herpes

Table 10-1 Randomly selected surgical applications of lasers*

Laser type	Spectral region, Å	Body tissue	Treatment
He-Ne	Visible, 6328	Dermal	Photoradiation, wrinkle removal
Argon	Visible, 4500	Otological, cholesterol clot, fallopian tube, gastrointestinal tract	Photocoagulation, skin blemishes, skin therapy, incision, ulcer
Argon	Ultraviolet, 3500	Nasal mucous membranes, dermal tissue	Ultraviolet therapy, germicidal agent, retinopathy
Nd-YAG	Infrared, 10,640	Stomach, liver, lungs, heart, kidneys, pancreas, brain, skin	Incision, control of hemophilia, cancer
CO_2	Infrared, 106,000	Stomach, liver, pancreas, skin, profuse bleeding, syphilitic tissue, herpes sores, melanoma, vocal cords, tonsils	Removal of tissue, sprained joint, cancerous tissue, fallopian tube
Erbium-YLF	Infrared, 12,280	Eye tissue	Ophthalmology
Ruby	Visible, 6943	Retinopathy, melanoma, skin blemishes	Eye disorders, cancerous tissue
Copper vapor	Visible, 5105	Herpes sores	Excision



Beam Penetration in Skin

- Nd:Yag penetrates the most: 4.2 mm typical
- CO_2 relatively shallow: 0.23 mm

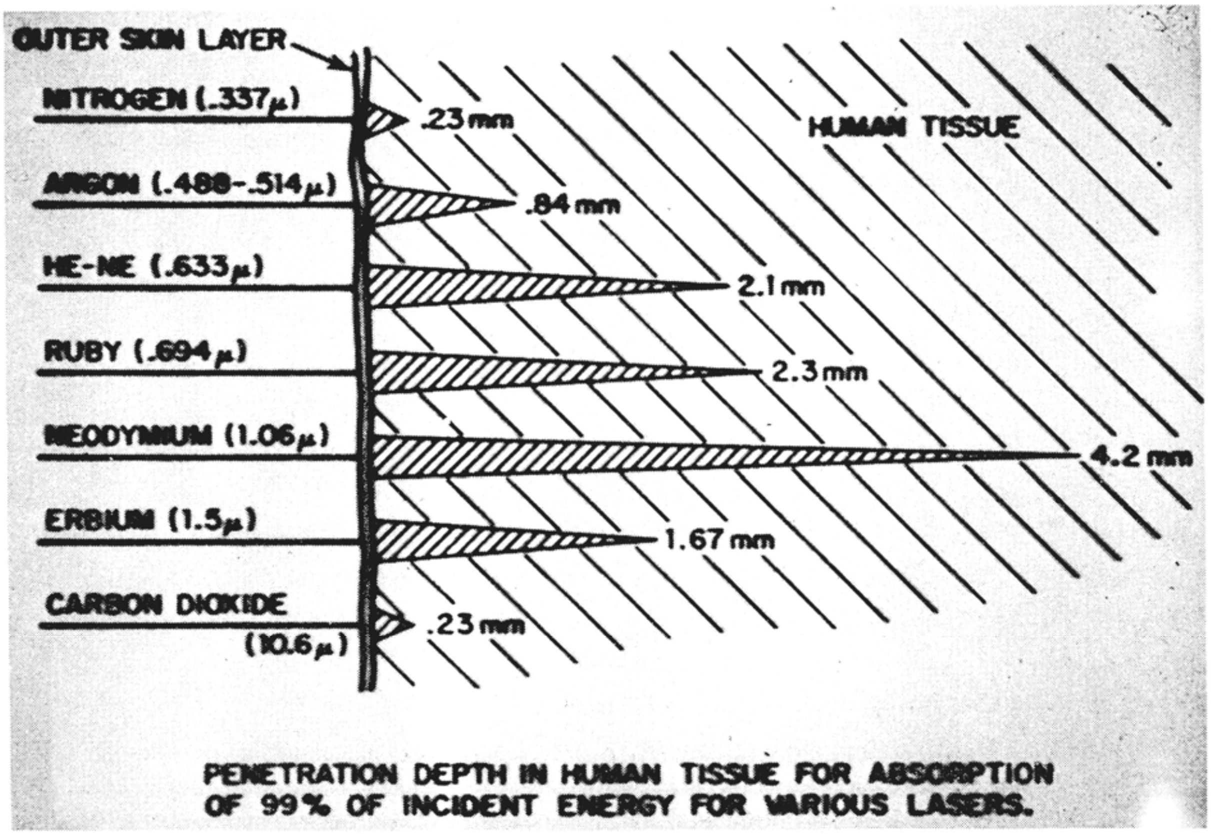
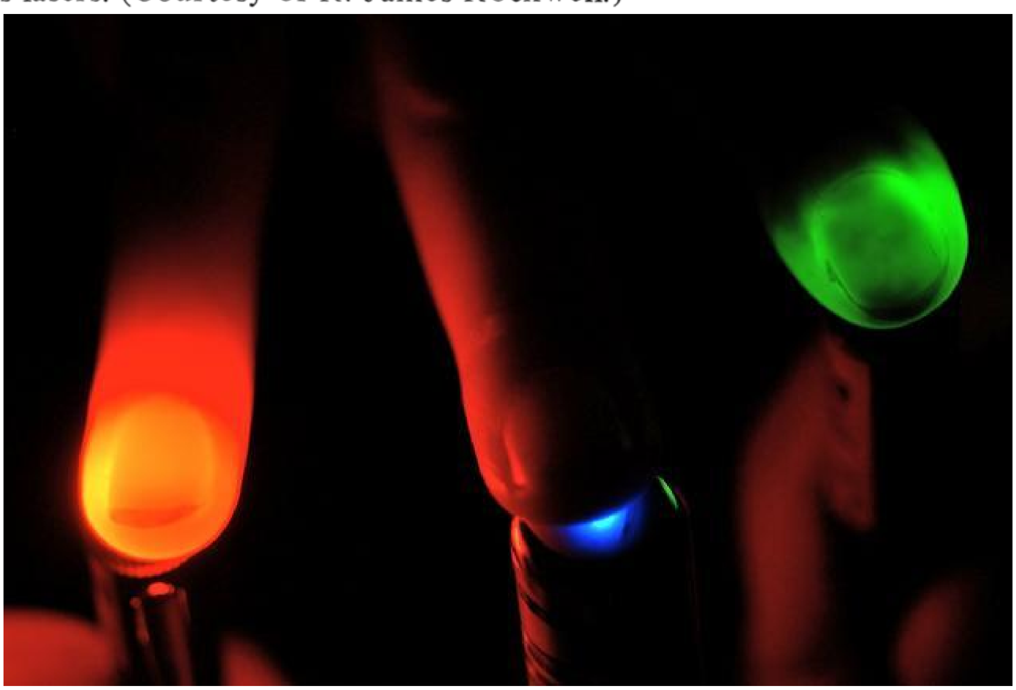


Figure 7.1 Comparative depth of penetration of laser energy in human tissue for various lasers. (Courtesy of R. James Rockwell.)



Laser Surgery

- Laser beam cuts and removes tissue
- Beam precisely positioned and automated
- Can reach inaccessible areas
- CO_2 laser uses rotating mirrors at joint in enclosed tube
- Nd:YAG or Argon uses fir

  & fiber optics (Nd:Yag)
- Limited damage to adjacent tissues
- Cauterizes nearby blood vessels - reduces bleeding

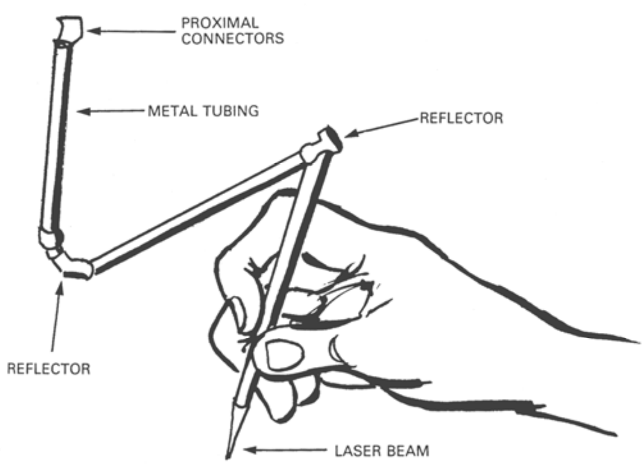


Figure 10-11 An experimental CO_2 articulated waveguide currently in use. (After Bell Laboratories.)

