INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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H4.SMR/453-30

TRAINING COLLEGE ON PHYSICS AND CHARACTERIZATION OF LASERS AND OPTICAL FIBRES

(5 February - 2 March 1990)

SOLID STATE LASERS

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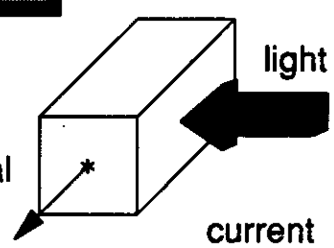
DEFINITION

□ SOLID STATE LASER

insulating crystal

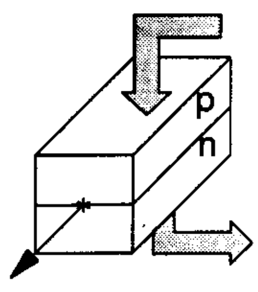
laser beam



□ SEMICONDUCTOR LASER

semiconductor crystal

laser beam



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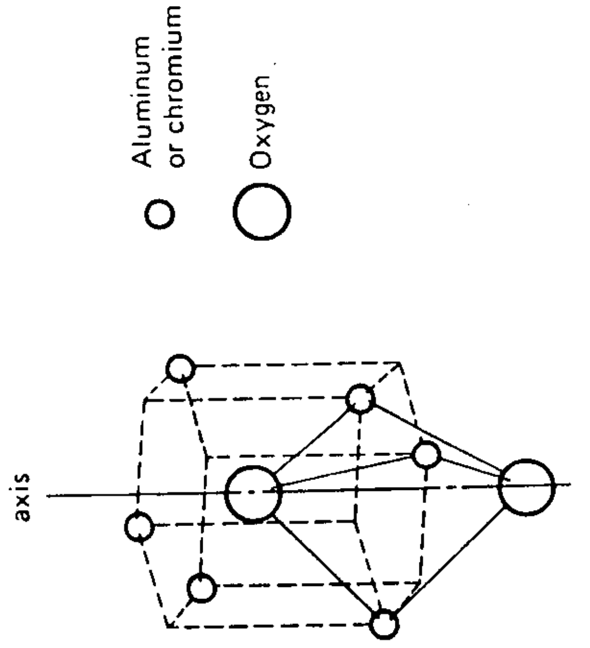
SOLID STATE LASER MATERIALS

- **HOST MATERIALS**
  - glasses (Nd:glass)
  - crystals (sapphire, garnets)
- **ACTIVE IONS**
  - rare earth (Nd, Er, Ho)
  - transition metals (Cr, Ti)

HOST MATERIALS

- **GLASSES**
  - ☐ advantages:
    - good optical quality
    - available in large size
    - low cost
  - ☐ disadvantages:
    - low thermal conductivity
- **CRYSTALS**
  - ☐ advantages:
    - high thermal conductivity
    - good mechanical properties
  - ☐ disadvantages:
    - available in small size
    - high cost

CRYSTAL STRUCTURE OF SAPPHIRE



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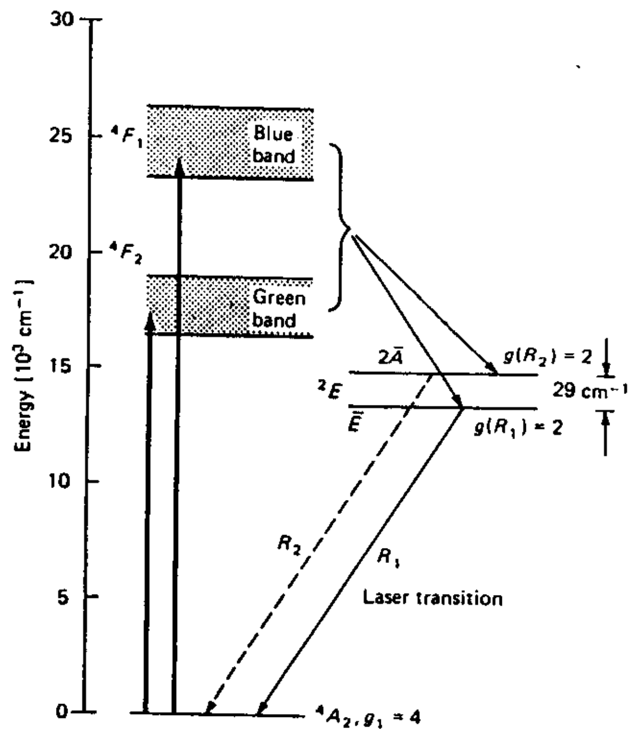
ENERGY LEVELS OF RUBY



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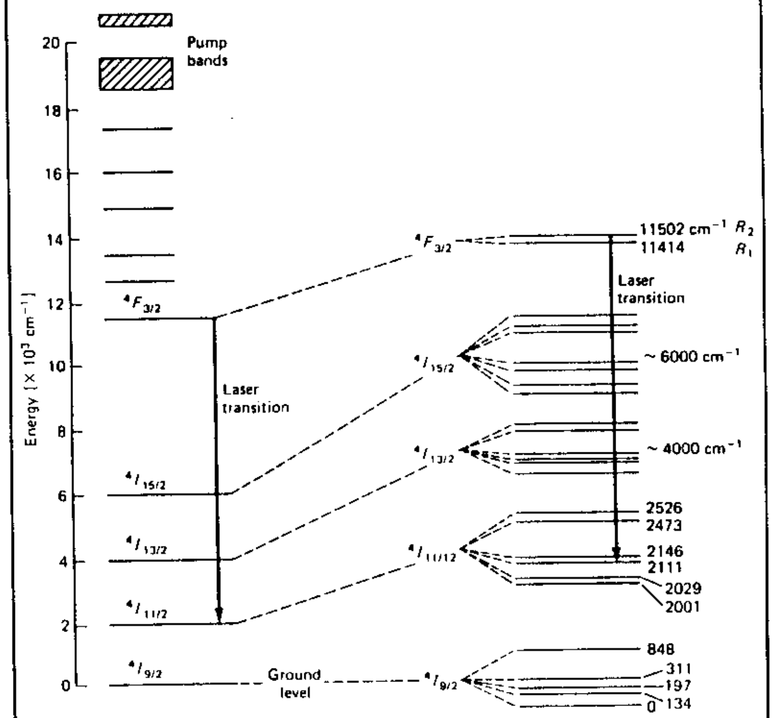
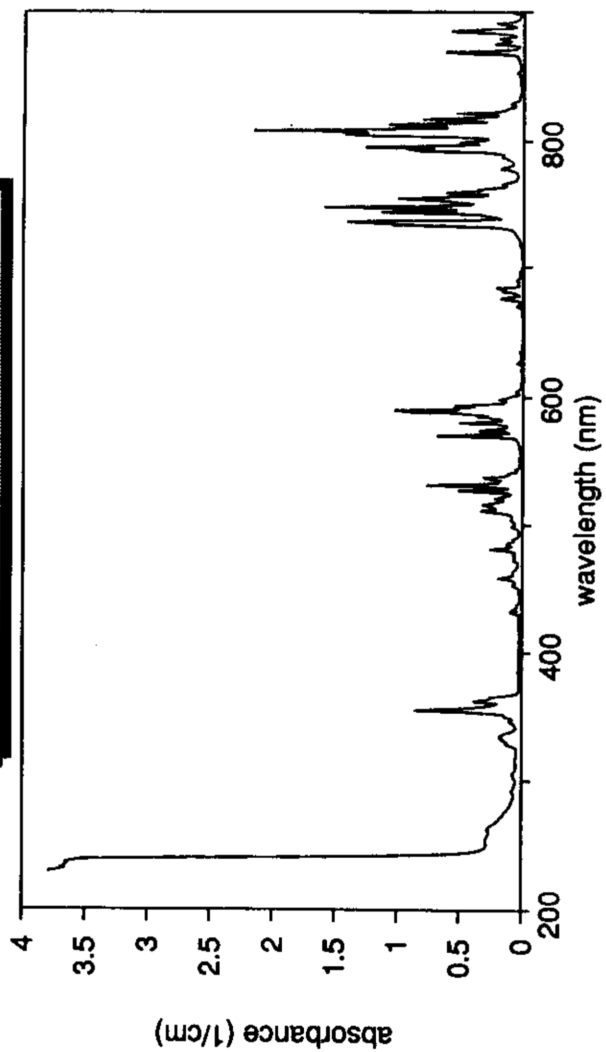
LASER PROPERTIES OF RUBY

Chemical formula	$Cr{:}Al_2O_3$
Cr doping	1.58E19 ions cm^{-3}
Emission wavelengths	694.3, 692.9 nm
Fluorescent lifetime	3.0 ms
Emission linewidth	0.53 nm
Quantum efficiency	70 %
Refractive index	1.76
Thermal conductivity	0.42 W/cm/K

ENERGY LEVELS OF Nd:YAG



Nd:YAG ABSORPTION



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LASER PROPERTIES OF Nd:YAG

Chemical formula	$Nd{:}Y_3Al_5O_{12}$.
Nd doping	1.38E20 ions cm^{-3}
Emission wavelengths	1.06414 μm
Fluorescent lifetime	0.23 ms
Emission linewidth	0.45 nm
Quantum efficiency	99.5 %
Refractive index	1.82
Thermal conductivity	0.13 W/cm/K

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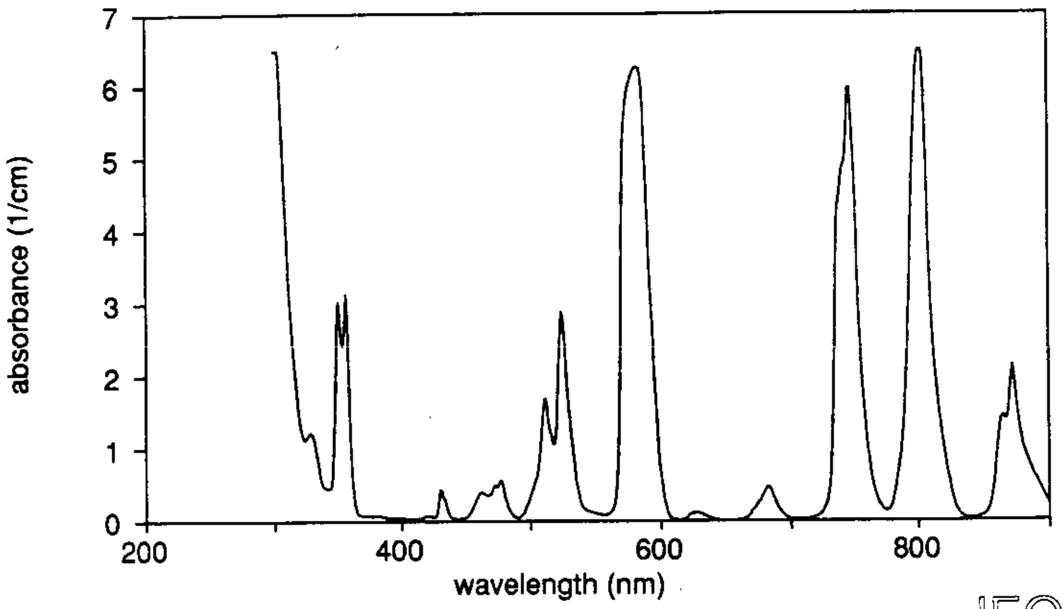
Nd:GLASS ABSORPTION



