Laser Types and Their Applications

Module 2-3

of

Course 2, *Laser Systems and Applications*

2nd Edition

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National Center for Optics and Photonics Education

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This text was developed by the National Center for Optics and Photonics Education (OP-TEC), University of Central Florida, under NSF ATE grant 1303732. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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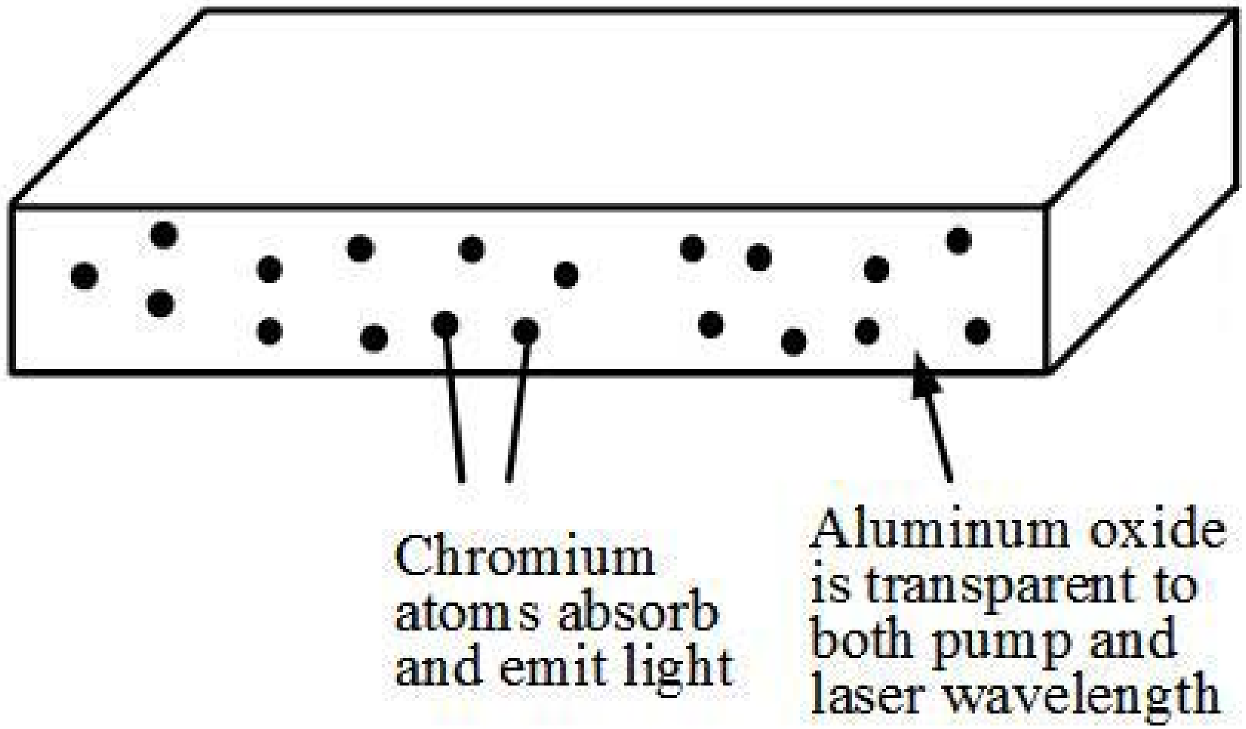


Figure 3-1 *Ruby crystal*

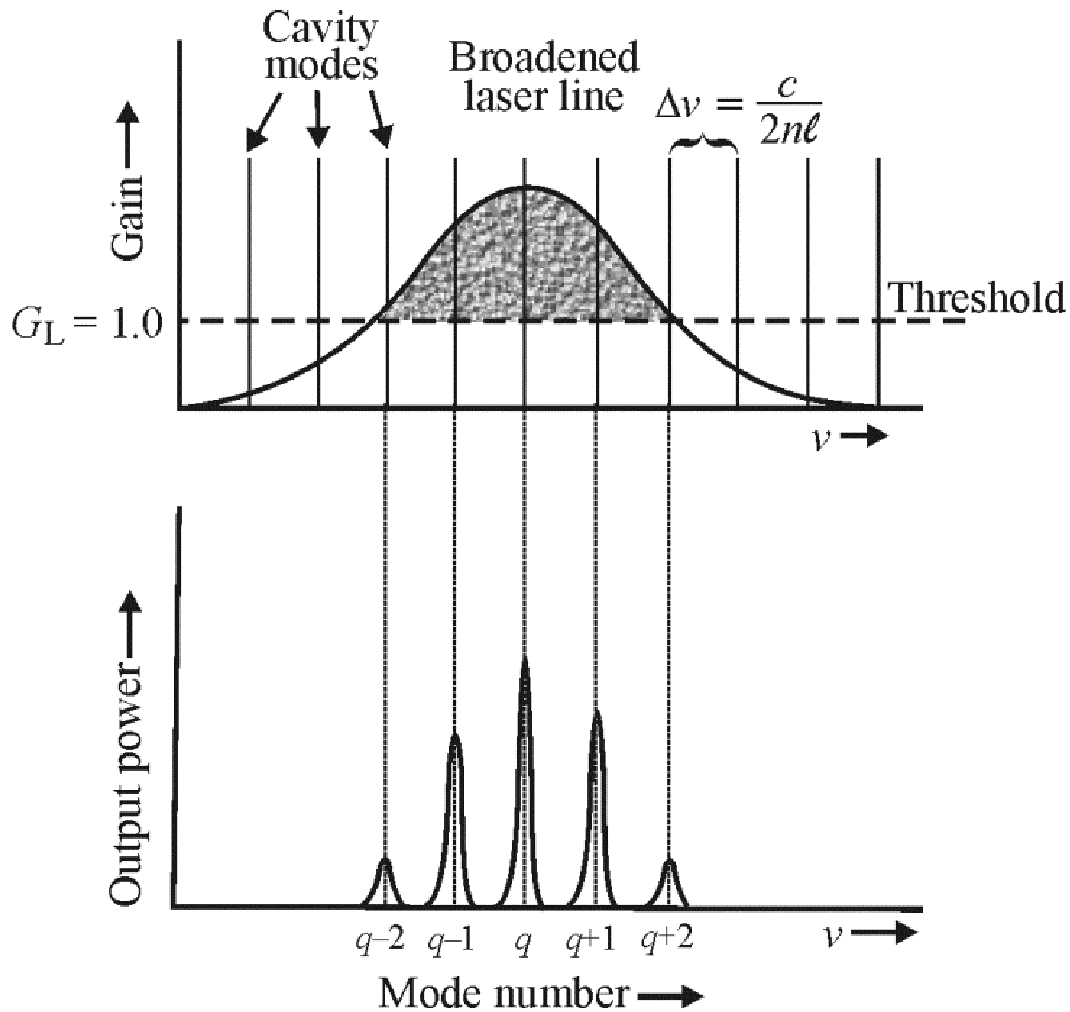


Figure 3-2 *Spectral distribution of laser output showing several longitudinal modes with various loop gains G_L*

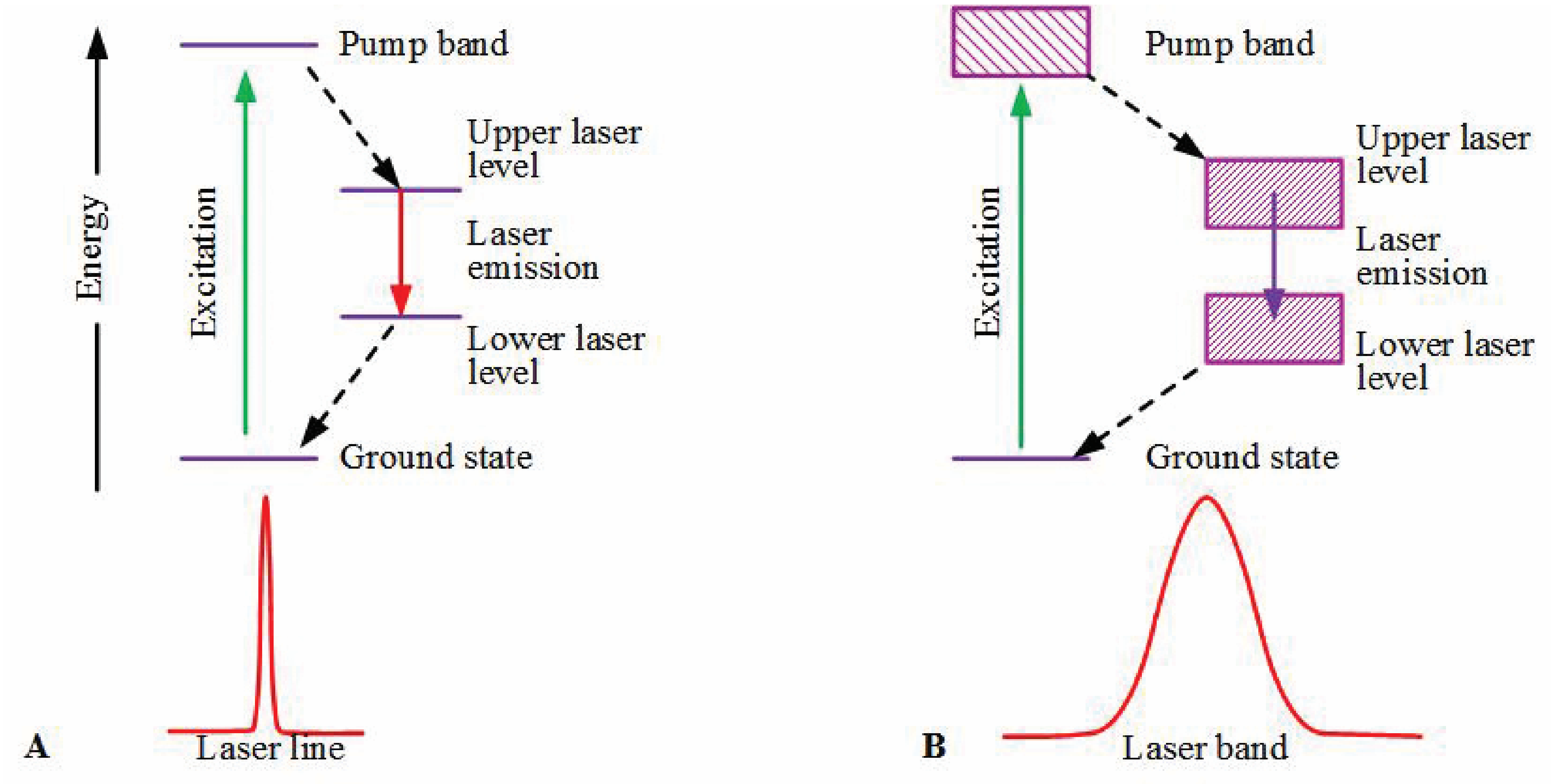


Figure 3-3 *Laser emission between two isolated states is a narrow line. But when the upper or lower laser level (or both) span a band of closely spaced energy levels, the emission spans a much wider range of wavelengths.*

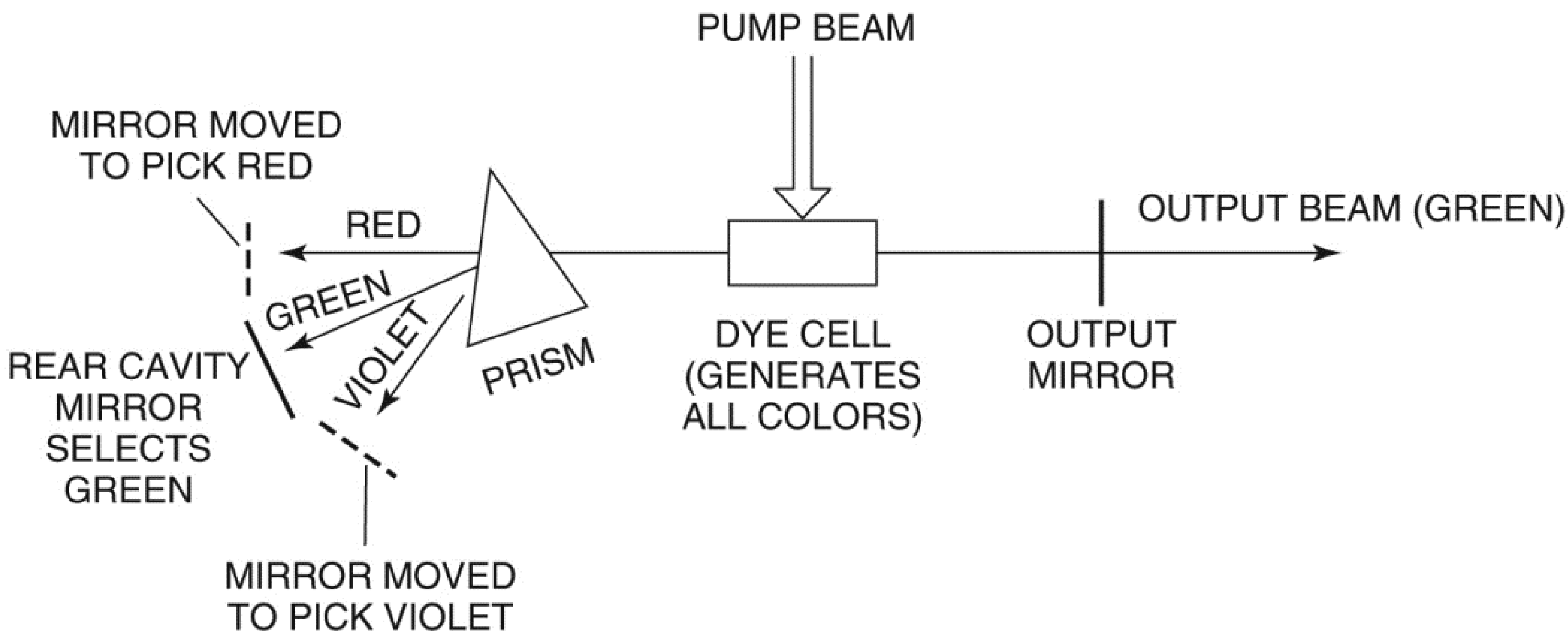


Figure 3-4 *Tunable dye-laser cavity using a stationary prism. The prism refracts light of different wavelengths at different angles, and a moving mirror selects which wavelength oscillates in the laser cavity. Moving the mirror would tune the cavity to emit other wavelengths.*