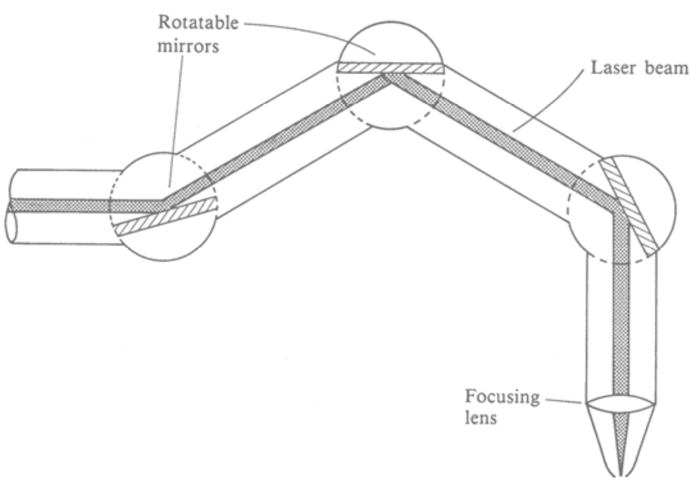


Fig. 5.21 Schematic diagram of articulated arm beam delivery system for use with CO_2 lasers in surgery.

Laser Operations using Fiber Optics

- Fiber optic cables contain light guides
- Very small, thus easy to insert into body
  removes need for major surgery in some cases
- Same fiber bundle can also transmit image of scene
- Eg Coronary Bypass & Stroke Prevention
  problem is build up of plague Artery
  reduces Artery size, causes stroke
- Fiber inserted into artery
- Plague absorbs Argon laser light
  removed from walls
  Plague has different absorption from Artery Walls

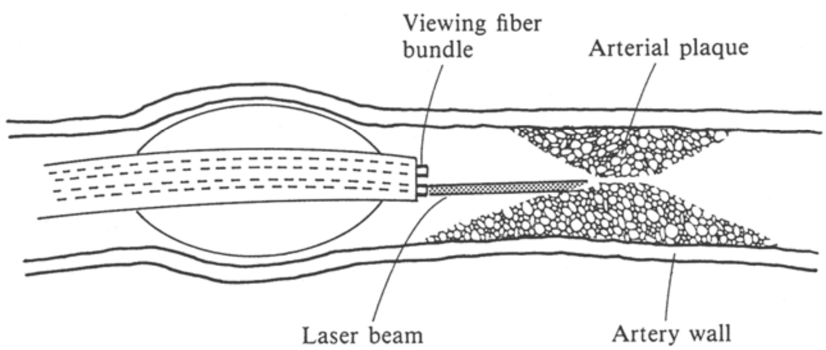
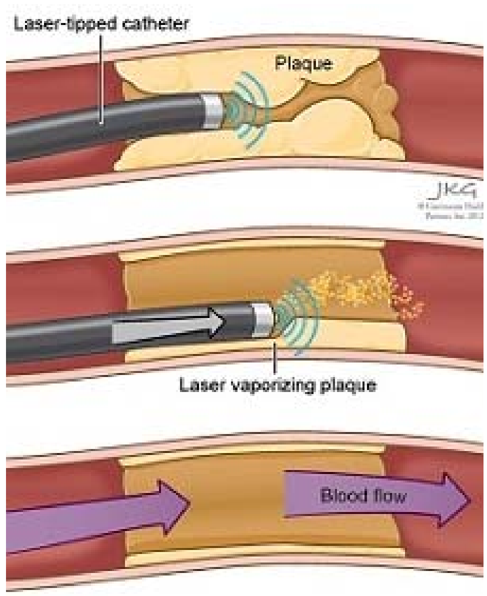
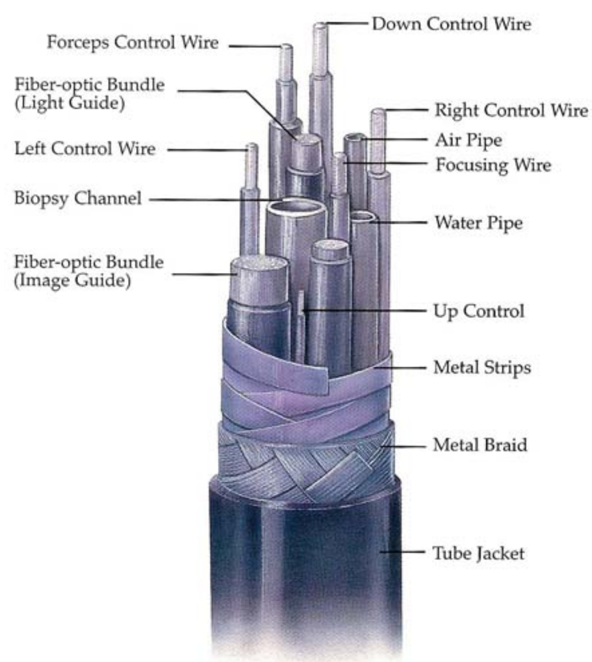