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PROPERTIES OF LASER GLASSES

Type	LG-680 Silicate	APG-1 Phosphate	LG-750 Phosphate	LG-760 Phosphate
Property:				
Refractive Index at Laser Wavelength	1.560	1.526	1.516	1.508
Refractive Index at 587.56 nm	1.570	1.535	1.526	1.519
Abbe Number	57.7	67.6	68.2	69.2
Laser Wavelength (nm)	1061	1052	1053.5	1053.5
Cross Section (10^{-20}cm^2)	2.9	3.5	4.0	4.2
Fluorescence Lifetime (μsec)	>350	>360	>360	>350
Non-linear Refractive Index (10^{-13}esu)	1.60	1.12	1.08	1.02
Temp. Coeff. Refractive Index (10^{-6}/K)	2.9	1.2	-5.1	-6.8
Temp. Coeff. Optical Path (10^{-6}/K)	8.1	5.2	0.8	0.4
Density (g/cm^3)	2.54	2.64	2.83	2.60
Elastic Modulus (1000 N/mm^2)	90.1	71.0	50.1	53.7
Poisson's Ratio	0.242	0.239	0.256	0.267
Thermal Expansion Coeff., 20-40°C	93	76	114	125
Thermal Conductivity (W/mK)	1.35	0.83	0.62	0.67
Pt-free?	no	yes	yes	yes
FOM*	1.22	1.17	0.81	0.73

*FOM = $\frac{K(1-\nu)}{\alpha E}$, excluding fracture toughness, S.

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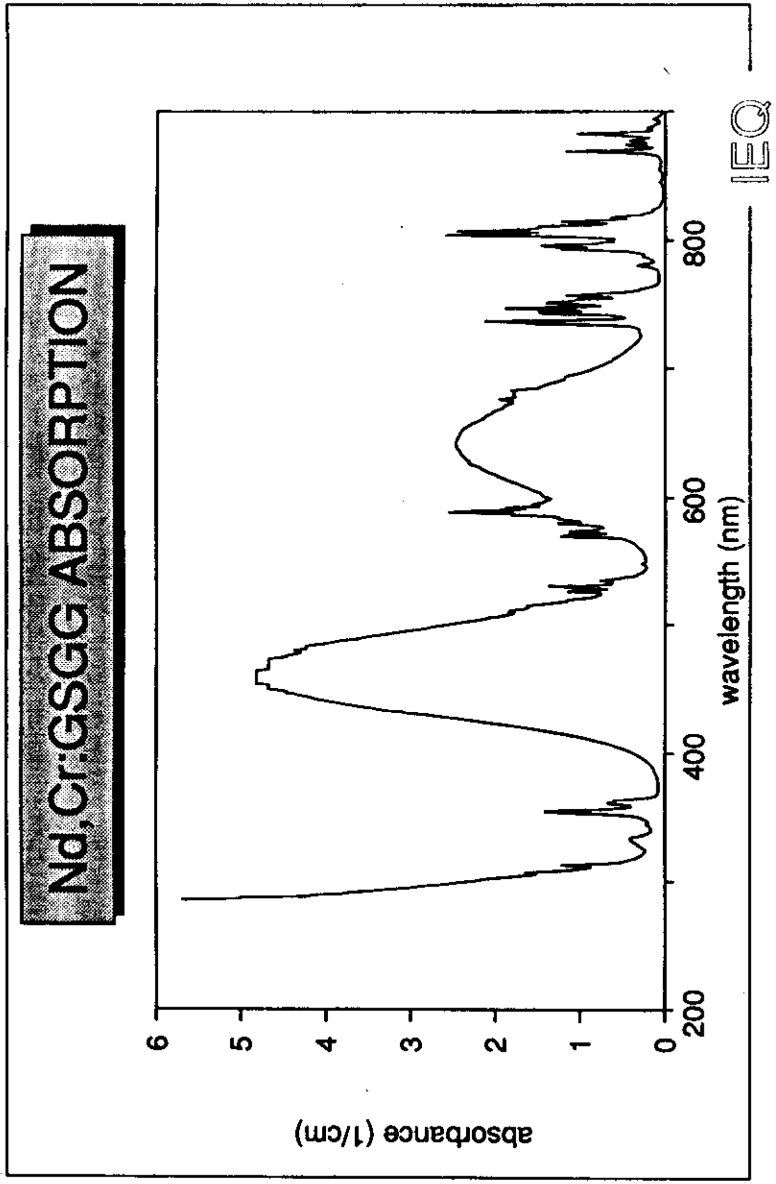

LASER PROPERTIES OF Nd,Cr:GSGG

Chemical formula	$Nd,Cr:Gd_3Sc_2Ga_3O_{12}$
Nd doping	1.6 %
Cr doping	2.5 %
Emission wavelengths	1061.2 nm
Fluorescent lifetime	0.24 ms
Emission linewidth	0.5 nm
Quantum efficiency	90 %
Refractive index	1.95
Thermal conductivity	0.06 W/cm/K

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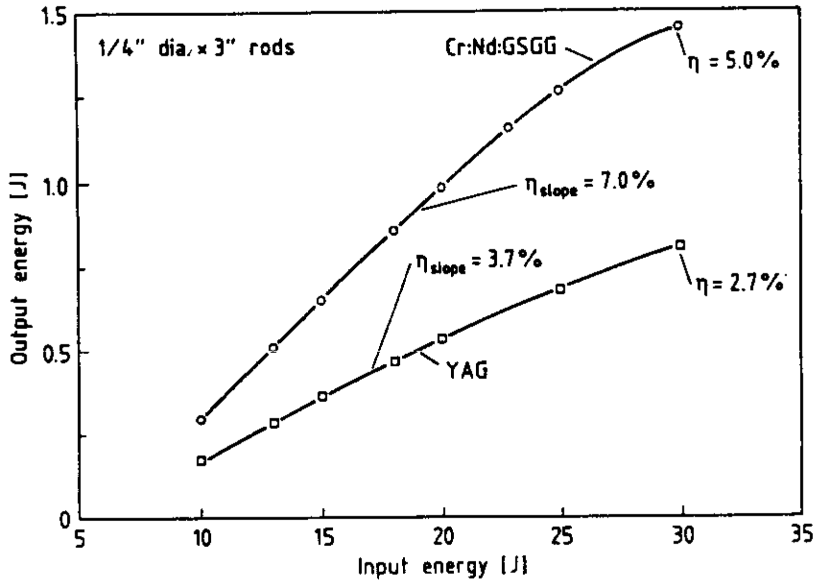
EFFICIENCY OF YAG AND GSGG



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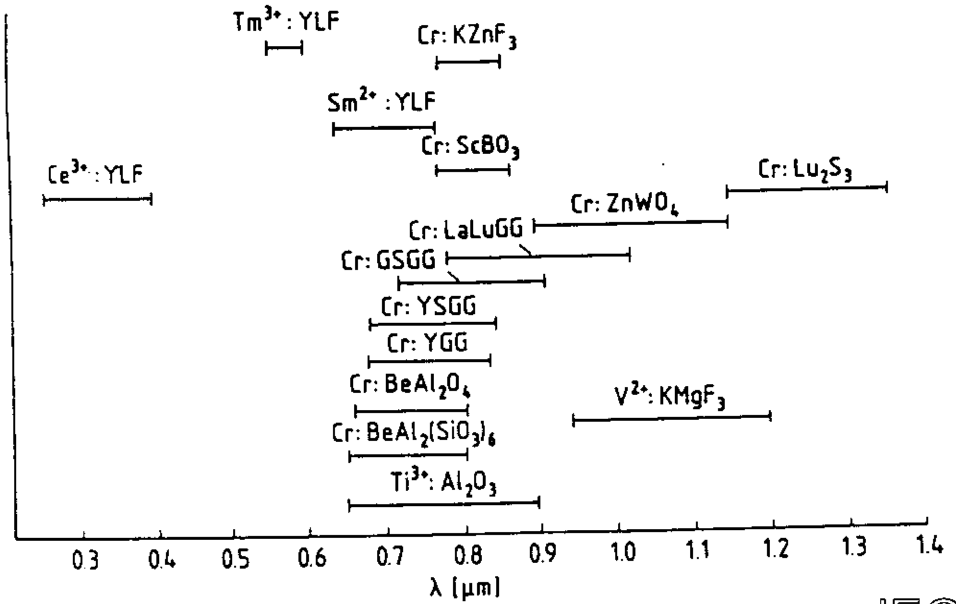
TUNABLE RANGE OF VIBRONIC LASERS



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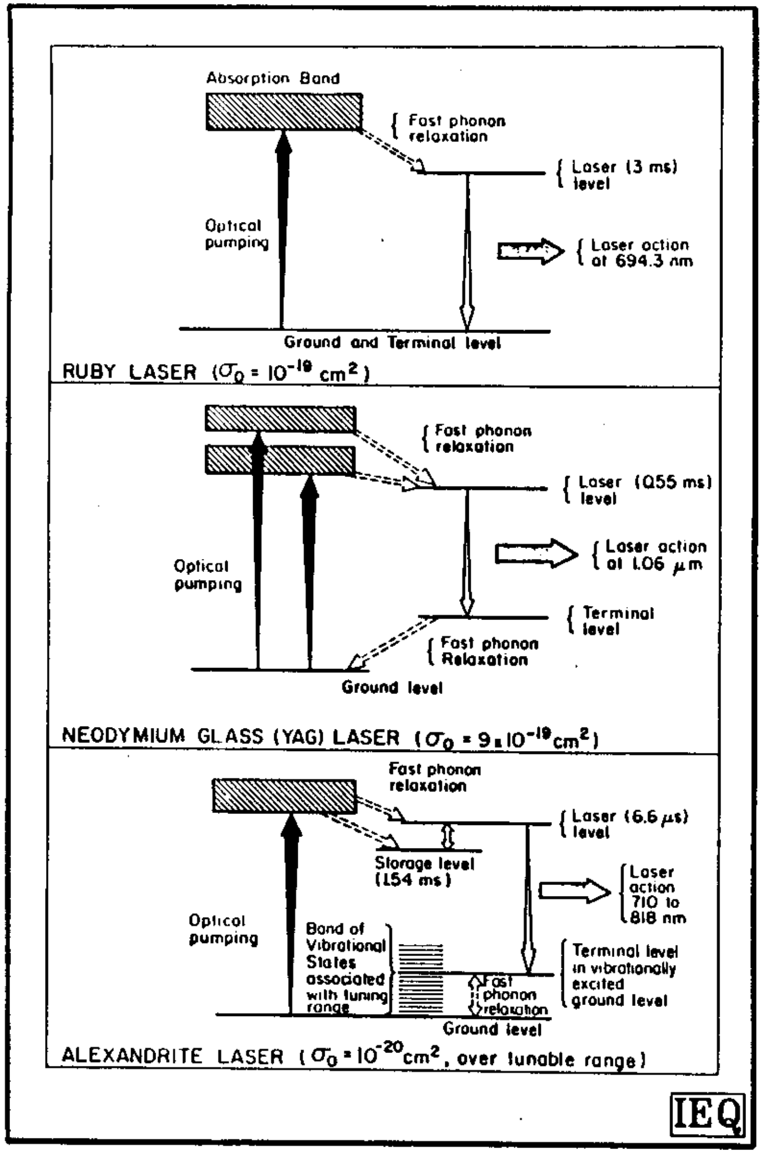