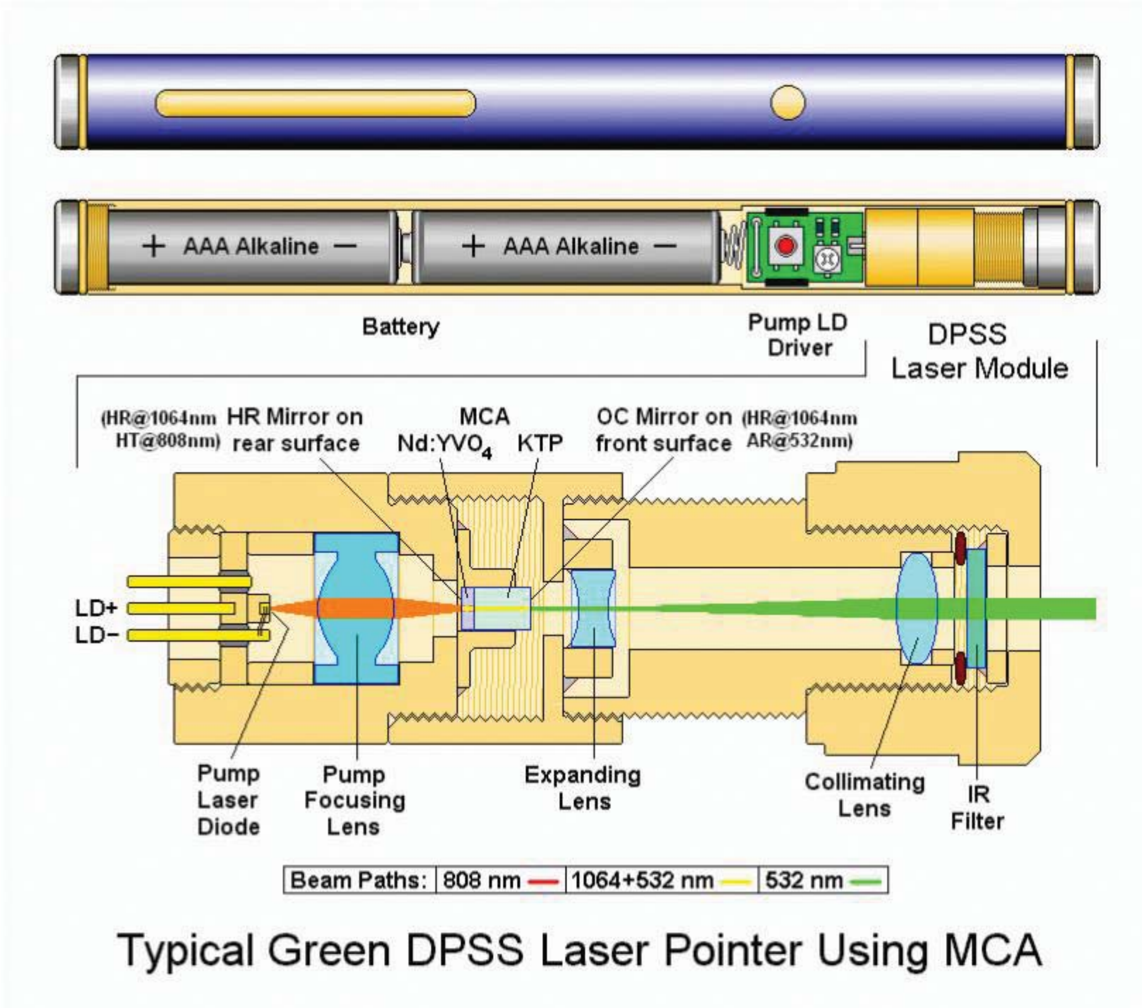


Figure 3-5 *This green laser pointer includes two batteries, an electronic drive, an 808 nm pump diode, a neodymium laser emitting at 1064 nm, and a harmonic generator that doubles the frequency to produce green light.*

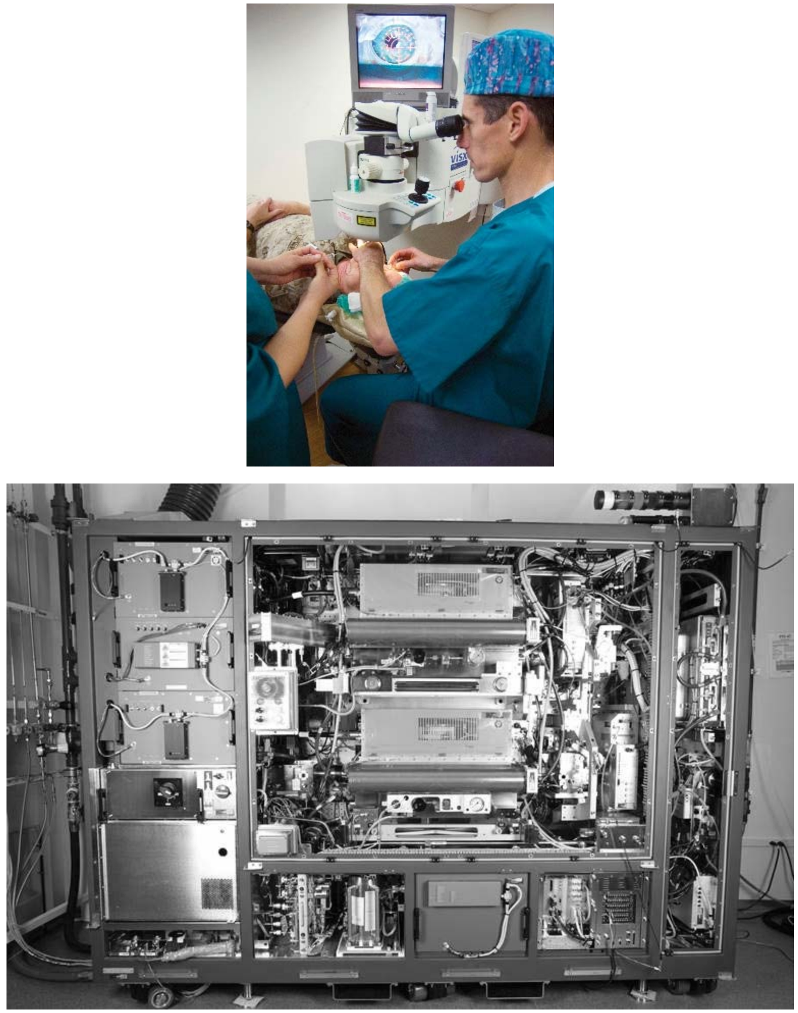


Figure 3-6 A) *An argon-fluoride excimer laser being used in LASIK surgery at the National Naval Medical Center Bethesda (government photo, not subject to copyright).* **B)** *A semiconductor photolithography system based on an argon-fluoride laser (courtesy* ASML).

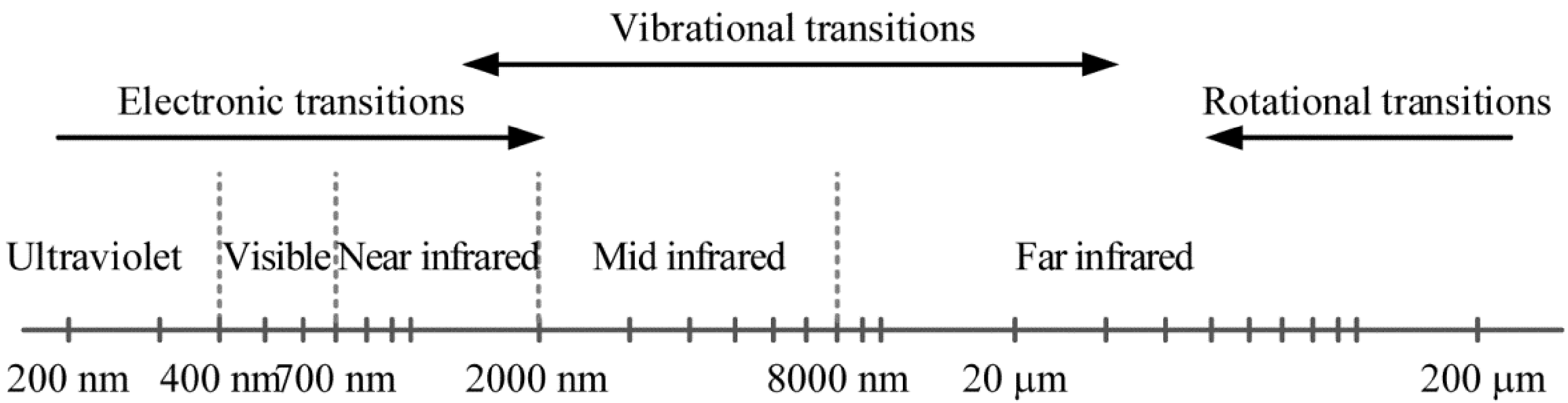


Figure 3-7 *Types of gas-laser transitions and the bands in which they occur*

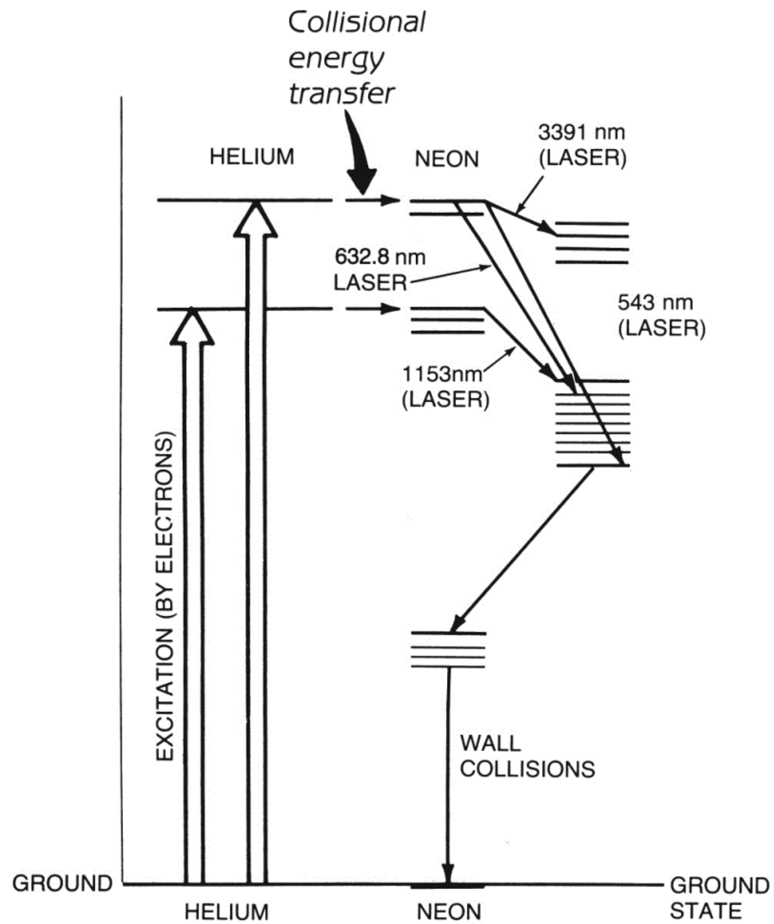


Figure 3-8 *Key energy levels and transitions in helium–neon lasers. Electrons collide with helium atoms and excite them; then the helium atoms collide with neon and excite the neon. Transitions go between different pairs of energy levels. These are the four best-known laser lines for the helium–neon laser.*