Fig. 5.22 Removal of arterial plaque using laser radiation carried down an optical fiber inserted into the artery. A viewing fiber bundle is also incorporated.





Oral &Throat Laser Surgery

- Laser Vocal Cord surgery: removal of cancer & pre cancer nodals
- Cuts of nodals on vocal cords before turn cancerous
- Also cut out cancer growths
- Laser Tonsillectomy uses CO_2 with mirror bouncing system
- Operation takes 15 minutes, no pain
- Cauterizes blood vessels & Lymphatic vessels no blood in throat
- Patient eat & drink just after operation unlike regular surgery

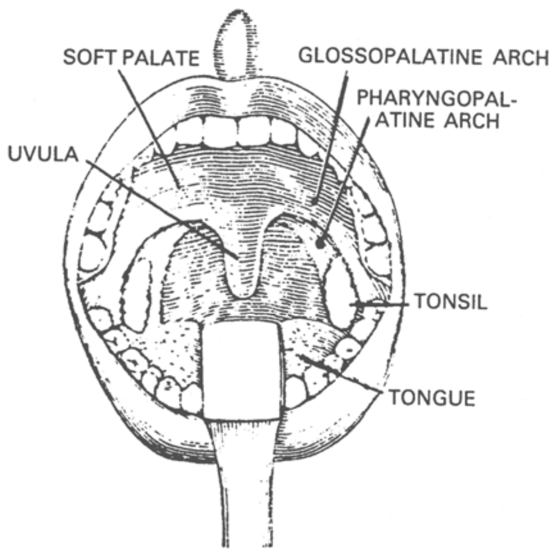
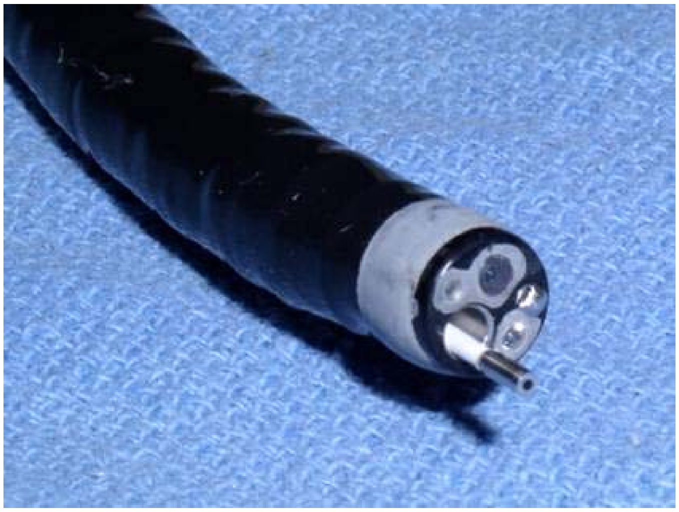