Absorption Band
Fast phonon relaxation
Laser (3 ms) level
Optical pumping
Laser action at 694.3 nm
Ground and Terminal level
RUBY LASER ($\sigma_0 = 10^{-19}$ cm^2)
Fast phonon relaxation
Laser (0.55 ms) level
Optical pumping
Laser action at 1.06 μm
Terminal level
Fast phonon Relaxation
Ground level
NEODYMIUM GLASS (YAG) LASER ($\sigma_0 = 9 \times 10^{-19}$ cm^2)
Fast phonon relaxation
Laser (6.6 μs) level
Storage level (1.54 ms)
Laser action 710 to 818 nm
Optical pumping
Band of Vibrational States associated with tuning range
Fast phonon relaxation
Terminal level in vibrationally excited ground level
Ground level
ALEXANDRITE LASER ($\sigma_0 = 10^{-20}$ cm^2, over tunable range)
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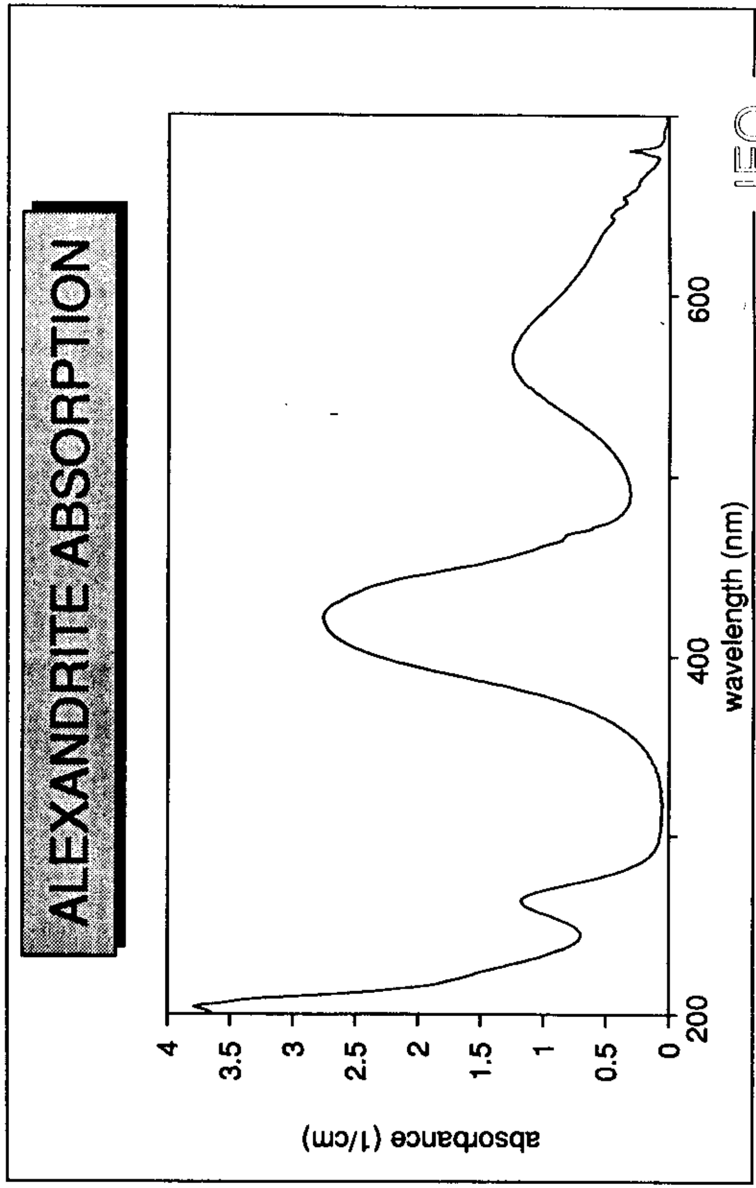

ALEXANDRITE ABSORPTION
absorbance (1/cm)
4
3.5
3
2.5
2
1.5
1
0.5
0
200
400
600
wavelength (nm)
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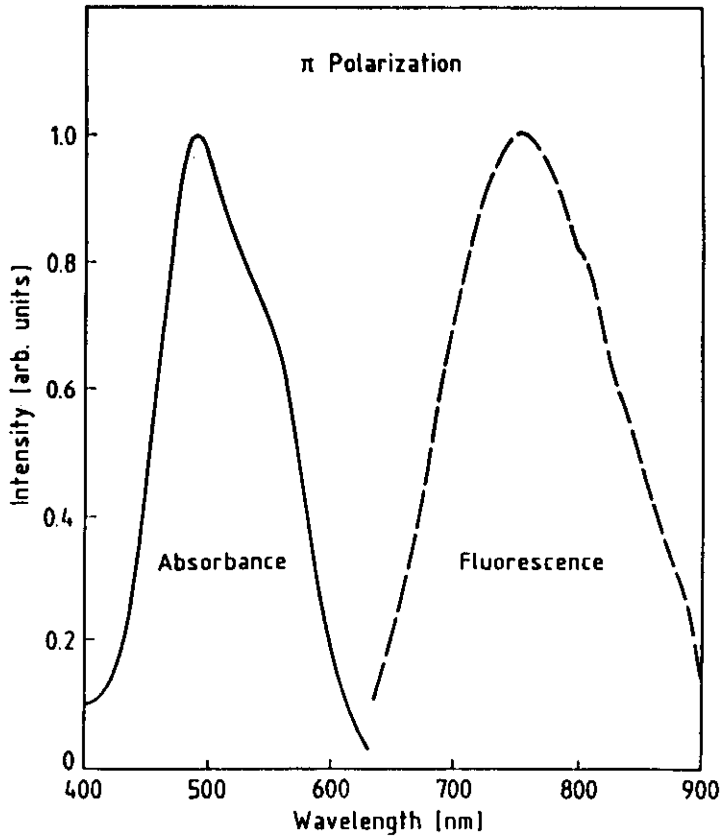
LASER PROPERTIES OF ALEXANDRITE

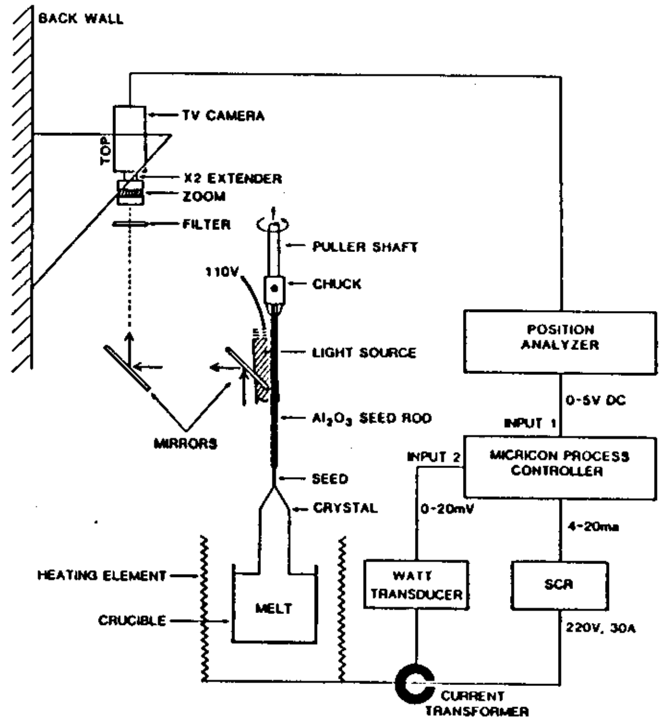
Chemical formula	$Cr{:}BeAl_2O_4$
Cr doping	0.3 %
Emission wavelengths	700-818 nm
Fluorescent lifetime	0.26 ms
Emission linewidth	100 nm
Quantum efficiency	70 %
Refractive index	1.74
Thermal conductivity	0.23 W/cm/K

ABSORPTION AND FLUORESCENCE OF TI:SAPPHIRE

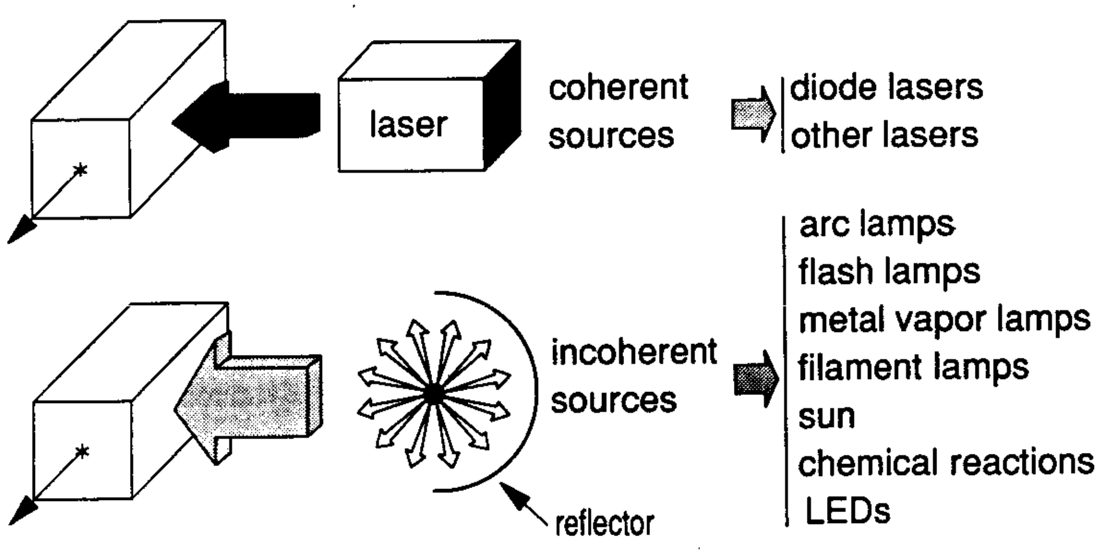


LASER PROPERTIES OF Ti:SAPPHIRE

Chemical formula	$Ti:Al_2O_3$
Ti doping	0.2 %
Emission wavelengths	650-1200 nm
Fluorescent lifetime	3.2 μs
Emission linewidth	120 nm
Quantum efficiency	100 %
Refractive index	1.76
Thermal conductivity	0.5 W/cm/K