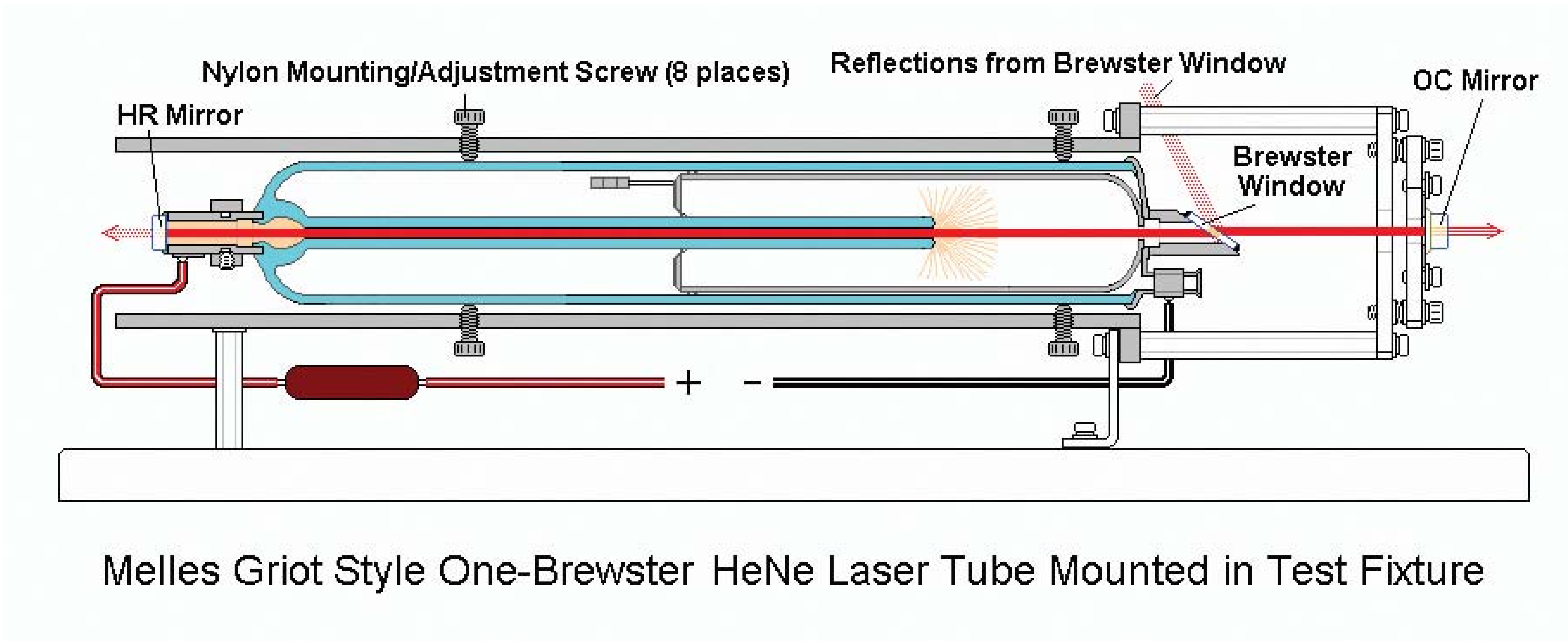


Figure 3-9 *Structure of a HeNe laser. Red light passes through a bore in the center of the tube. HR is a high-reflectivity back mirror. OC is an output coupling mirror, which typically transmits a small fraction of the light circulating in the cavity.*

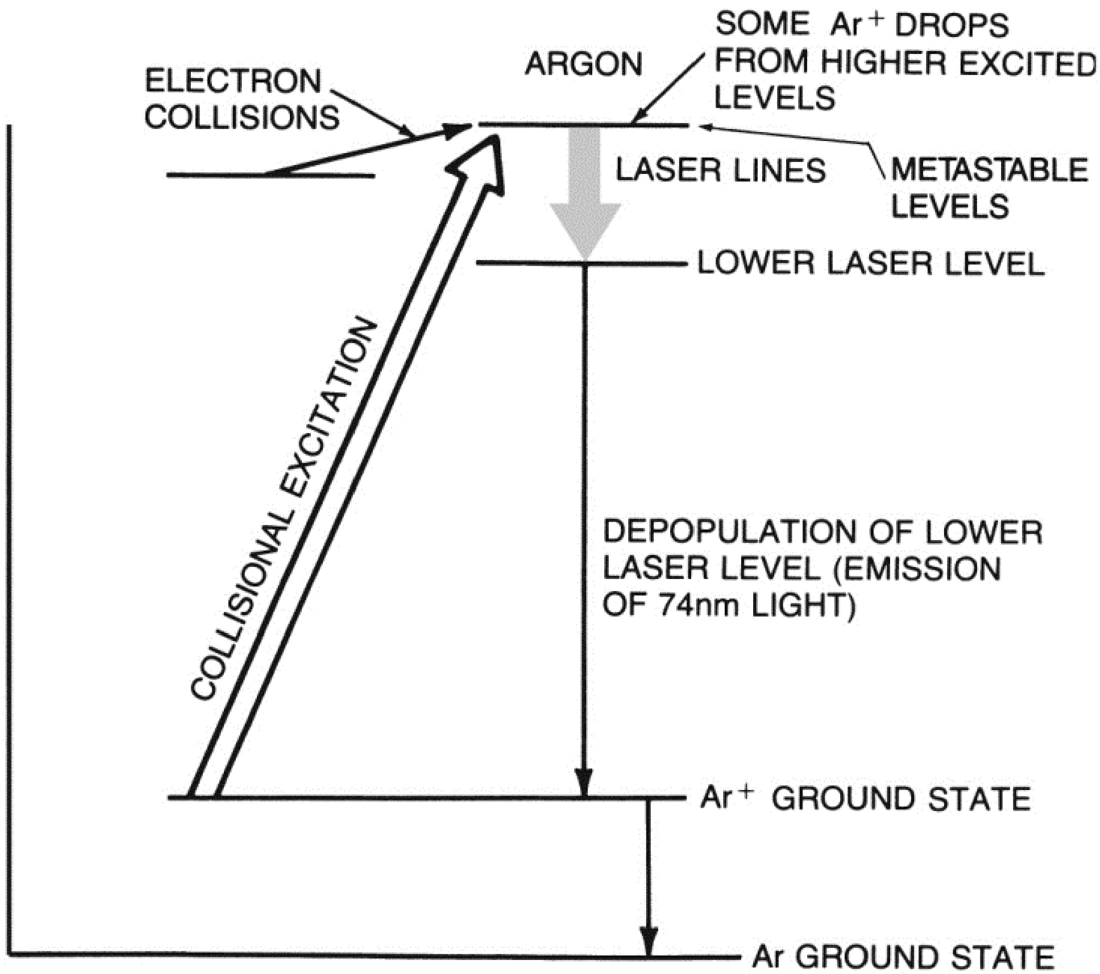


Figure 3-10 *Argon-ion laser lines*

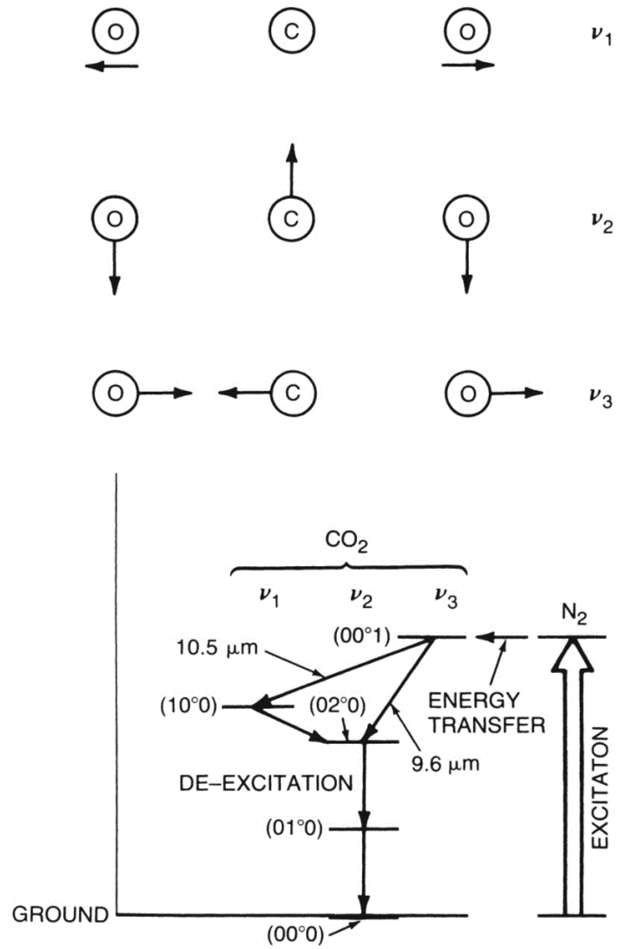


Figure 3-11 CO_2 *molecular vibration modes (top) and laser transitions between them (bottom). The numbers are conventional codes for the particular vibrations modes.*

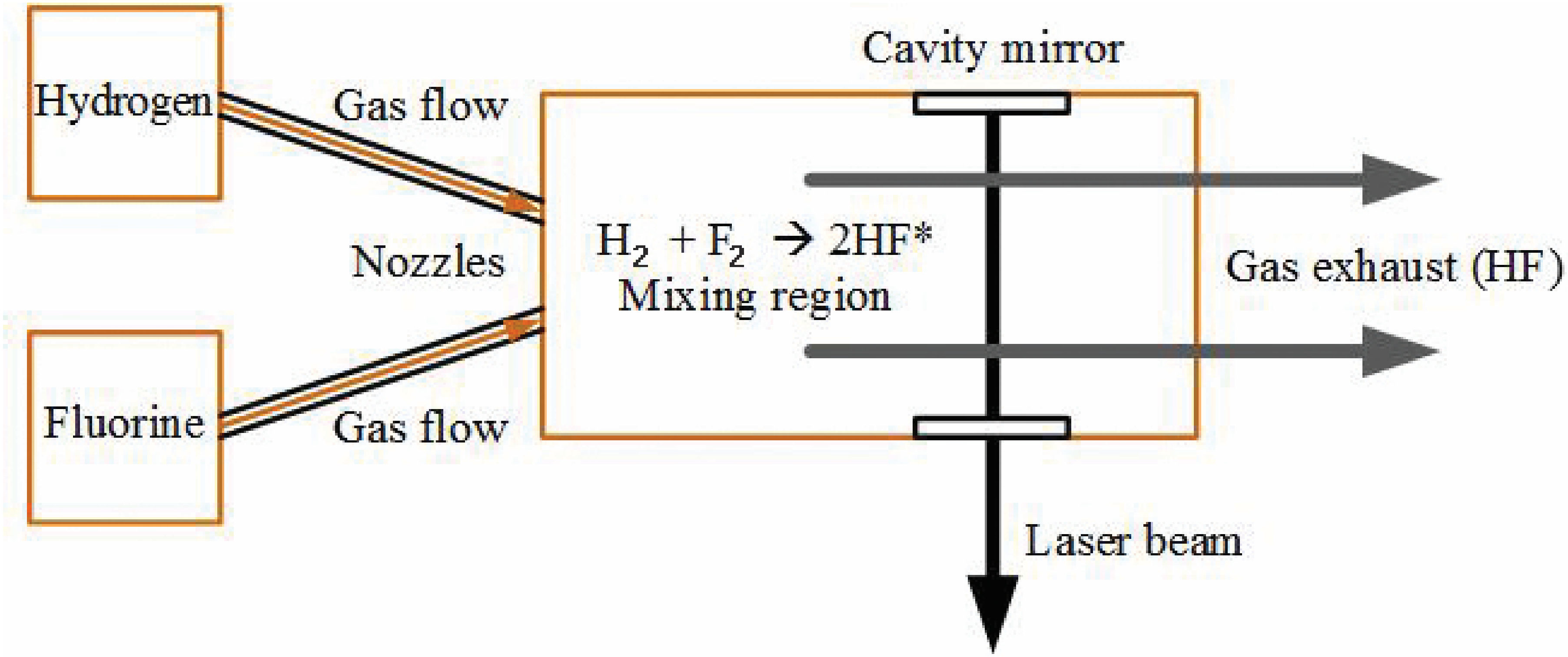


Figure 3-12 *Schematic of a chemical laser*

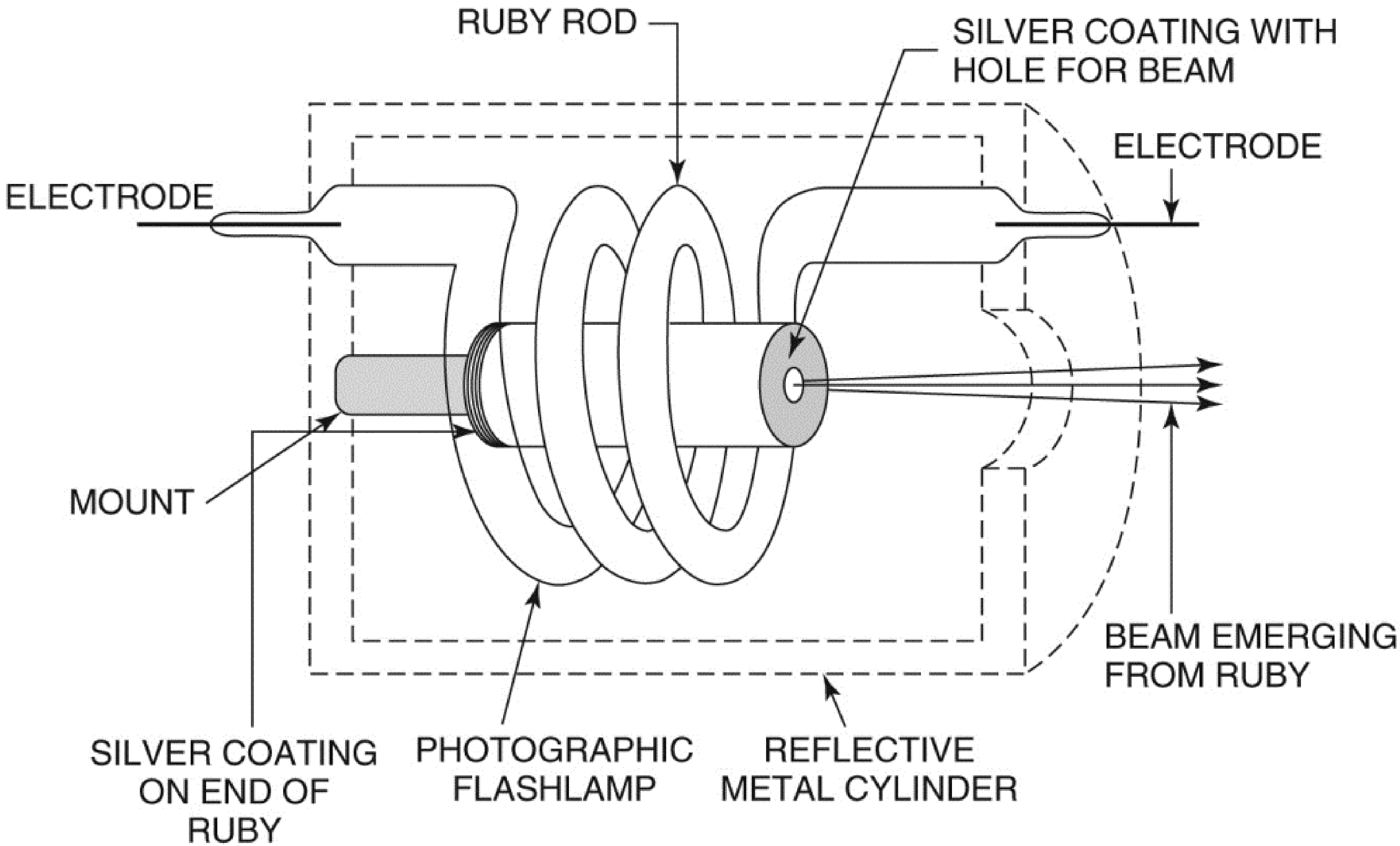


Figure 3-13 *Cutaway drawing of the first ruby laser. The laser rod is the glassy pink cylinder inside the coils of the lamp; the beam it emits to the right is a deeper red. Mirrors are at both ends of the rod.*