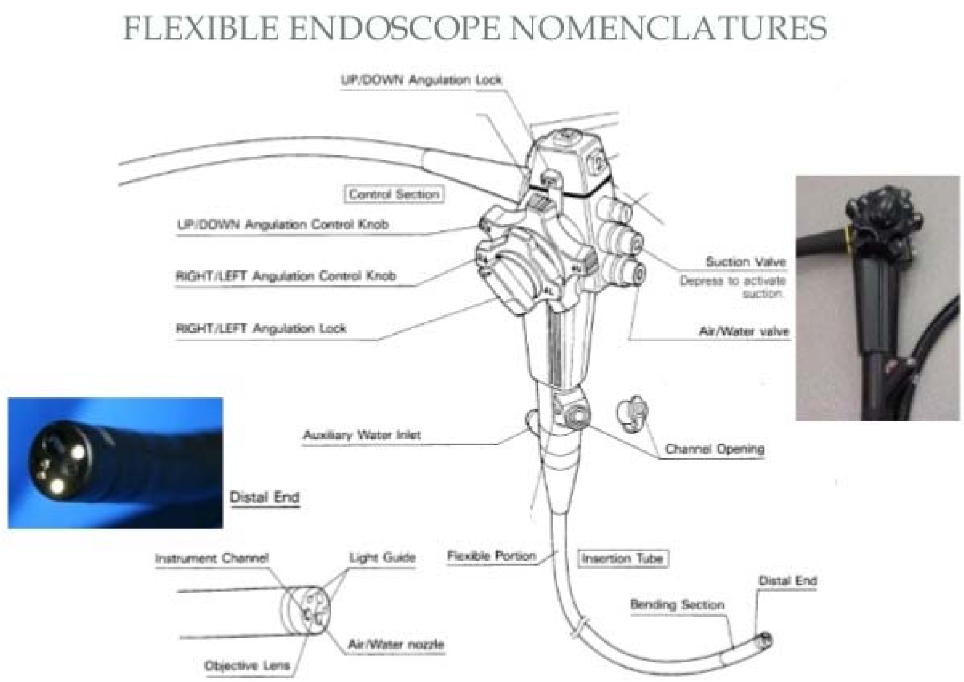
Figure 10-5 Front view of the tonsils, with open mouth.



Vocal Cord Nodals

Gastrointesinal Surgery

- Uses fiber to bring in Argon Beam
  Same system my combine CO_2 gas to remove blood
- Cauterizes blood vessels
- Beam used to stop bleeding internally
- Esophagus, Stomach & Intestines
- Endoscopic (Fiber Optic) Laser
- Fallopian Tube Surgery: remove blockages
  common cause of infertility in Women
- Use Endoscopic Laser
  fiber optic direction of CO_2 beam
- Burns away blockages, in 1-2 pulses



Throat through Endoscope

Laser Dermatology (Skin Operations)

- Use the ability of the Laser to penetrate the skin
- Most common Argon laser removing skin discolourations
- eg Portwine marks: blood coloured birth defects
- Argon laser bleaches out blood spots
- Green light strongly absorbed by the red blood colour defects
- Much less absorbed by skin

Almost removes such spots as they are near the surface

Laser Tatoo Removal

- Laser tattoo removals: done with Nd:Yag
- Nd:Yag Near IR light penetrates skin to tattoo depth
- Near IR strongly absorbed by dye: bleaches tattoo dye
- but is weakly absorbed by skin so no damage to skin
- Breaks down die particles – removed by the body
- Costs 10x more to remove the tattoo than to put it on