PUMPING SOURCES



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PUMPING LAMPS OVERVIEW

SHAPE	EMITTER	COOLING	POWER	ARC
linear	noble gas	water →	300 W/cm^2	wall stabilized
helical	mercury	forced gas →	50 W/cm^2	vortex stabilized
point	alkaly metals	convection →	25 W/cm^2	
	tungsten halogen			

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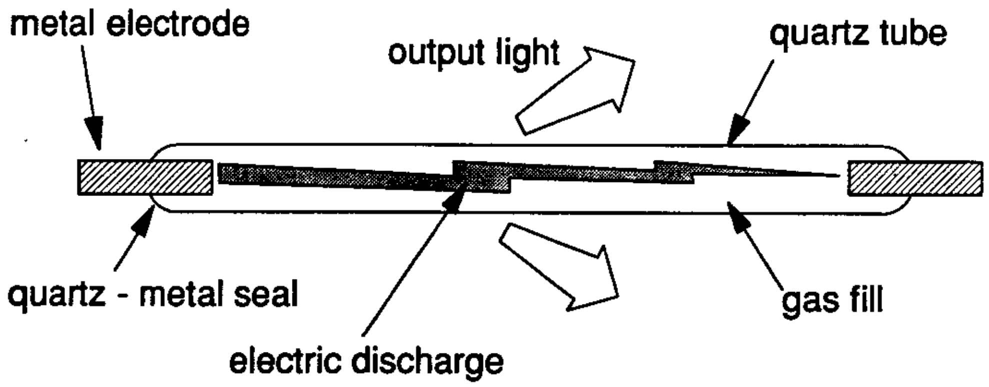
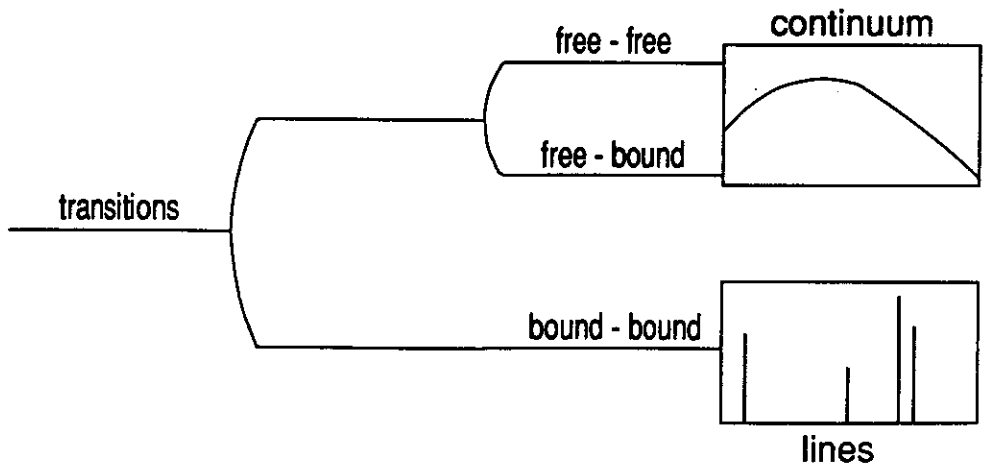
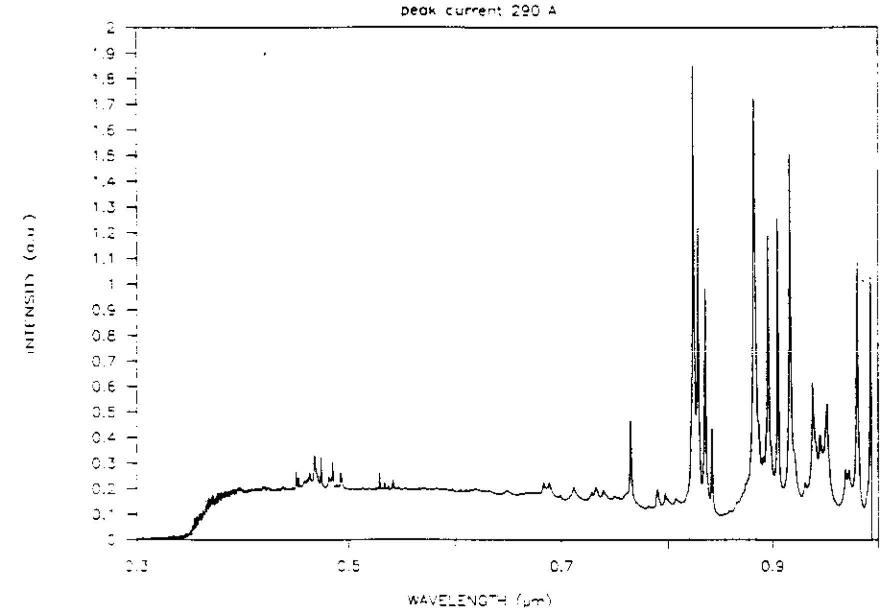
LINEAR ARC LAMP



SPECTRAL COMPONENTS



FLASHLAMPS EMISSION SPECTRA



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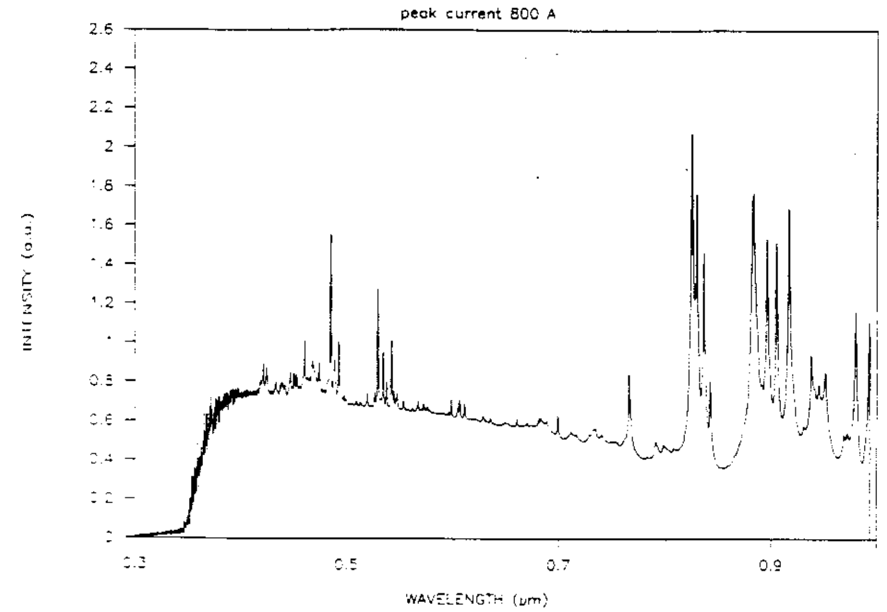
FLASHLAMPS EMISSION SPECTRA



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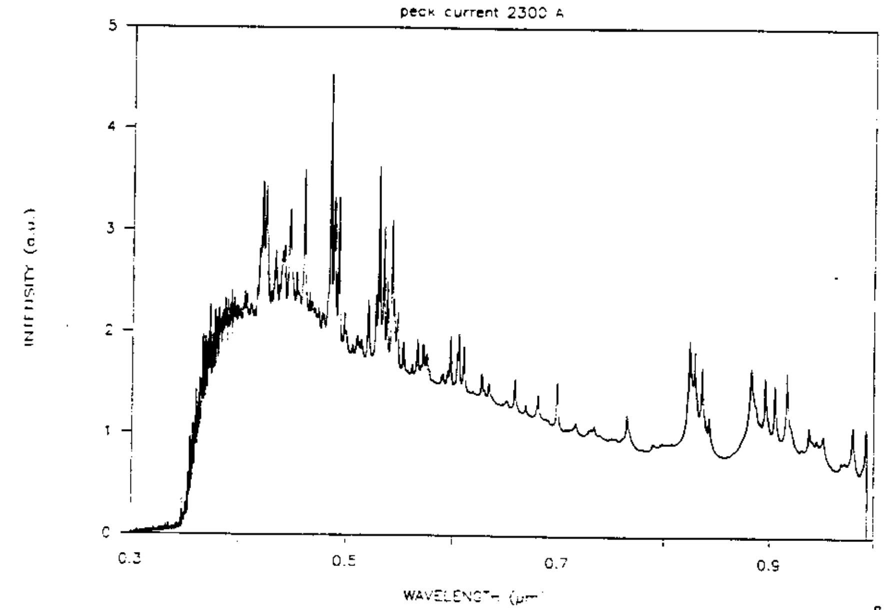
FLASHLAMPS EMISSION SPECTRA



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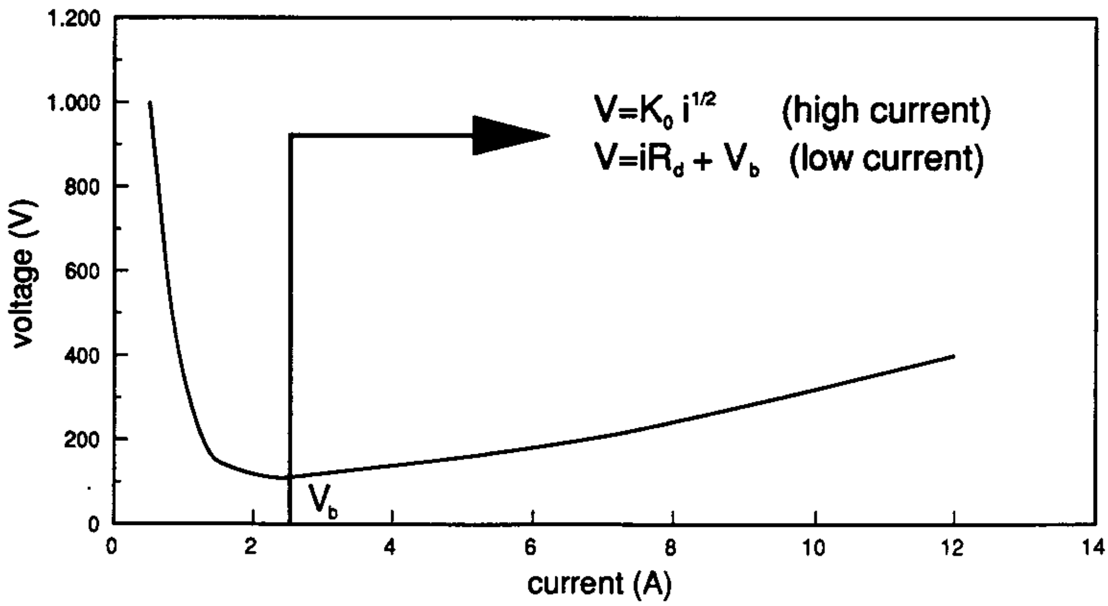
ELECTRICAL CHARACTERISTIC OF AN ARC LAMP