1 **H** 1.008																		2 **He** 4.0026
3 **Li** 6.94	4 **Be** 9.0122												5 **B** 10.81	6 **C** 12.011	7 **N** 14.007	8 **O** 15.999	9 **F** 18.998	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.305												13 **Al** 26.982	14 **Si** 28.085	15 **P** 30.974	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.948
19 **K** 39.098	20 **Ca** 40.078		21 **Sc** 44.956	22 **Ti** 47.867	23 **V** 50.942	24 **Cr** 51.996	25 **Mn** 54.938	26 **Fe** 55.845	27 **Co** 58.933	28 **Ni** 58.693	29 **Cu** 63.546	30 **Zn** 65.38	31 **Ga** 69.723	32 **Ge** 72.63	33 **As** 74.922	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.798
37 **Rb** 85.468	38 **Sr** 87.62		39 **Y** 88.906	40 **Zr** 91.224	41 **Nb** 92.906	42 **Mo** 95.96	43 **Tc** [97.91]	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	*	71 **Lu** 174.97	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** [208.98]	85 **At** [209.99]	86 **Rn** [222.02]
87 **Fr** [223.02]	88 **Ra** [226.03]	**	103 **Lr** [262.11]	104 **Rf** [265.12]	105 **Db** [268.13]	106 **Sg** [271.13]	107 **Bh** [270]	108 **Hs** [277.15]	109 **Mt** [276.15]	110 **Ds** [281.16]	111 **Rg** [280.16]	112 **Cn** [285.17]	113 **Uut** [284.18]	114 **Fl** [289.19]	115 **Uup** [288.19]	116 **Lv** [293]	117 **Uus** [294]	118 **Uuo** [294]

*Lanthanoids	*	57 **La** 138.91	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** [144.91]	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.5	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05
**Actinoids	**	89 **Ac** [227.03]	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** [237.05]	94 **Pu** [244.06]	95 **Am** [243.06]	96 **Cm** [247.07]	97 **Bk** [247.07]	98 **Cf** [251.08]	99 **Es** [252.08]	100 **Fm** [257.10]	101 **Md** [258.10]	102 **No** [259.10]

Figure 3-14 *Highlighted elements are the most important for solid state lasers. Note that most are rare earth elements with similar electron configurations.*

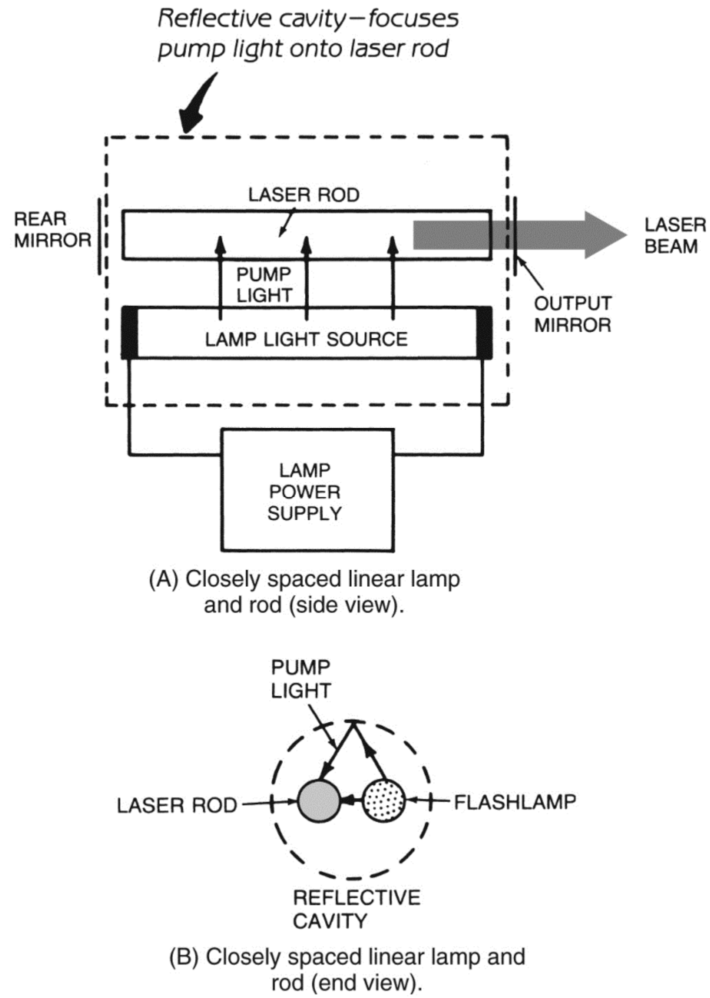


Figure 3-15 *Lamp pumping a solid state laser rod in an elliptical laser cavity*

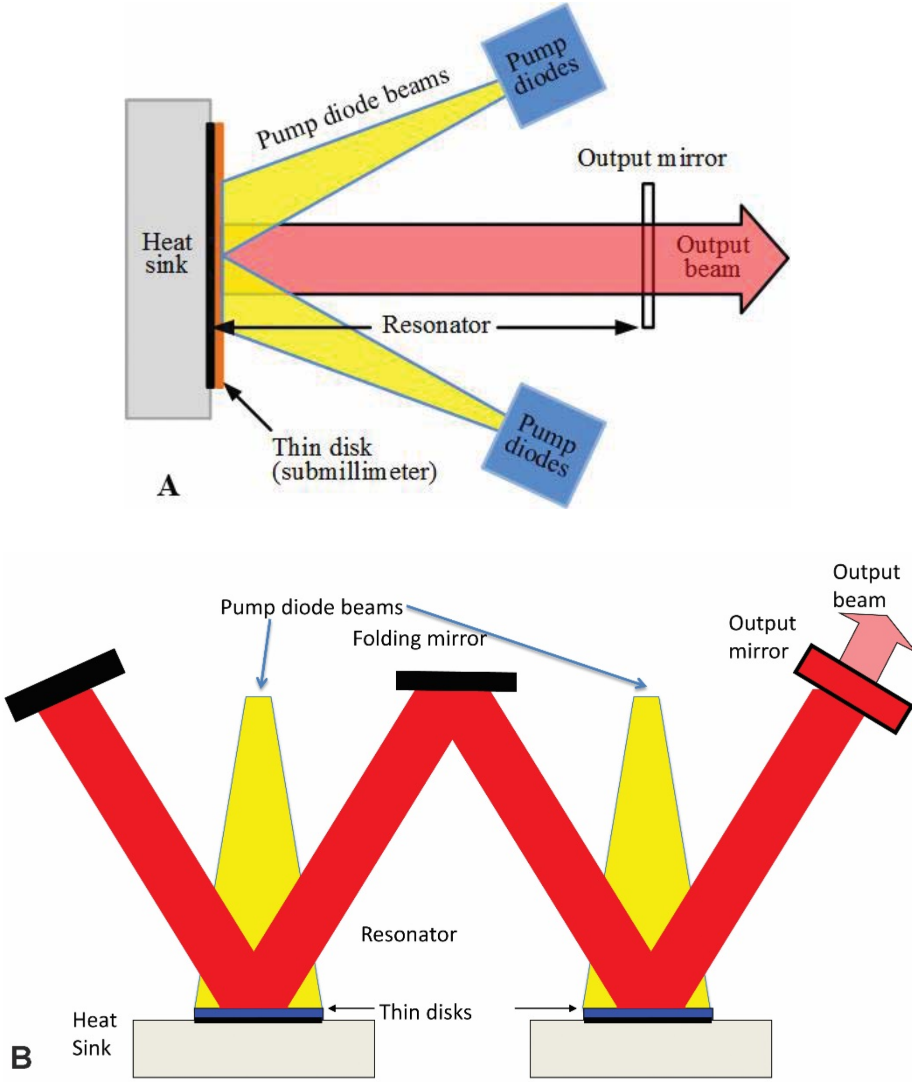


Figure 3-16 *Thin disk lasers. A) shows a single thin disk, illuminated from the side with pump diodes. B) show how a pair of thin disks can be put in series optically in a W-shaped cavity.*

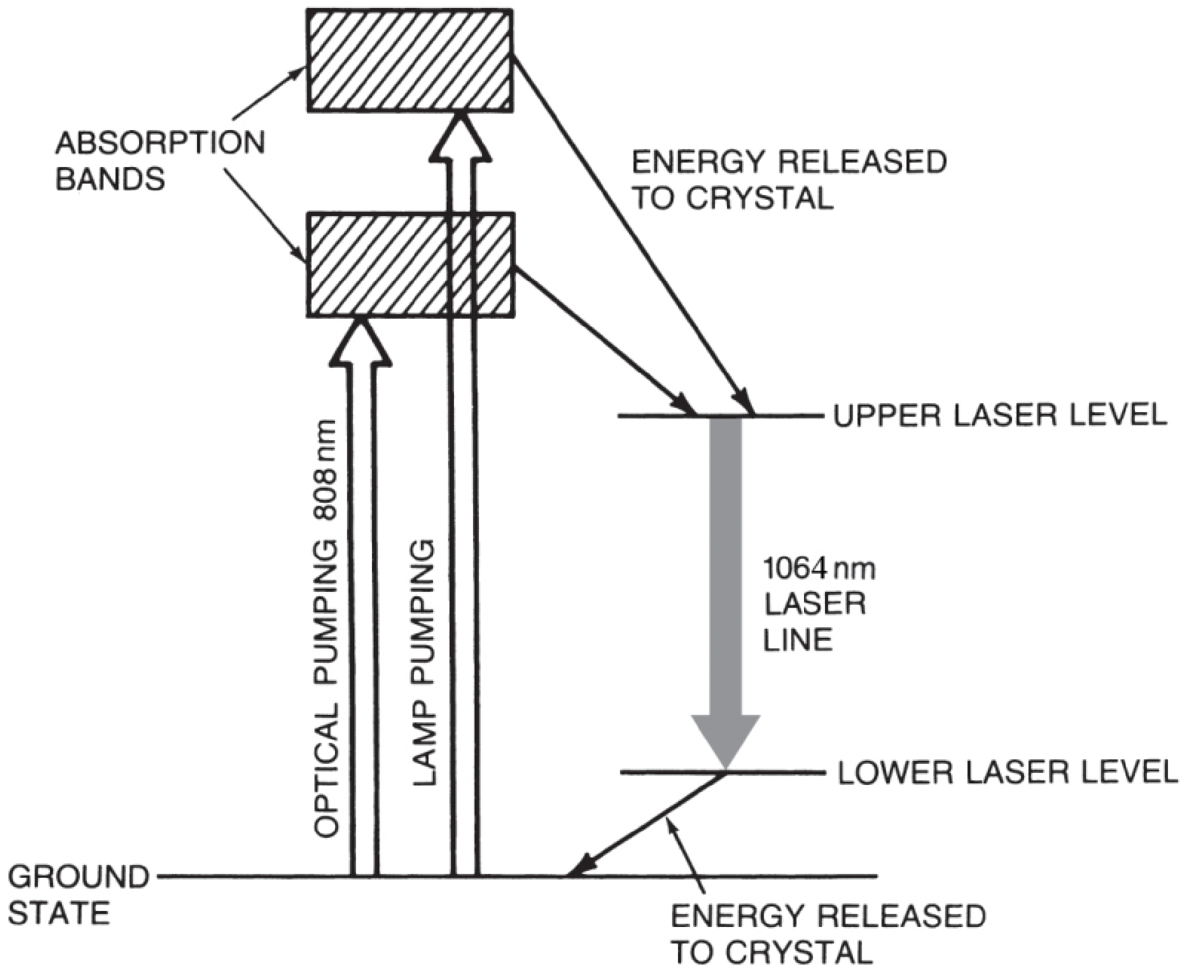


Figure 3-17 *Laser energy levels in neodymium, showing pumping both with lamps and with 808 nm diode laser*