Photoradiation Therapy

Herpes

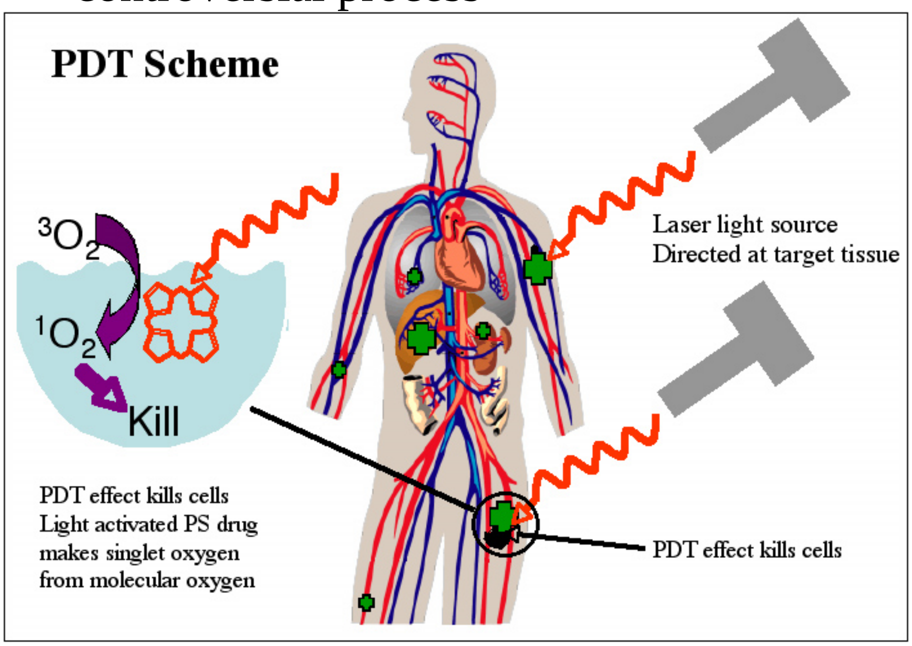
- Uses laser light to cause direct or indirect treatment
- eg Herpes virus creates lesions in skin and moist tissue
- Little in conventional treatment
- CO_2 used to destroy diseased cells & virus
- Beam directed on lesions using a microscope
  destroys tissue without bleeding

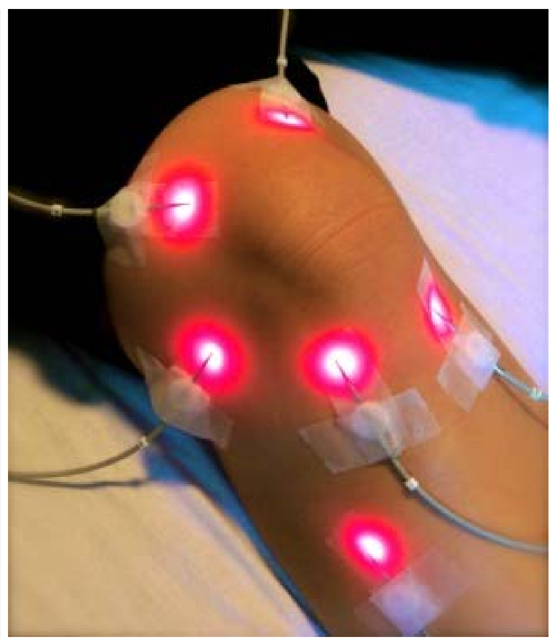
Cancer PhotoDynamic Therapy (PDT)

- Patient injected with dye (eg HpD)
- Dye absorbed preferentially by Cancer tissue
  normal tissue excretes dye
- Exposed to 630 nm HpD has photochemical reaction
  produces a poison directly only in cancer tissue
- 630 nm obtained from Argon pumped Dye laser