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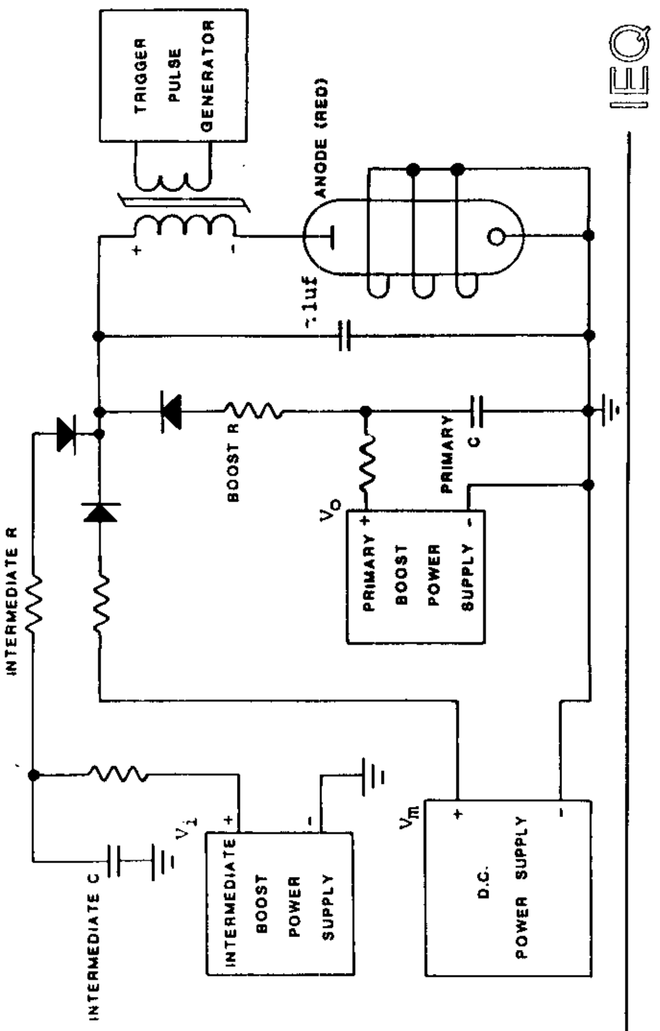
POWER SUPPLY FOR ARC LAMPS



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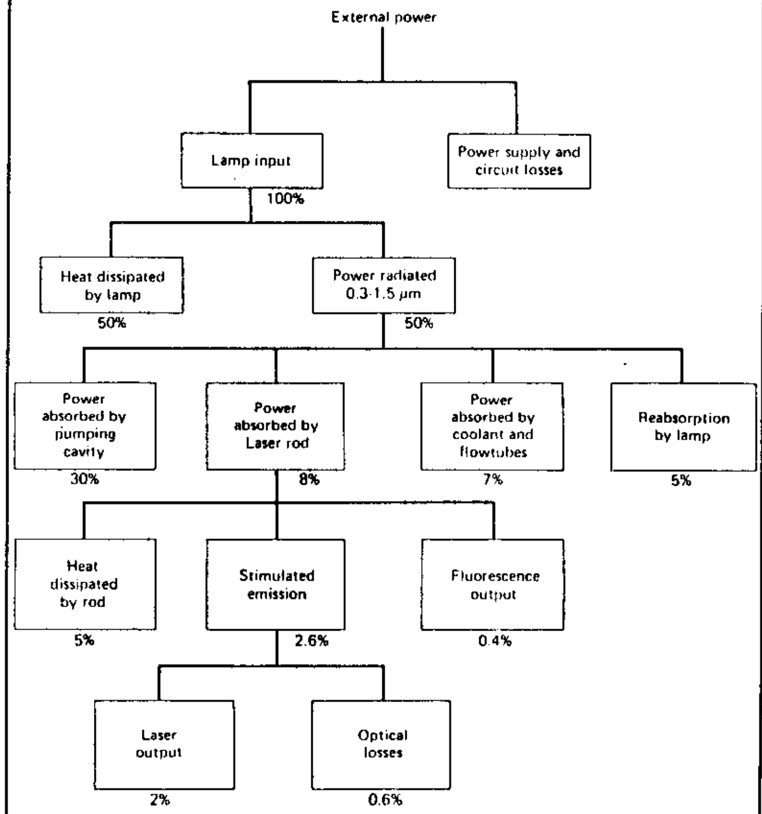
ENERGY BALANCE



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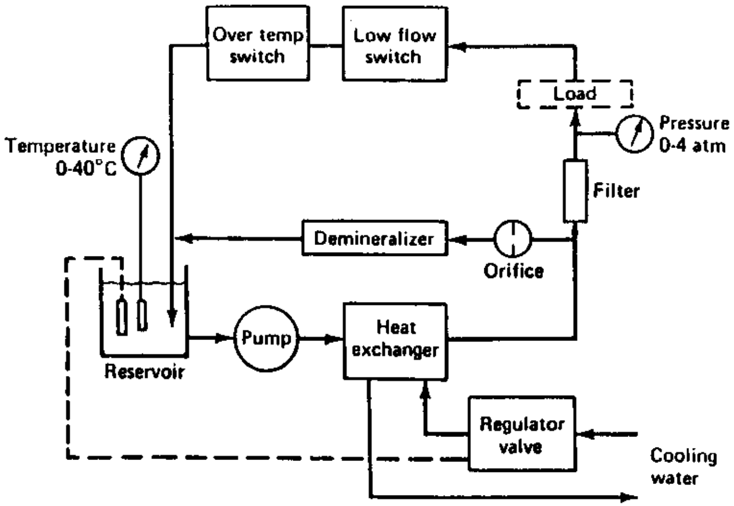
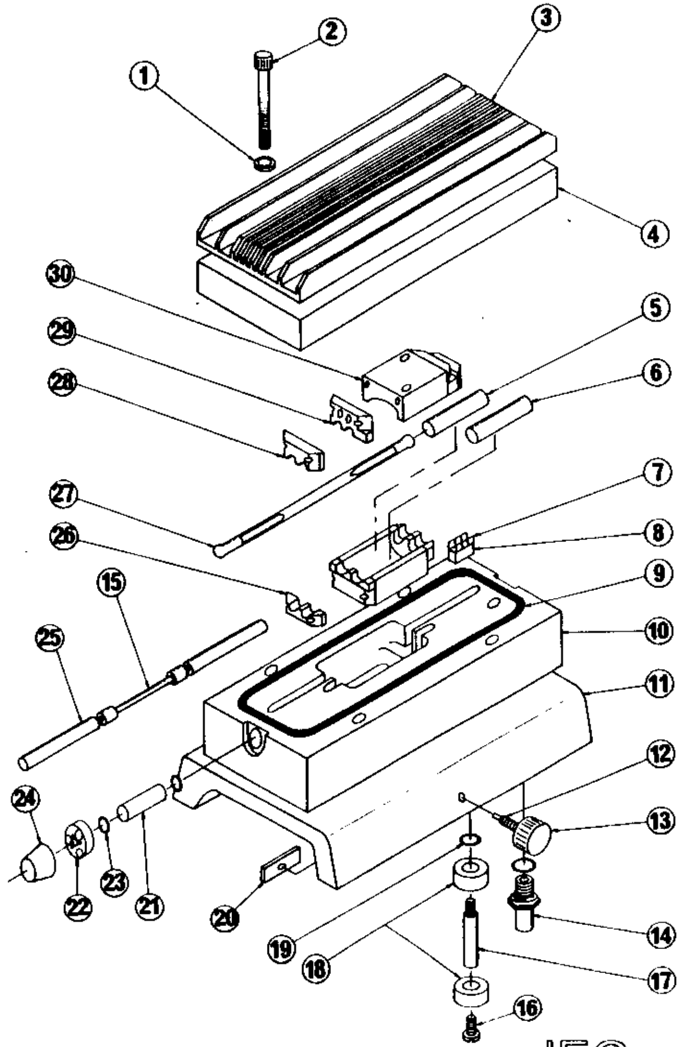
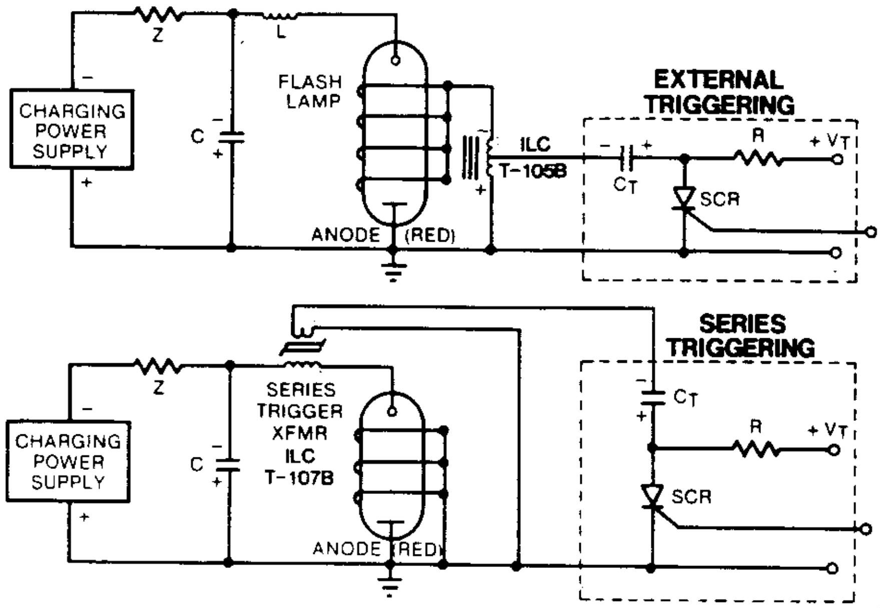
WATER COOLING SYSTEM



CW Nd:YAG LASER



FLASHLAMP DISCHARGE CIRCUITS



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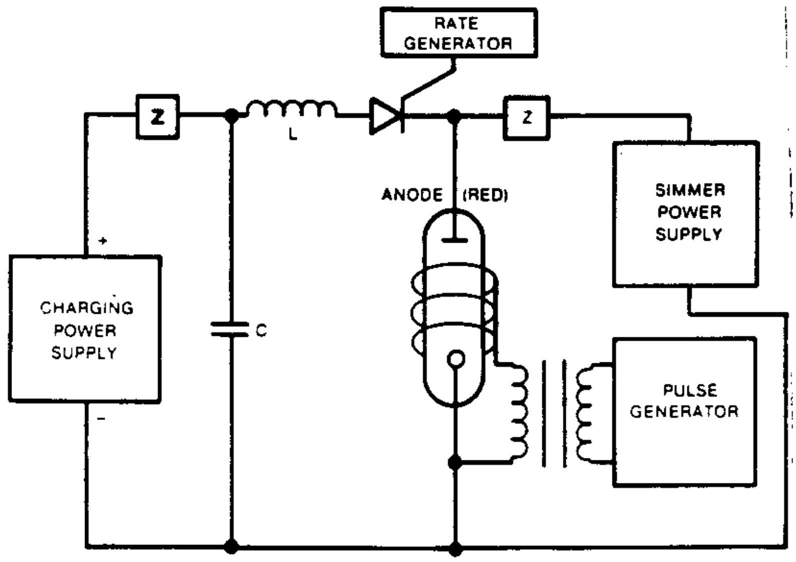
SIMMER POWER SUPPLY