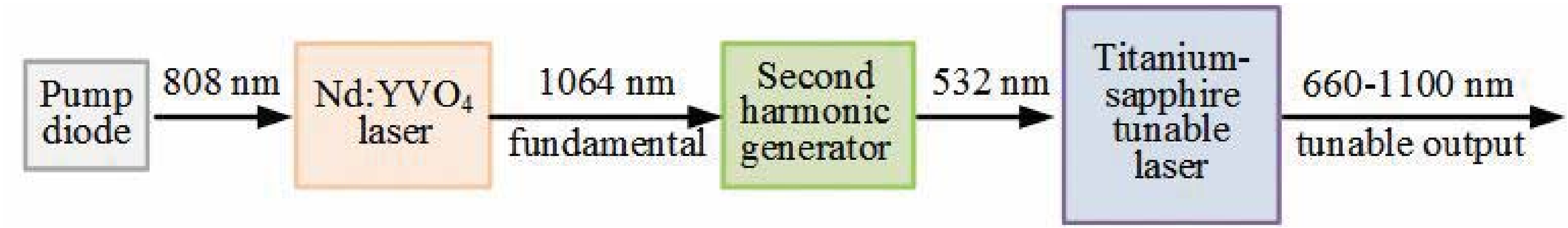


Figure 3-18 *Laser wavelength conversion. Light from 808 nm pump diodes excites neodymium, generating laser light at 1064 nm, and harmonic generation shifts the wavelength to 532 nm in the green range. The green light pumps a titanium-sapphire laser that is tunable across wide range of wavelengths.*

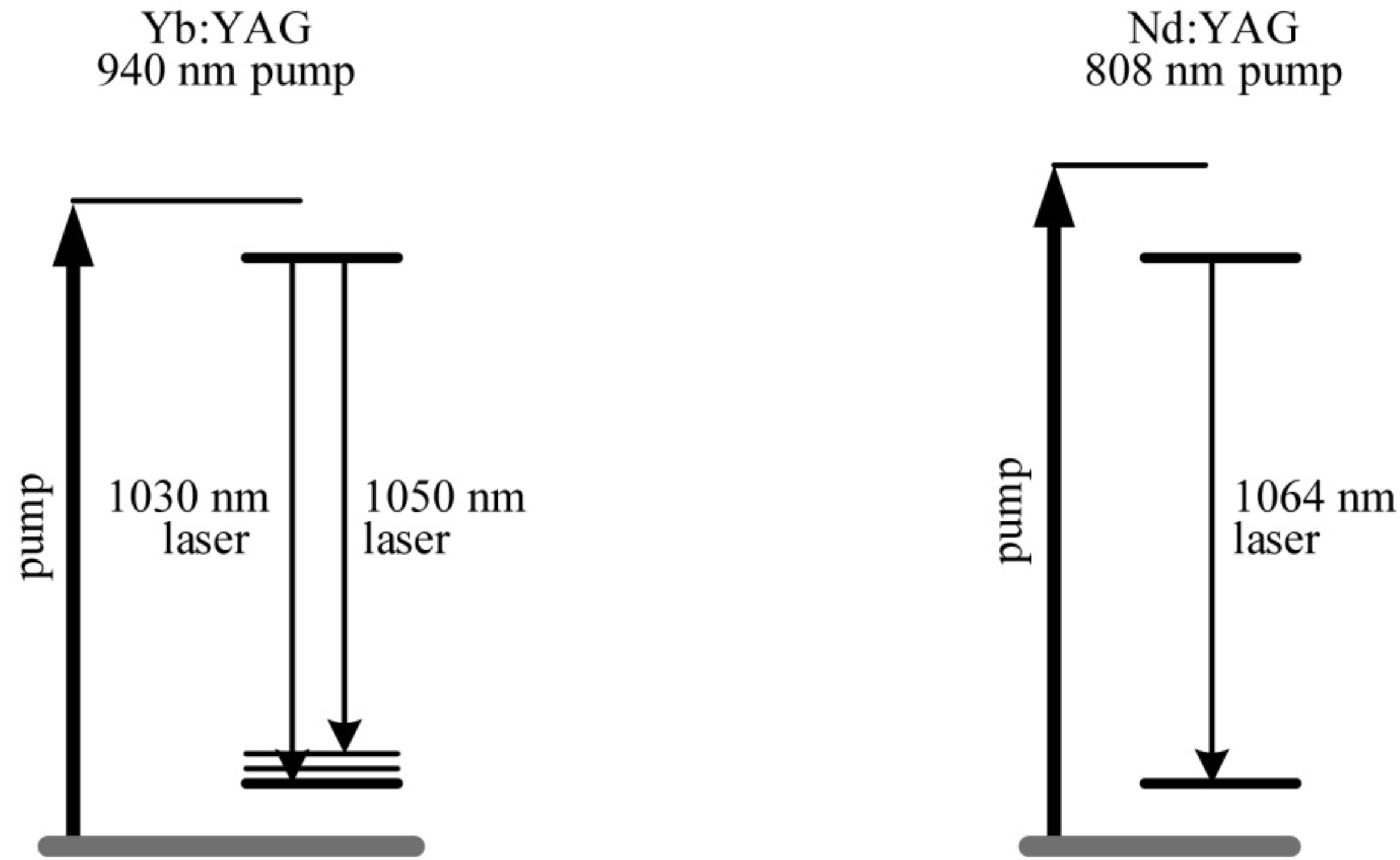


Figure 3-19 *Ytterbium laser transition in YAG compared with that of neodymium. The pump line for Yb is much closer to the laser line that it is for Nd, making ytterbium the more efficient laser.*

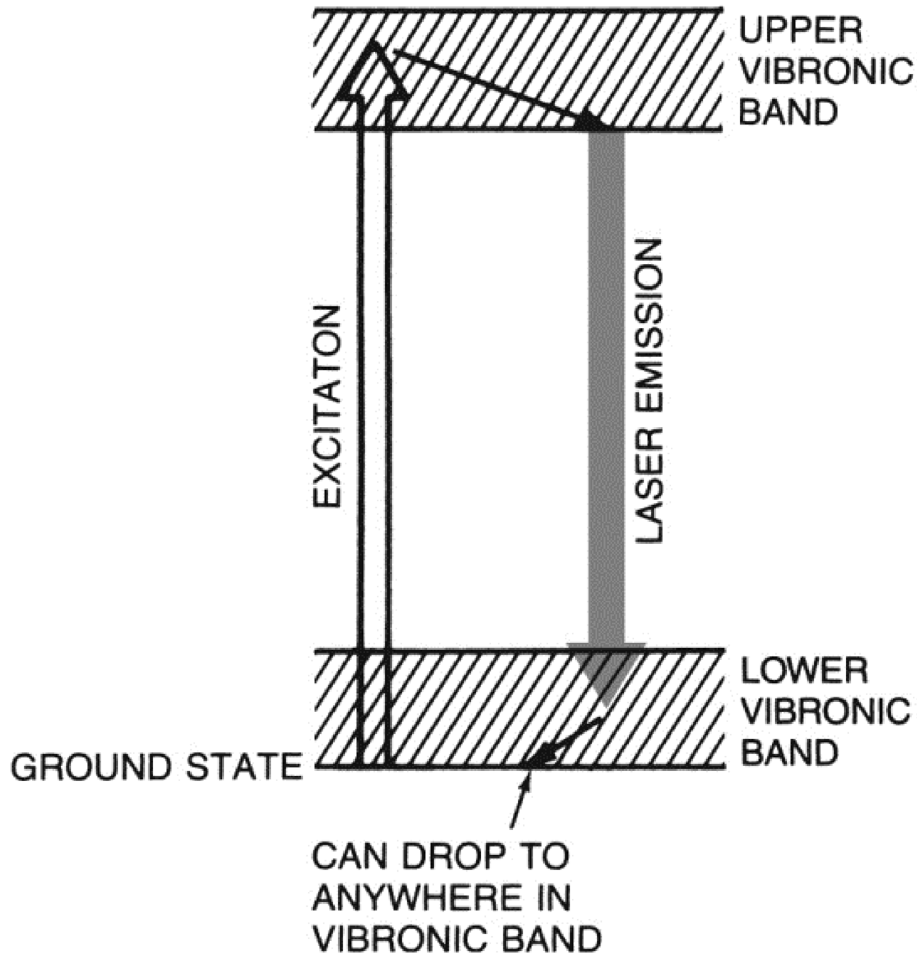


Figure 3-20 *In a vibronic laser, transitions occur between bands of energy states rather than discrete energy levels, so the laser can emit across a range of wavelengths as electrons drop from different points in one band to different points in the other.*

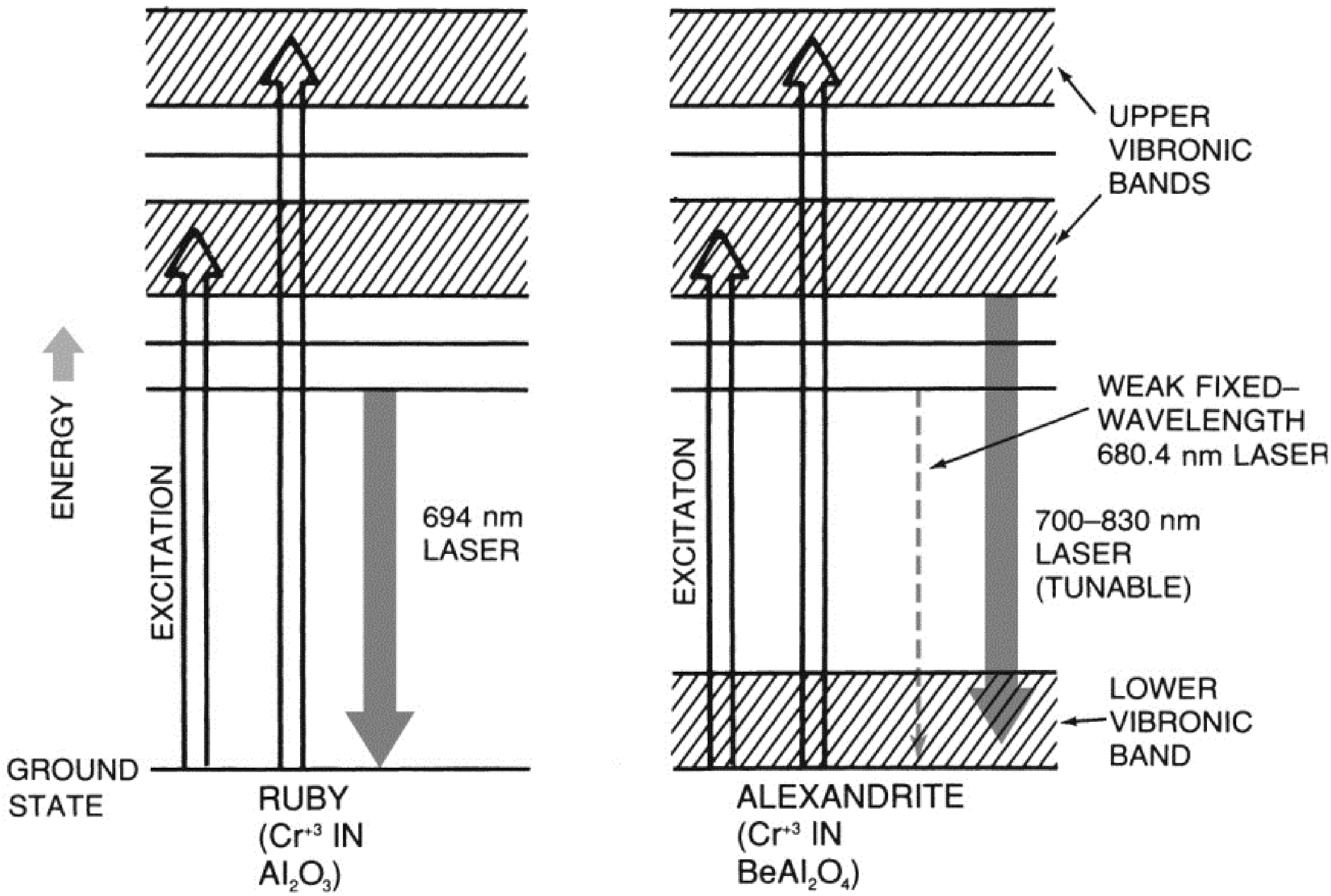


Figure 3-21 *Energy levels in an alexandrite laser*

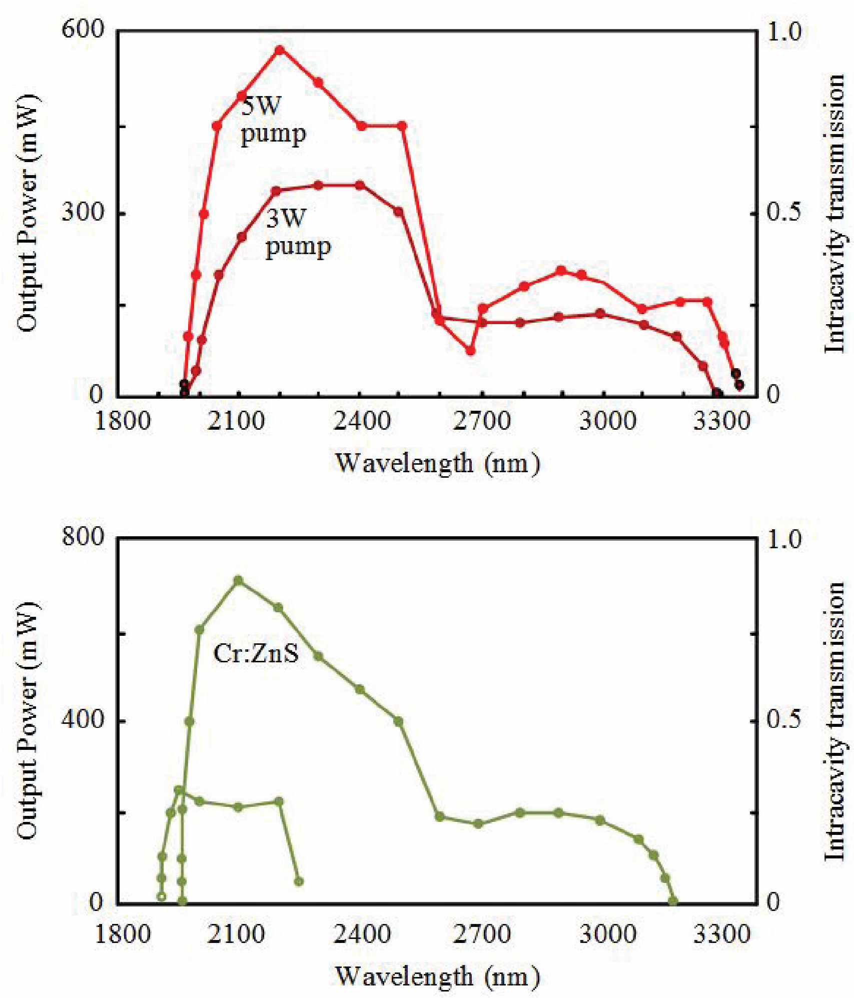


Figure 3-22 *Power generated by Cr:ZnSe and Cr:ZnS lasers across their operating range, with atmospheric absorption shown in the background. (Courtesy IPG Photonics)*