Laser Acupuncture

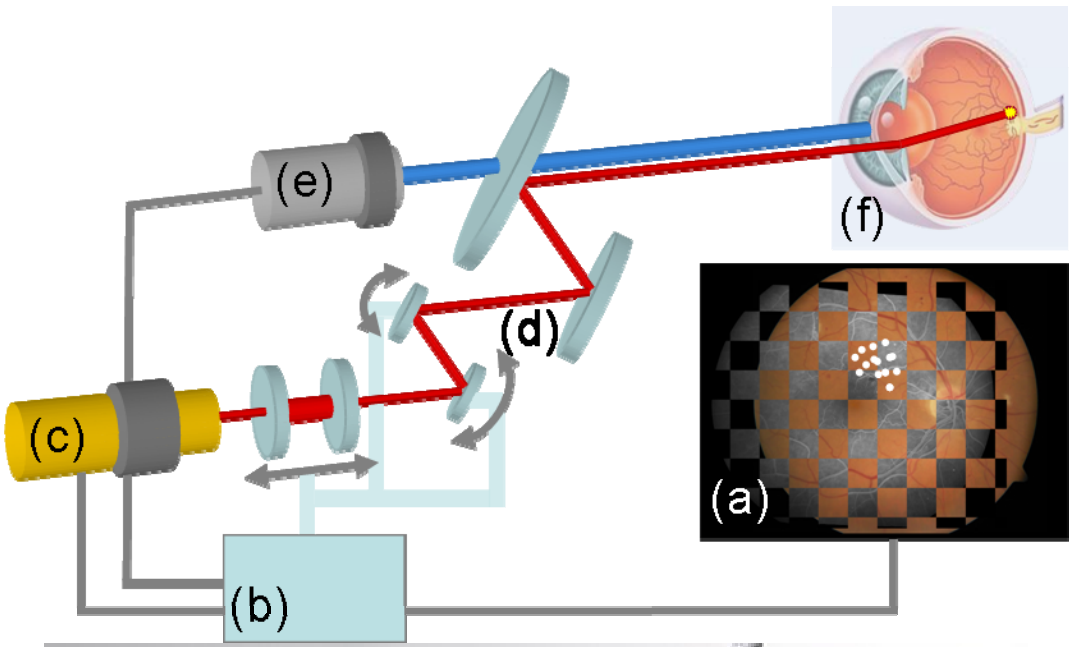
- He-Ne laser, penetrates 3-10 mm
- Laser irradiated for 60 sec at 2 mW
  controversial process





Ophthalmology (eye operations) & Dentistry

- Most common attaching detached retinas
- Uses Argon laser beam (Sometimes Ruby laser)
- Beam strongly absorbed by blood
- Creates a burn scar which reattaches retina
- Also use Nd:Yag to cut holes in cornea



Optical Applications in Tissue

- Also different tissue affects different wavelengths
- Hence can tell state of the tissue by looking at different λ
- Example blood changes colour & absorption with oxyget
- Oxygenated red, deoxygenated blue
- By looking at 650 nm see large difference in the absorption
- While at 800 nm both are same
- Simple diode sensor used for this in medical applications

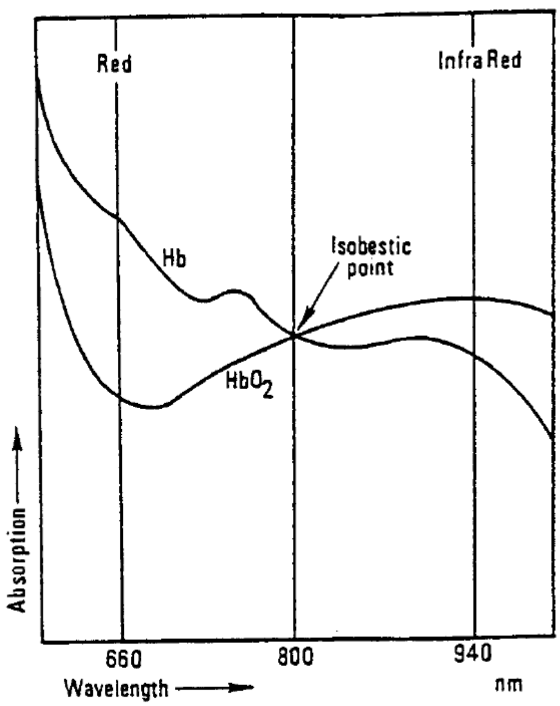


Figure 33: Absorption spectra of Hb and HbO_2