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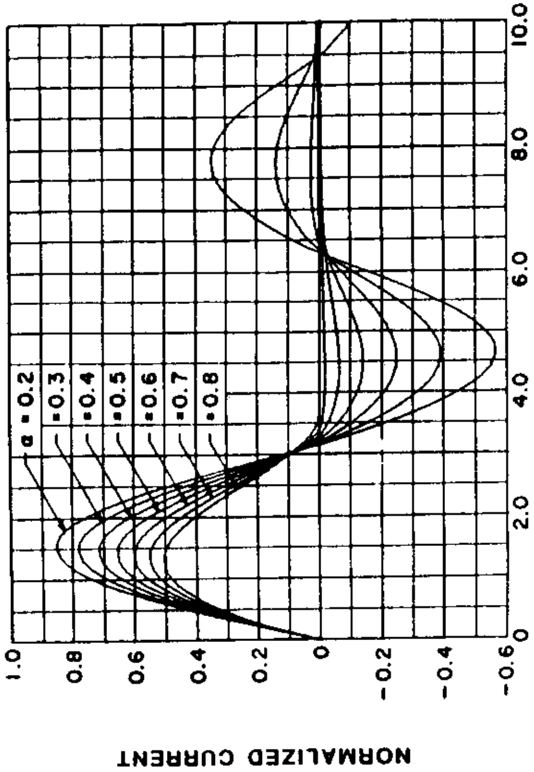
FLASHLAMPS DAMPING PARAMETER



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DISCHARGE CIRCUIT CALCULATIONS

Assumptions:

- ❒ Constant lamp impedance during the pulse
- ❒ Pulse durations from 30 μs to 10 ms
- ❒ $V=K_0\, I^{1/2}$

$$C^3 = \frac{2E_0\alpha_4 t_2}{K_0{}^4}$$

$$L = \frac{t^2}{C}$$

$$V_0 = (2E_0/C)^{1/2}$$

Where:

E_0	=	storage energy (Joules)
L	=	total inductance (henries)
C	=	capacitance (farad)
t	=	1/3 pulse width (seconds)
K_0	=	impedance parameter
V_0	=	capacitor voltage (volts)
α	=	damping factor (0.8)

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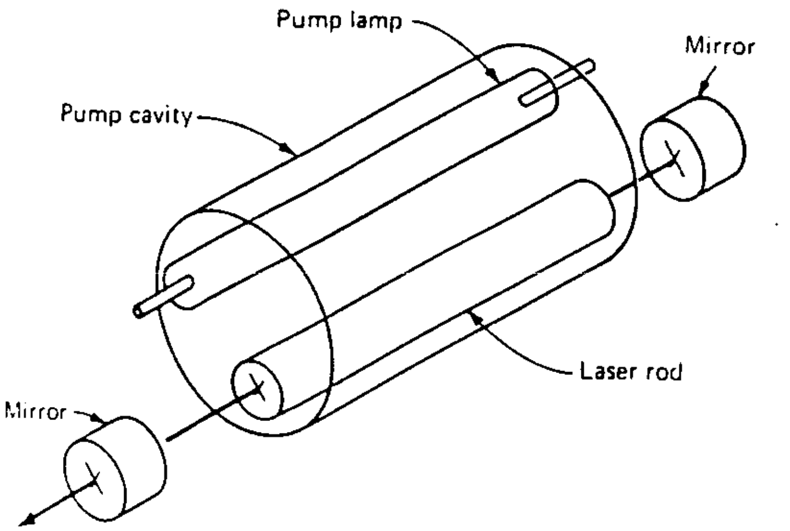
COMPONENTS OF A LAMP PUMPED LASER



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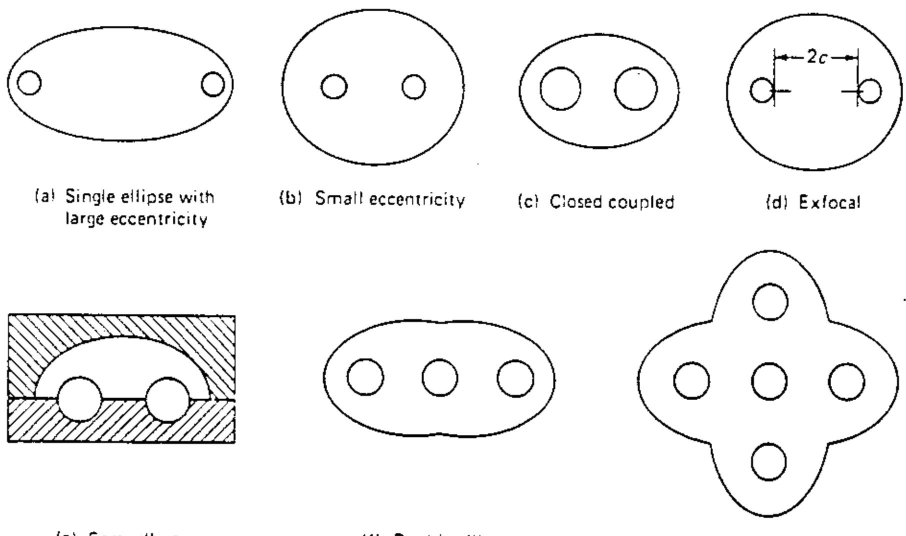

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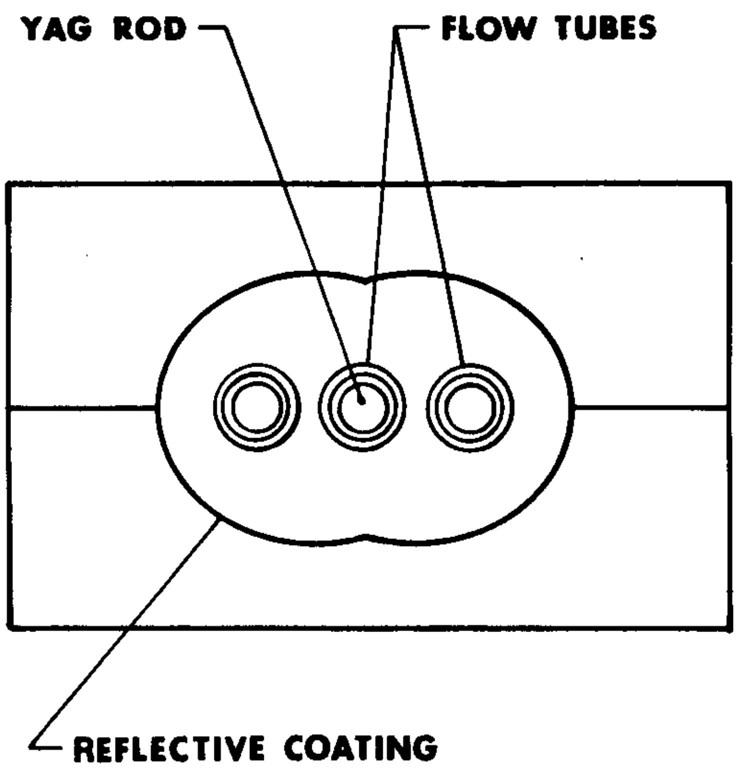
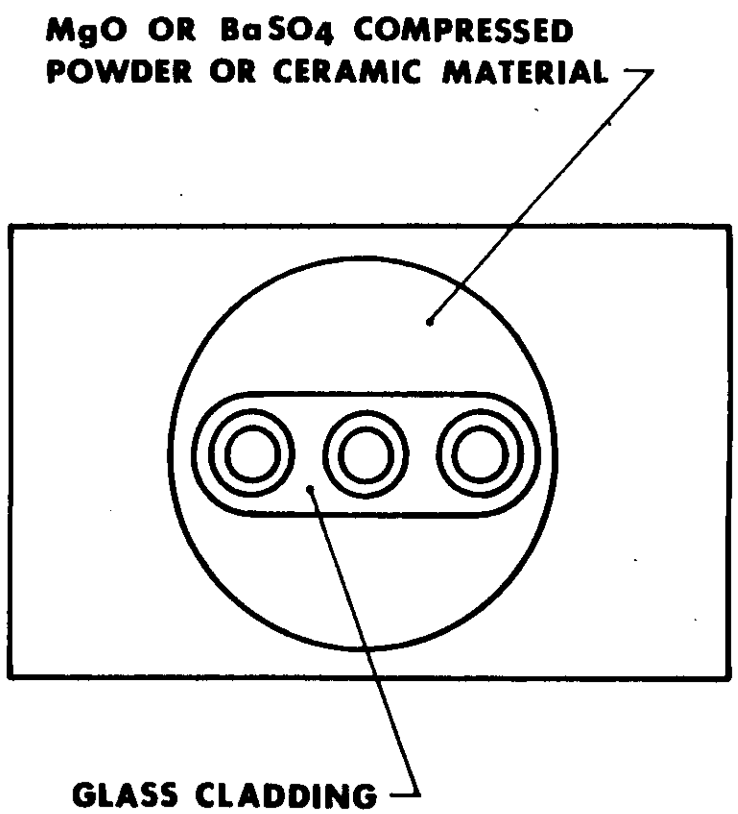
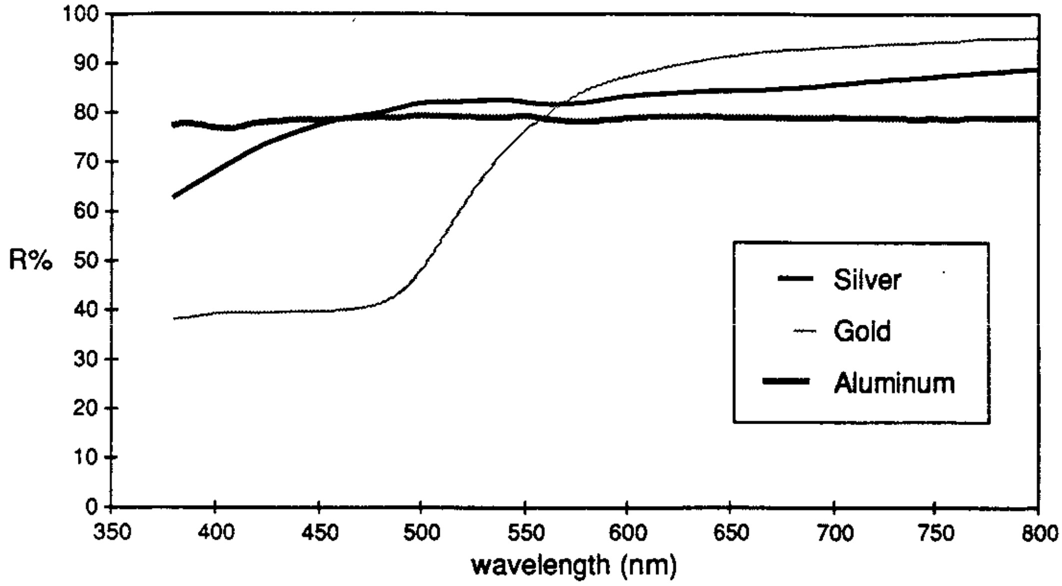
DOUBLE ELLIPSE REFLECTIVE CAVITY