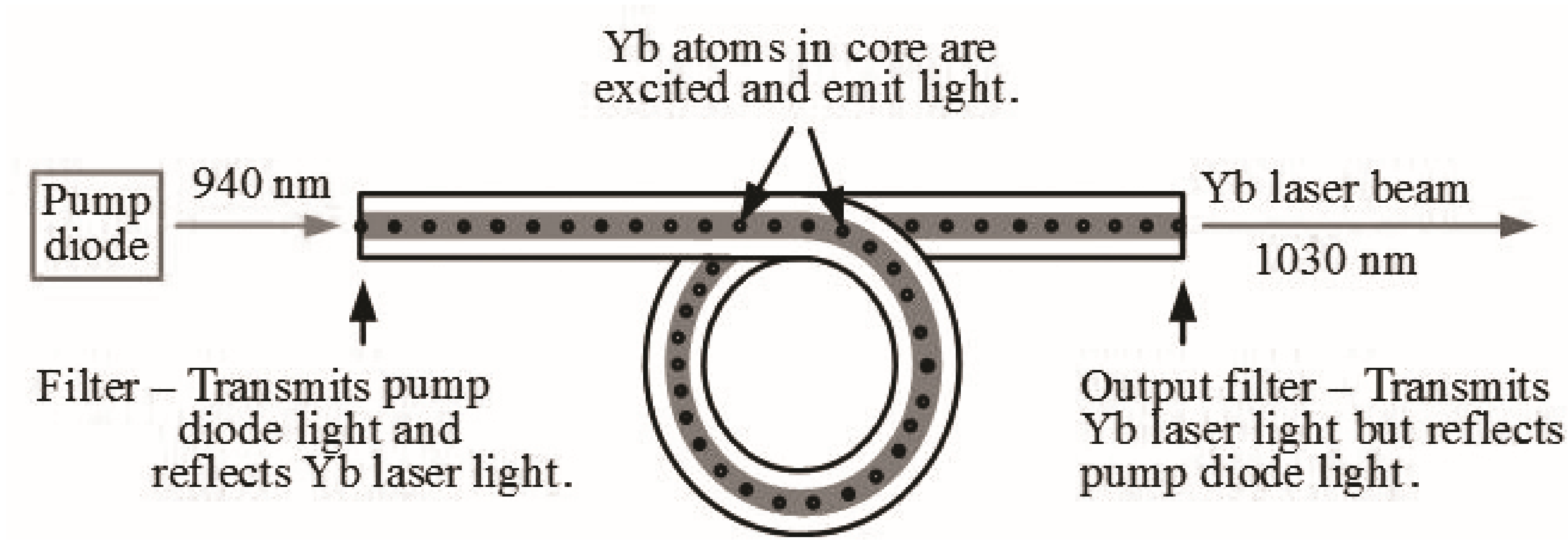


Figure 3-23 *A simple Yb-fiber laser with wavelength-selective mirrors forming a laser cavity*

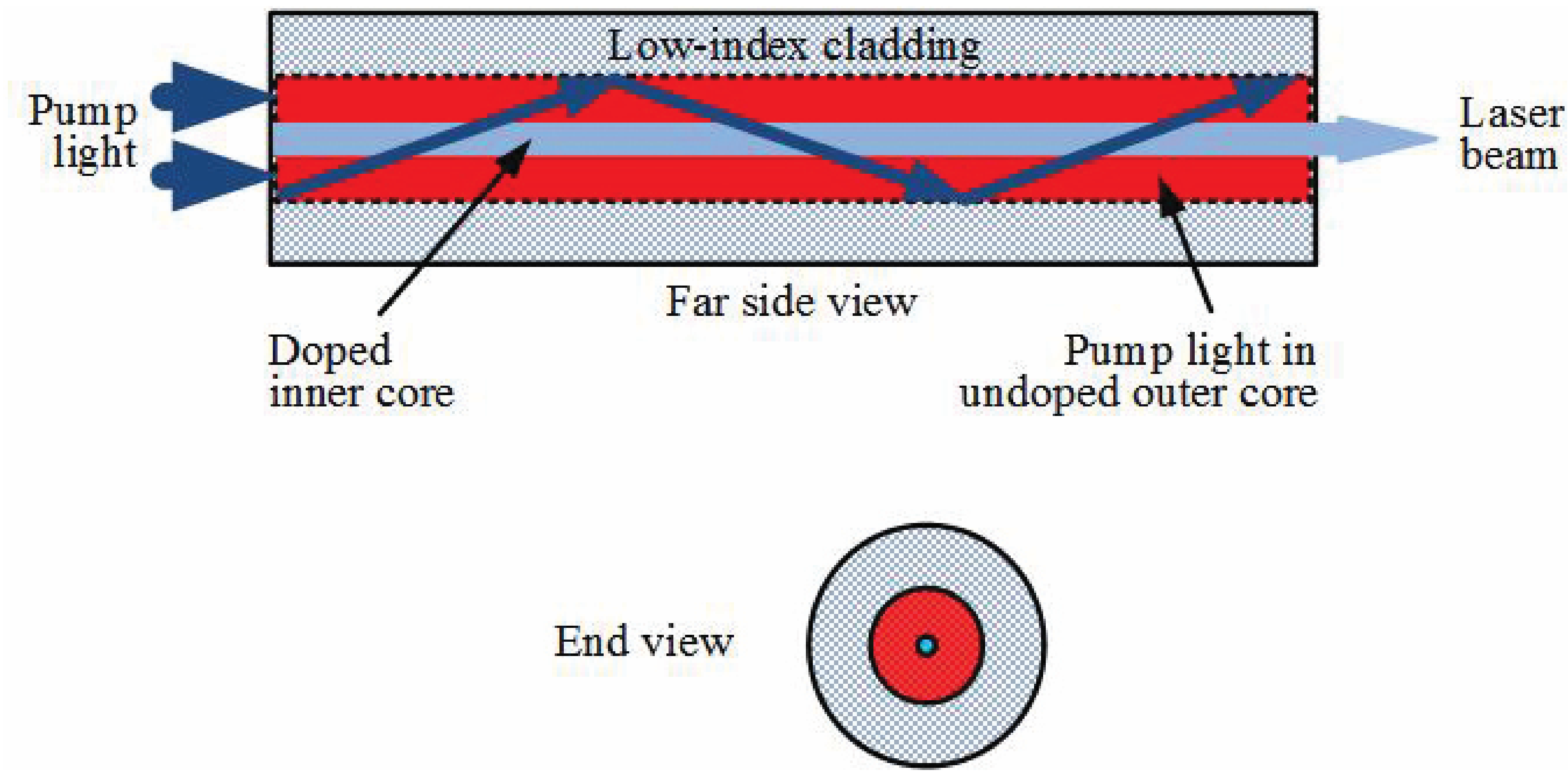


Figure 3-24 *Dual-core fiber structure*

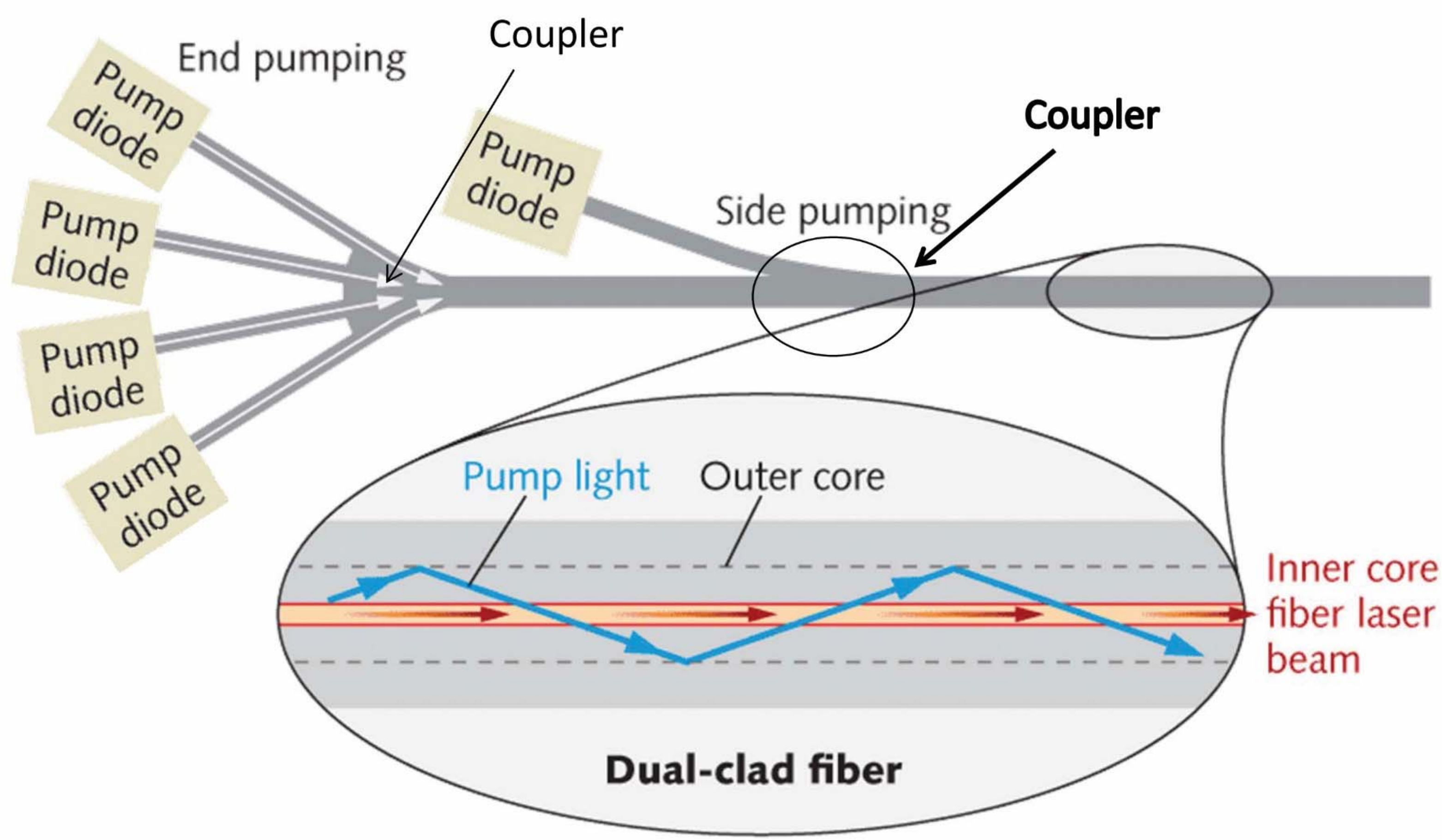


Figure 3-25 *Pump diodes can direct light into the outer core of a fiber laser in two ways: through a coupler at the end, or through a coupler spliced into the length of the fiber*