CLOSE COUPLED DIFFUSIVE CAVITY



REFLECTIVITY OF METALLIC COATINGS



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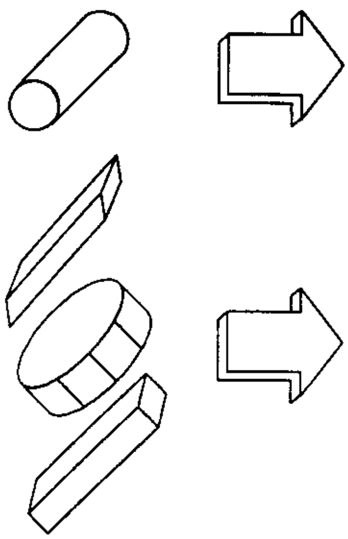
CRYSTAL GEOMETRIES

- ROD
- SLAB
- DISK
- MIRROR



- high efficiency
- small crystal

- thermal lens compensation
- good cooling

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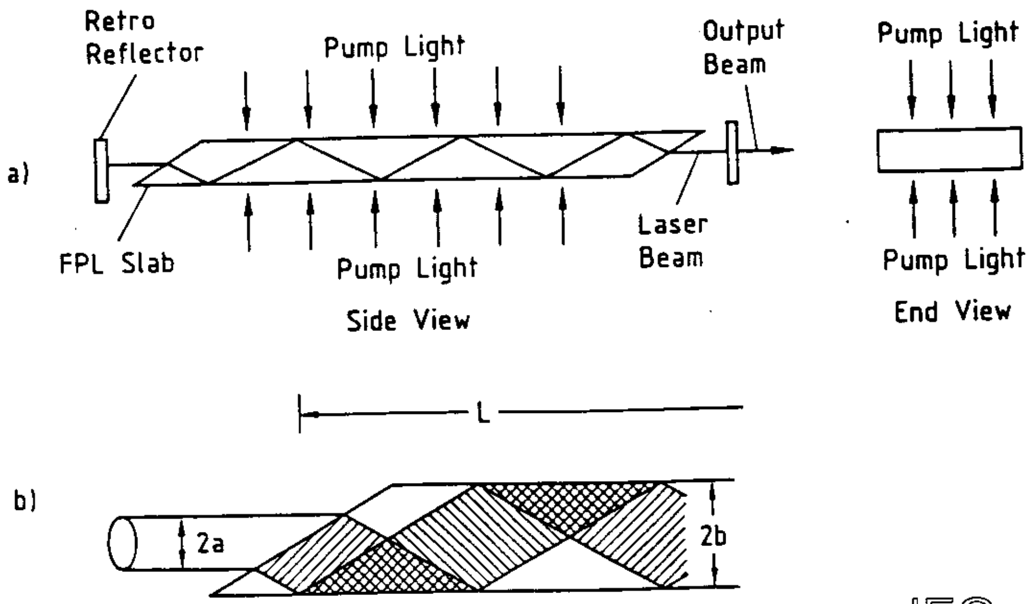
ZIG-ZAG SLAB LASER



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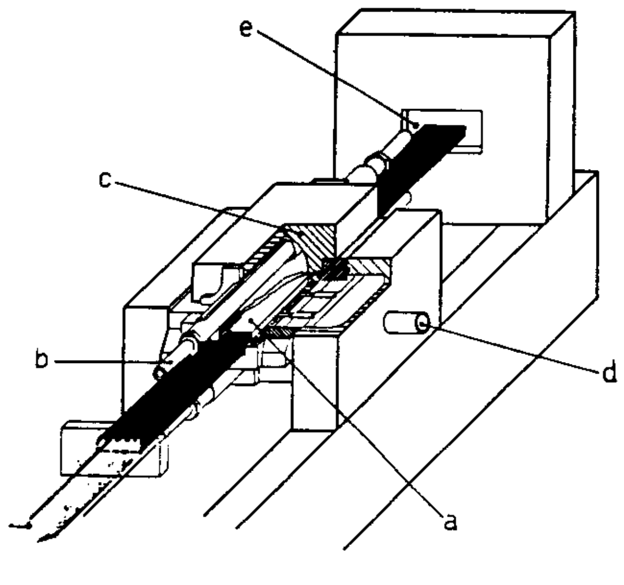
ZIG-ZAG SLAB LASER



Laser head:

a) slab

b) flashlamp

c) pumping reflector

d) slab coolant inlet

e) back mirror

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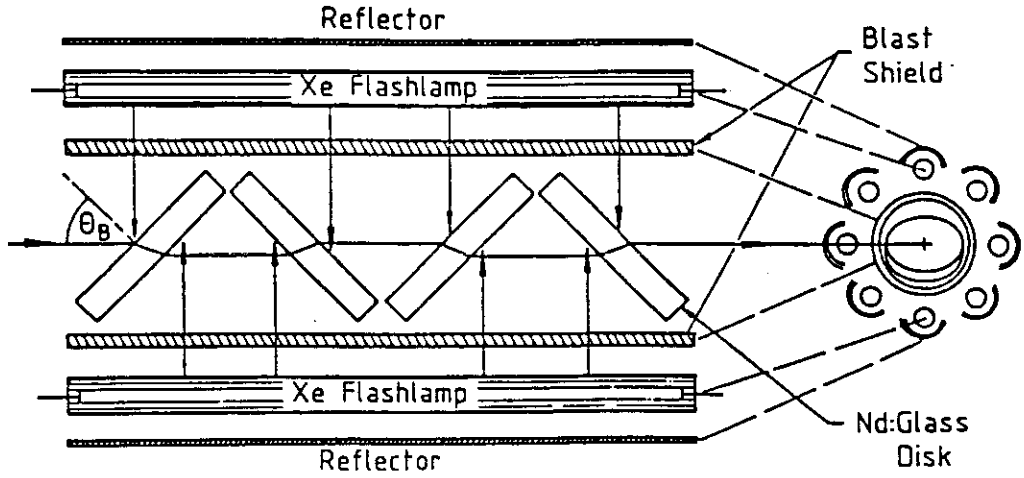
DISK AMPLIFIER



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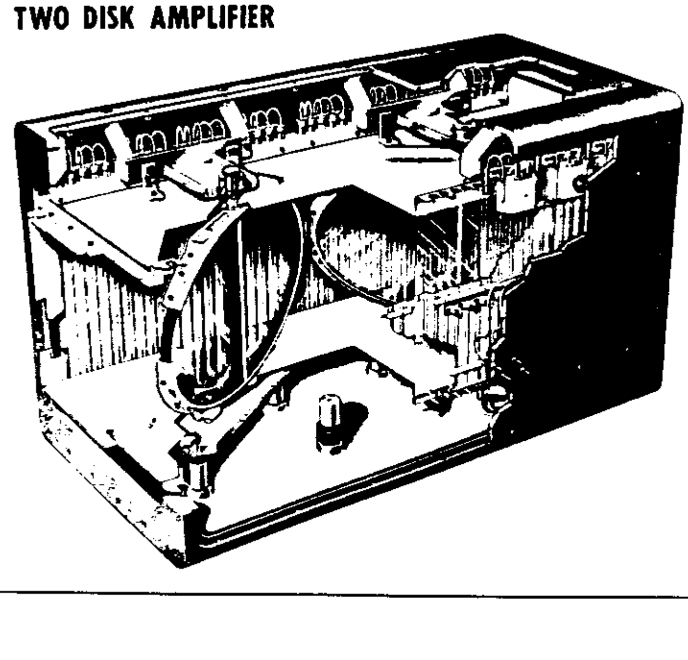
DISK AMPLIFIER

46CM TWO DISK AMPLIFIER



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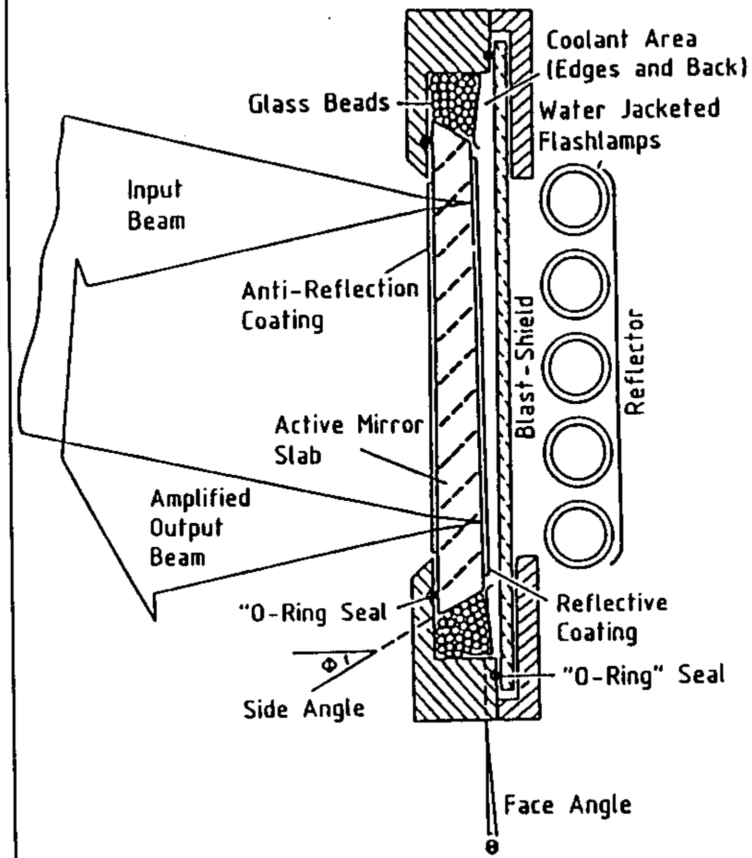
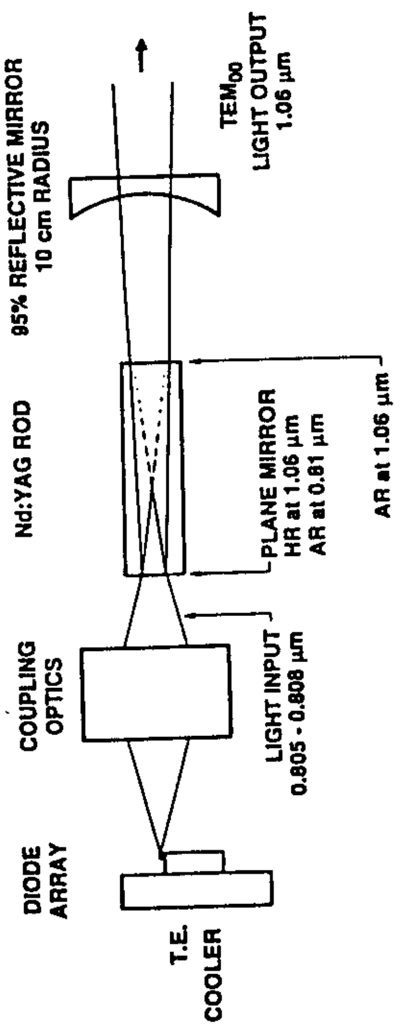
ACTIVE MIRROR AMPLIFIER