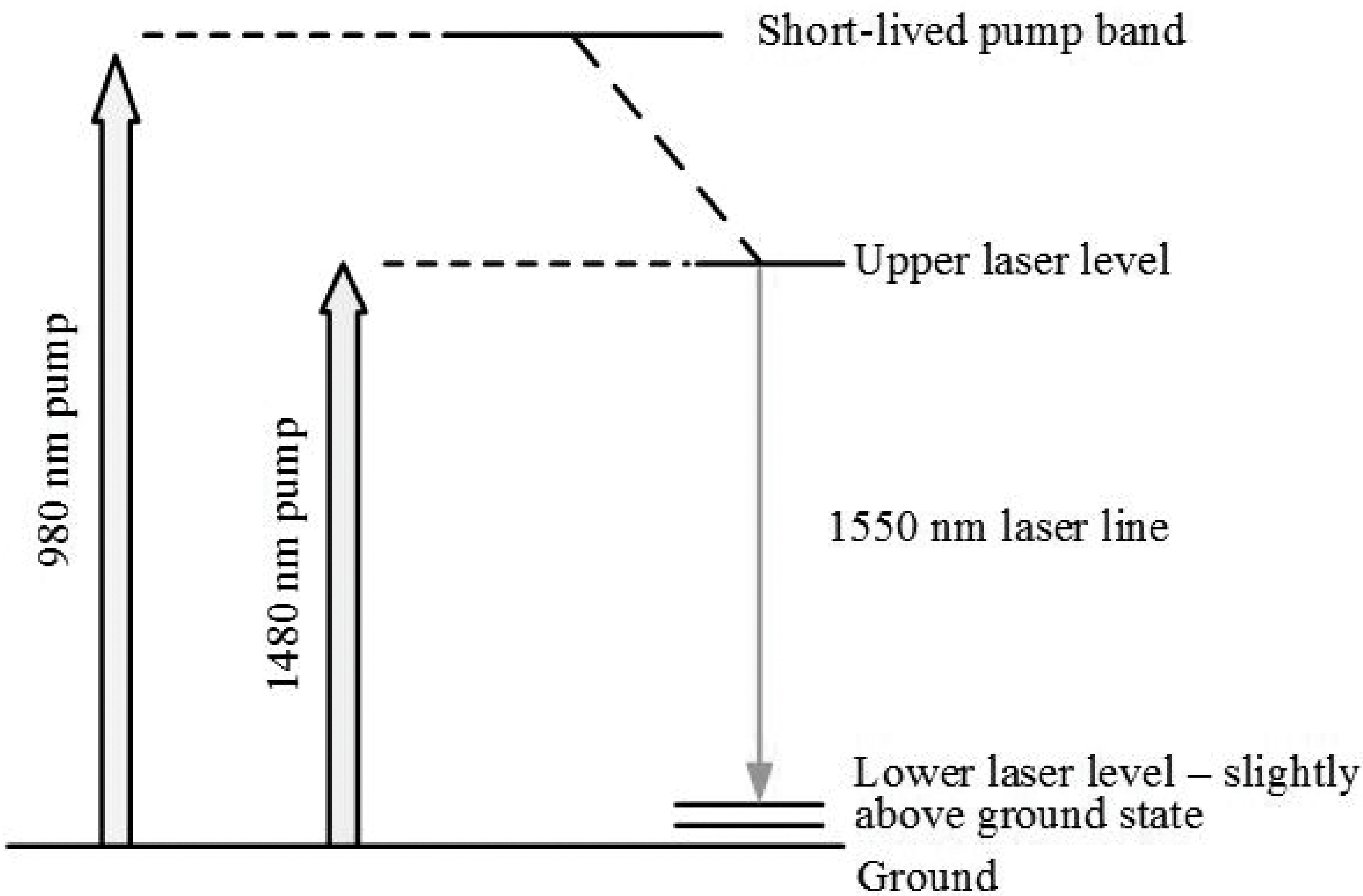


Figure 3-26 *Erbium energy levels*

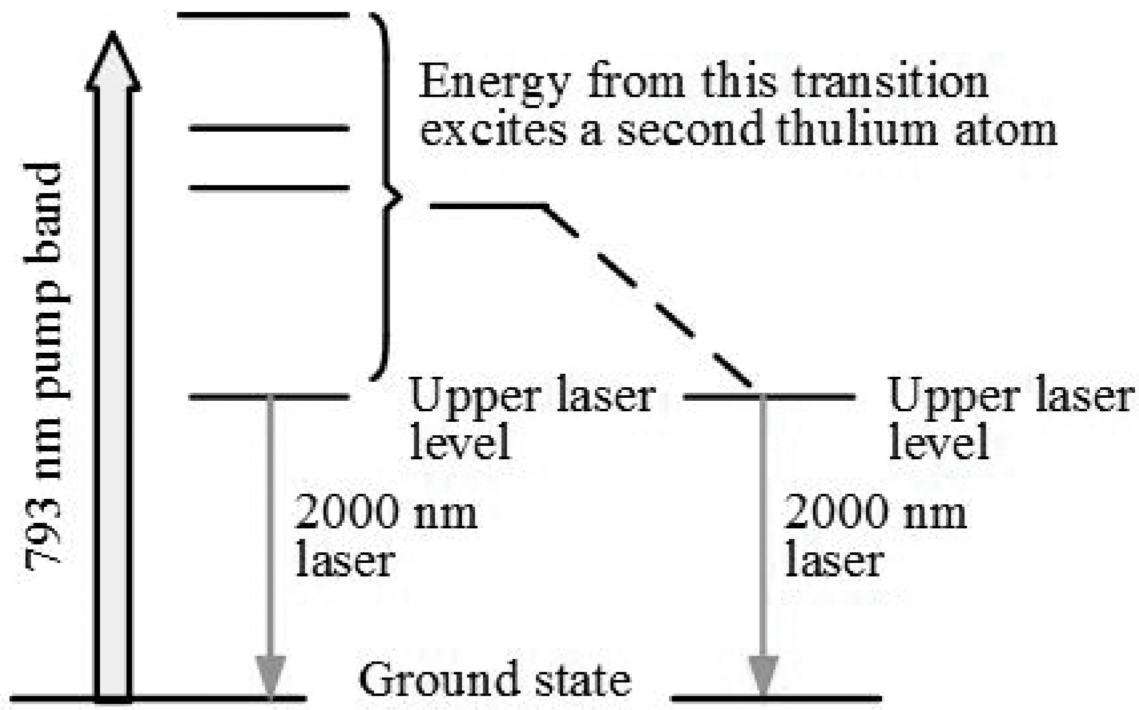


Figure 3-27 *How a single pump photon can excite two thulium atoms to the upper laser level. The trick is getting the thulium atom that absorbed the light to transfer some of the energy to a second thulium atom, exciting it to the upper laser level.*

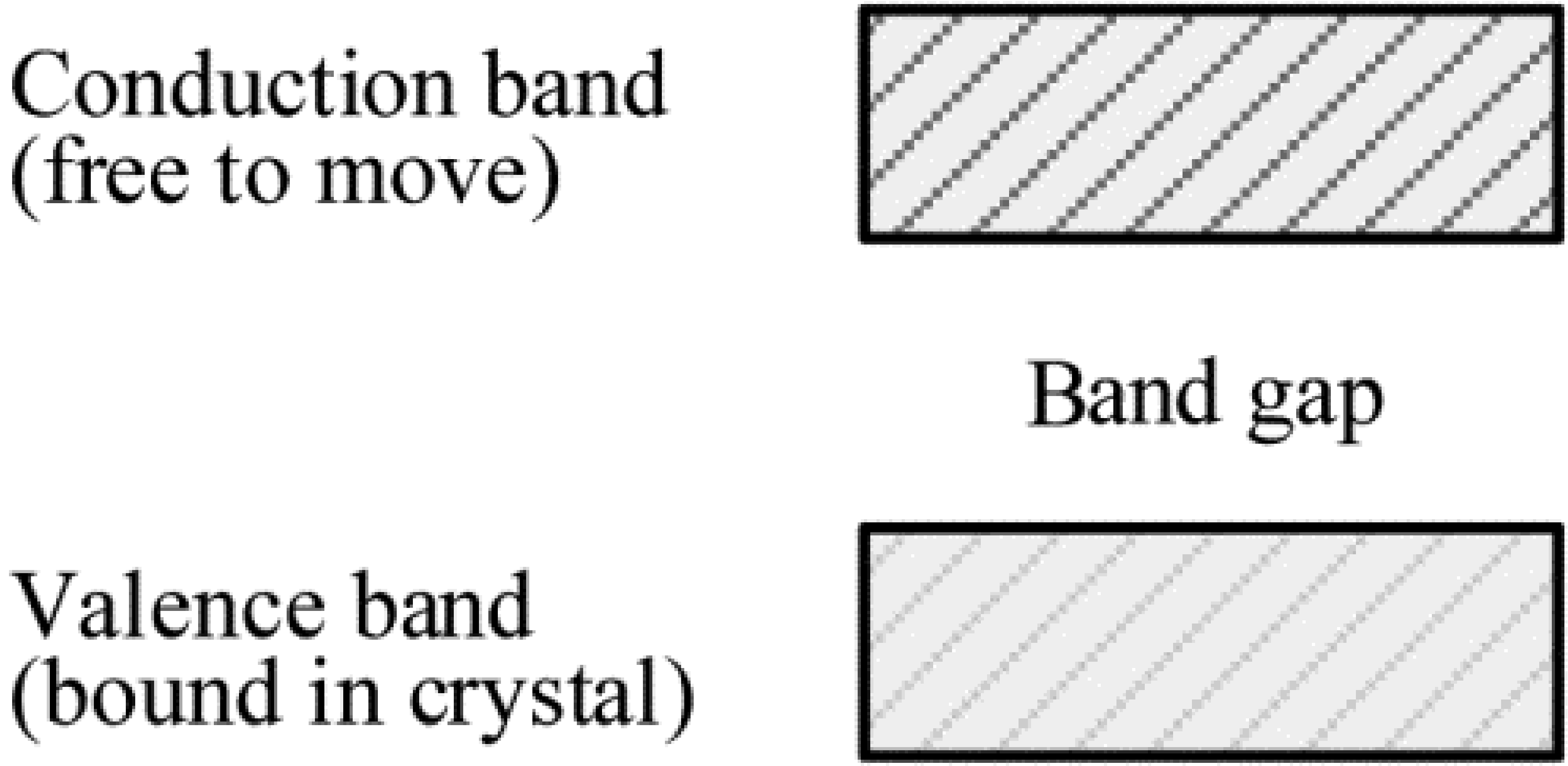


Figure 3-28 *Energy bands in a semiconductor. LEDs and diode lasers emit light carrying the band-gap energy that is released when an electron drops from the conduction band into the valence band.*

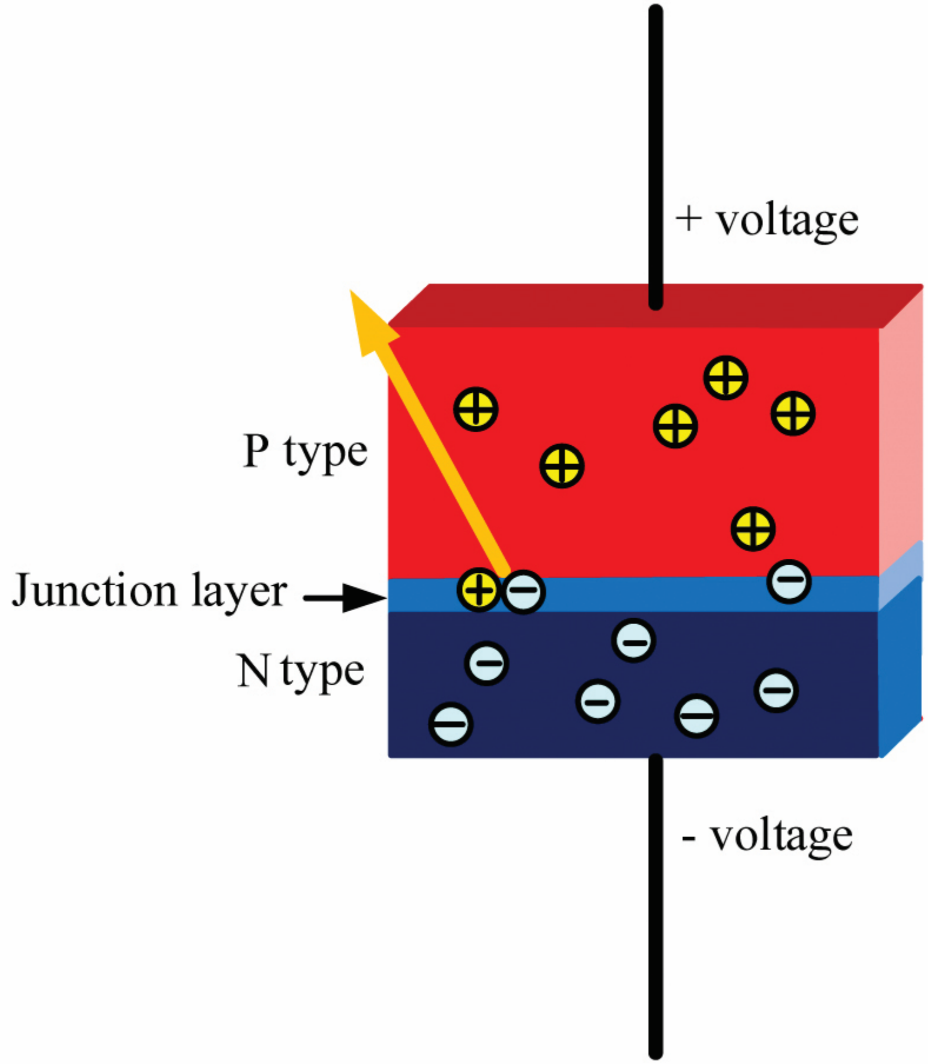


Figure 3-29 *Positive and negative carriers combine at the junction between p- and n-type semiconductors, releasing light in a LED*