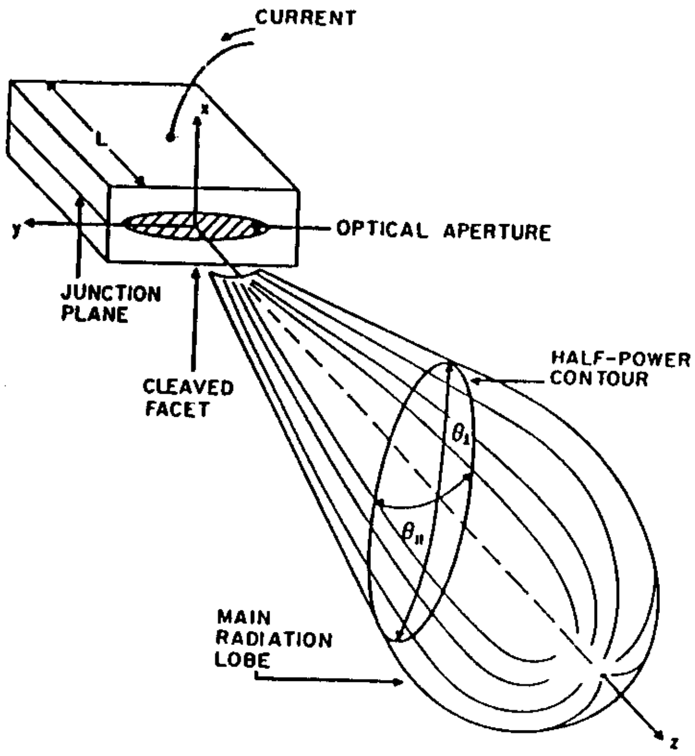
SEMICONDUCTOR LASER PUMPING

- **ADVANTAGES:**
  - ☐ high transfer and overall efficiency
  - ☐ system lifetime and reliability
  - ☐ low voltage operation
  - ☐ compactness and ruggedness
  - ☐ good beam quality (TEM 00)
  - ☐ output peak peak power (Q-switch)
  - ☐ emission wavelenght and linewidth
- **DISADVANTAGES**
  - ☐ very high cost / watt
  - ☐ low power available
  - ☐ complicated pumping arrangement

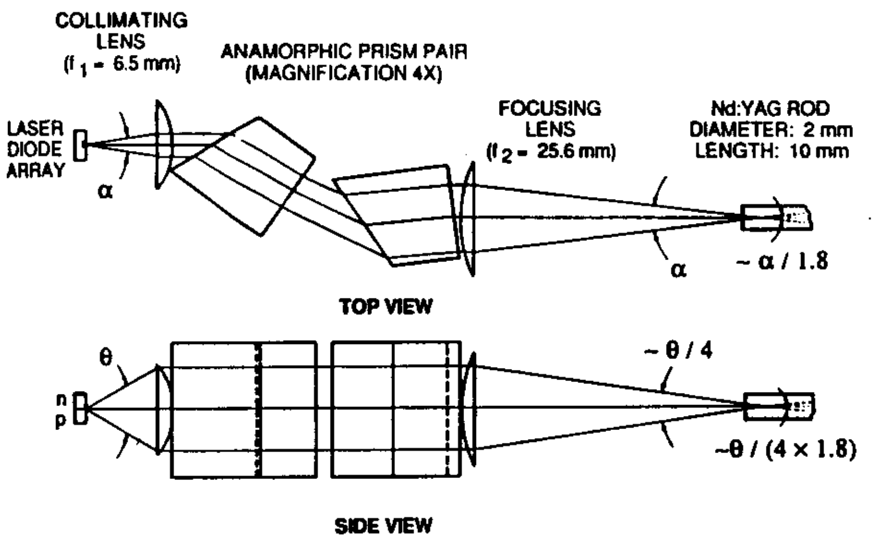
RESONATORS PARAMETERS



RADIATION PATTERN FROM A SEMICONDUCTOR LASER



DIODE ARRAY COUPLING OPTICS



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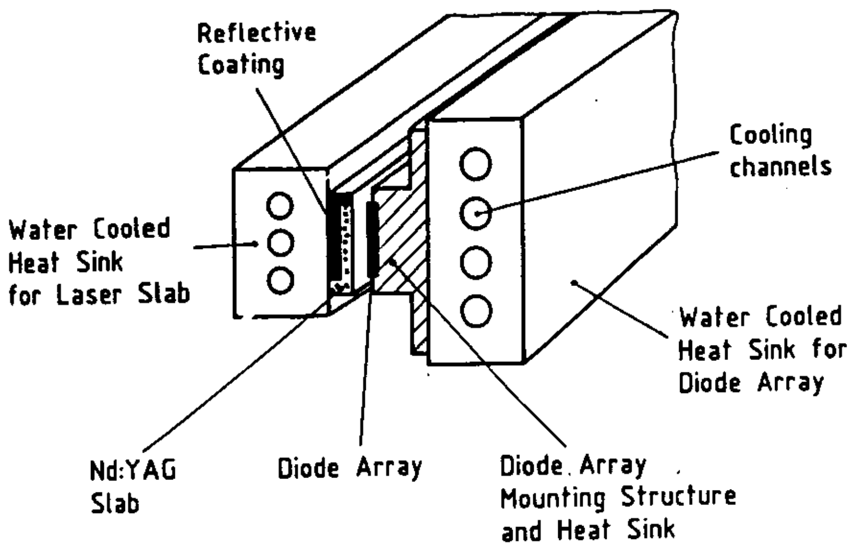
LASER-DIODE-PUMPED SLAB



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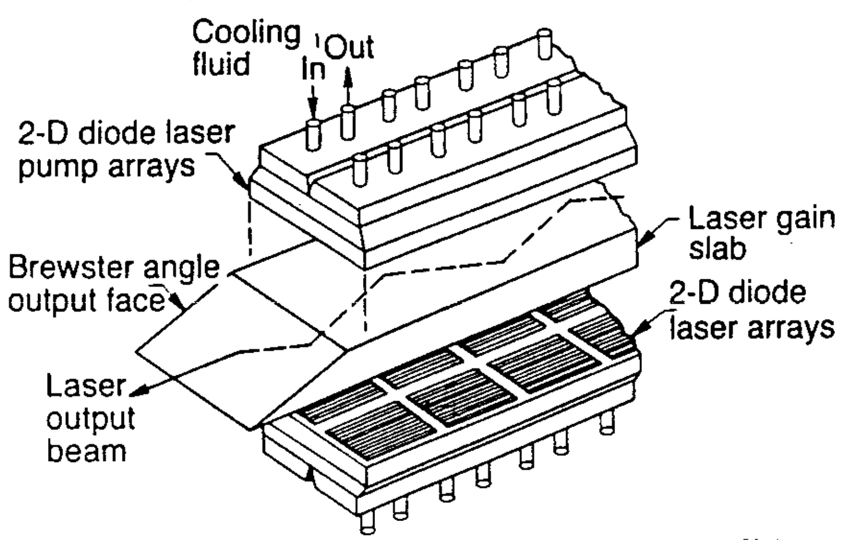
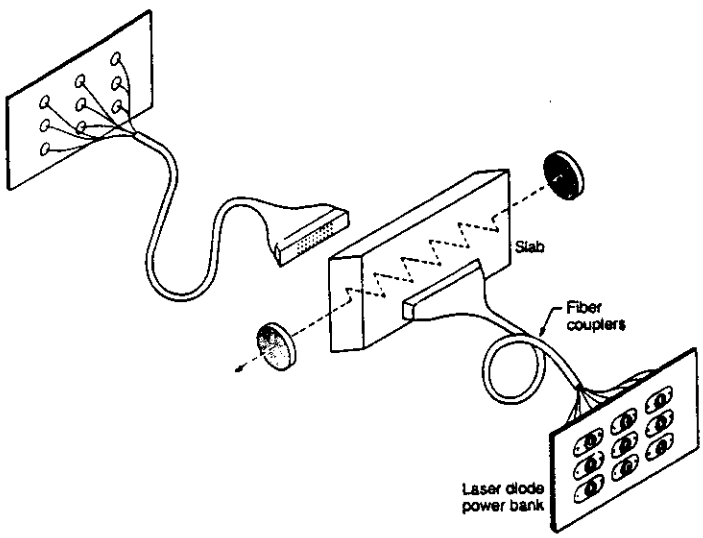
SEMICONDUCTOR LASER PUMPED SLABS



SEMICONDUCTOR LASER PUMPED SLABS



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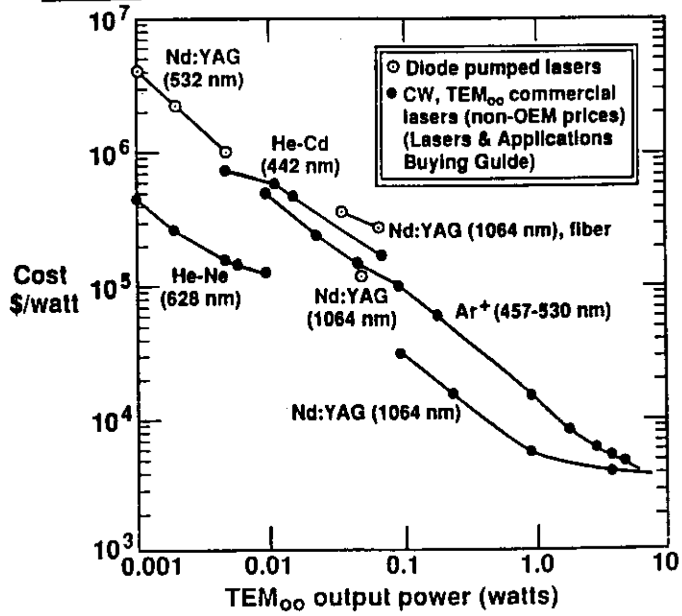
COST OF TEM 00 LASERS



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