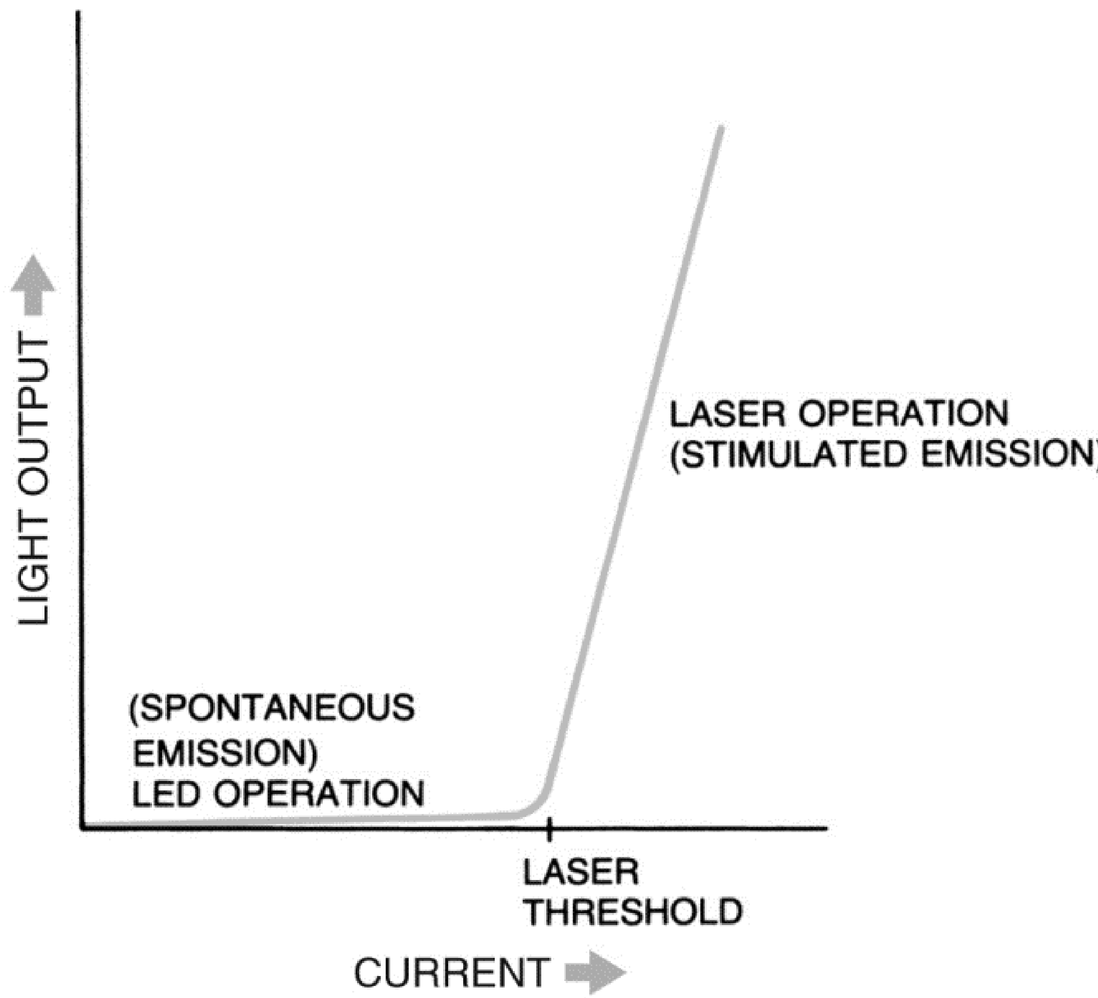


Figure 3-30 *Threshold in a diode laser marks the change from spontaneous emission of an LED to stimulated emission in a laser*

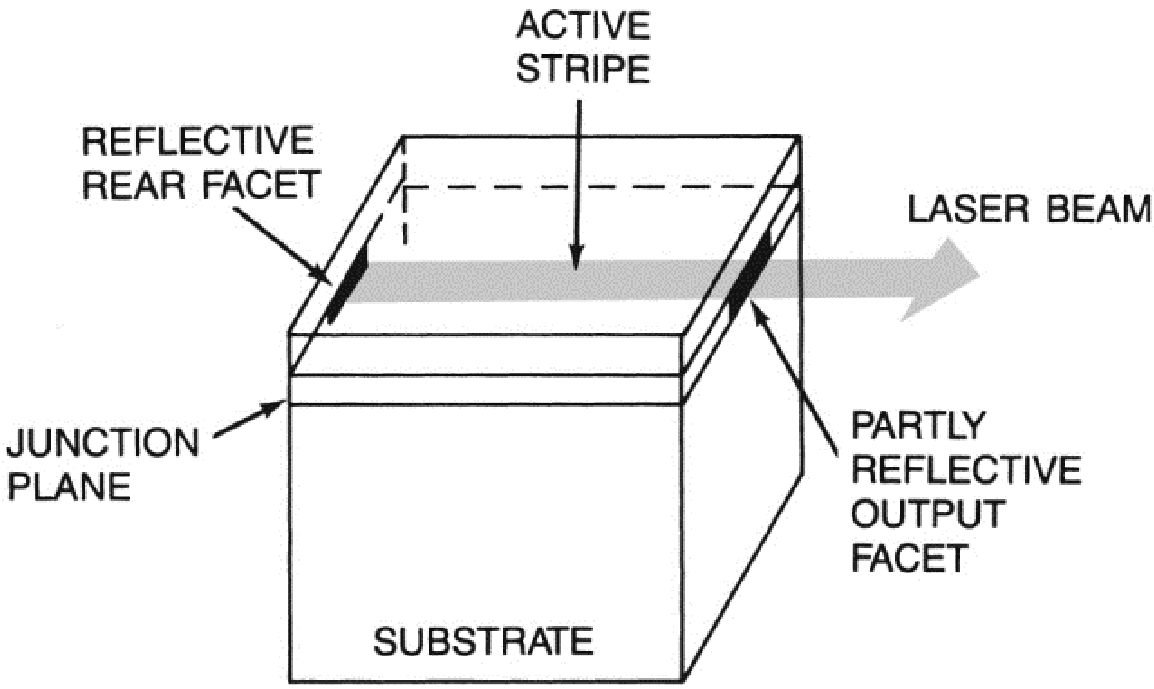


Figure 3-31 *A simple stripe-geometry diode laser. Current flow is vertical and confined to a stripe in the junction about 5μm wide and 300 to 500μm long–the length of the crystal (horizontal). In this example, the right edge of the chip is the output mirror, and the left edge is a total reflector.*

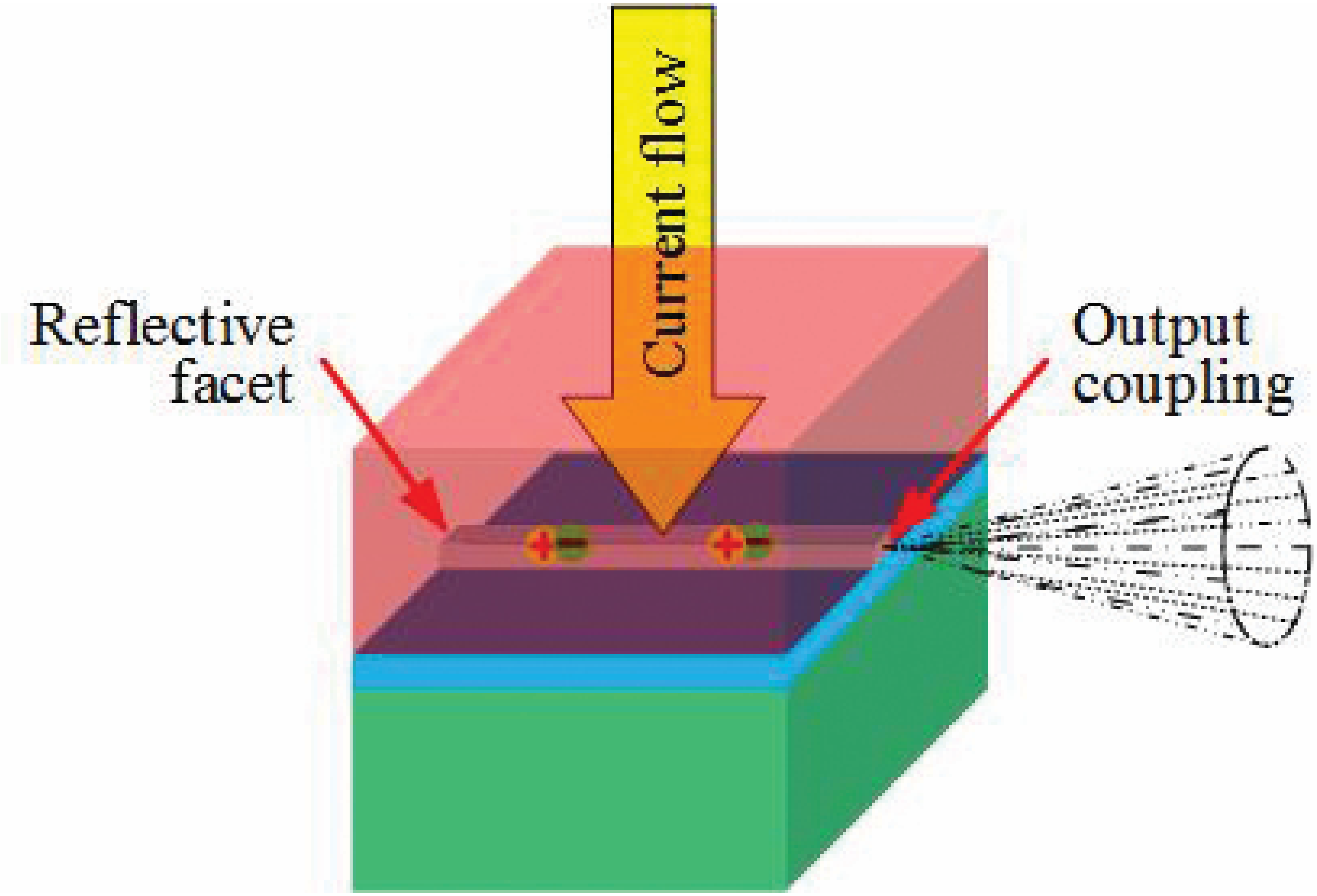


Figure 3-32 *Beam divergence from an edge-emitting diode laser*

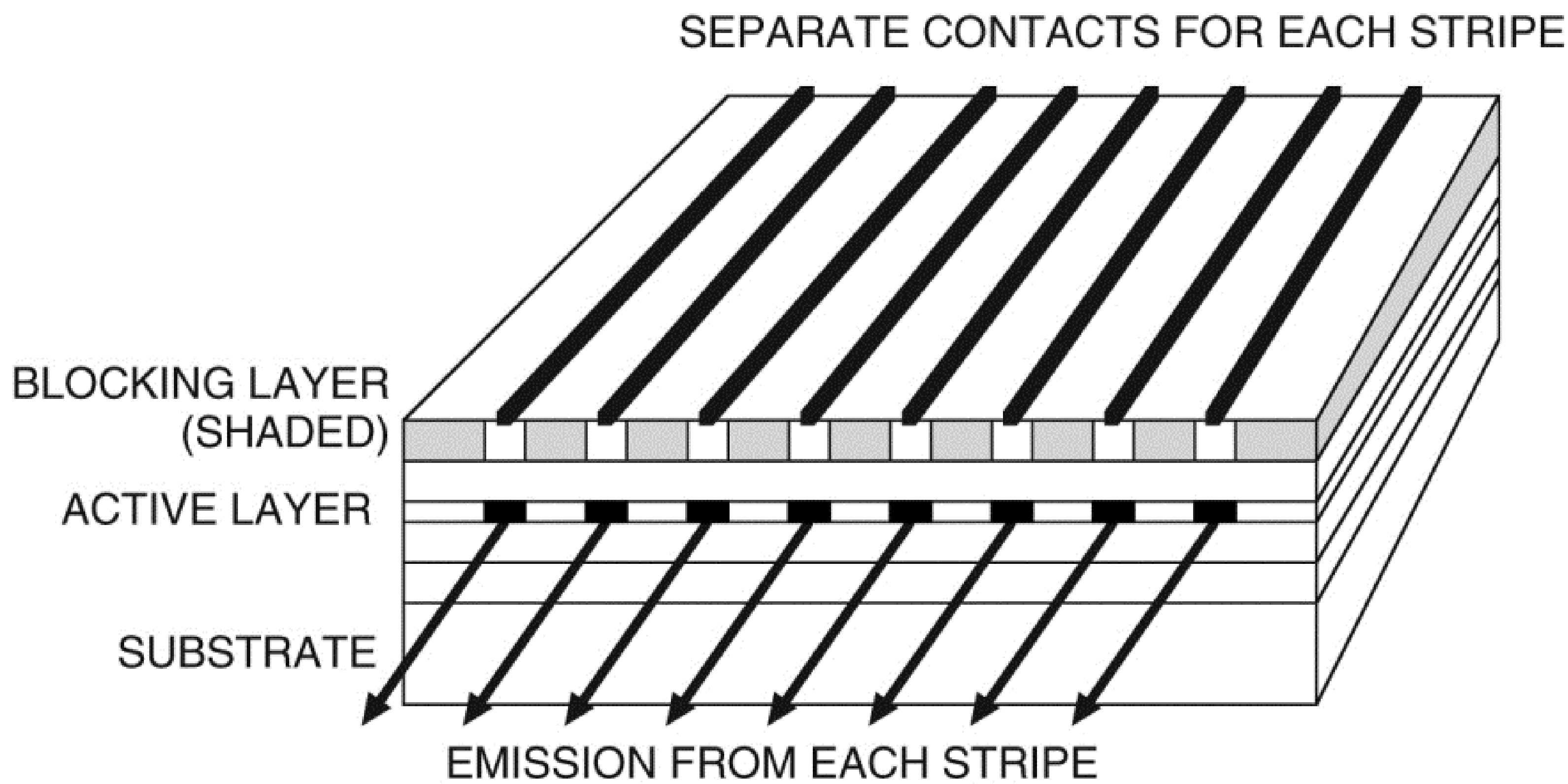


Figure 3-33 *Output of an array of several parallel stripes on a single chip can be combined to generate higher powers. Several arrays can be combined in a monolithic laser bar, and bars can be stacked together to form a "stack."*

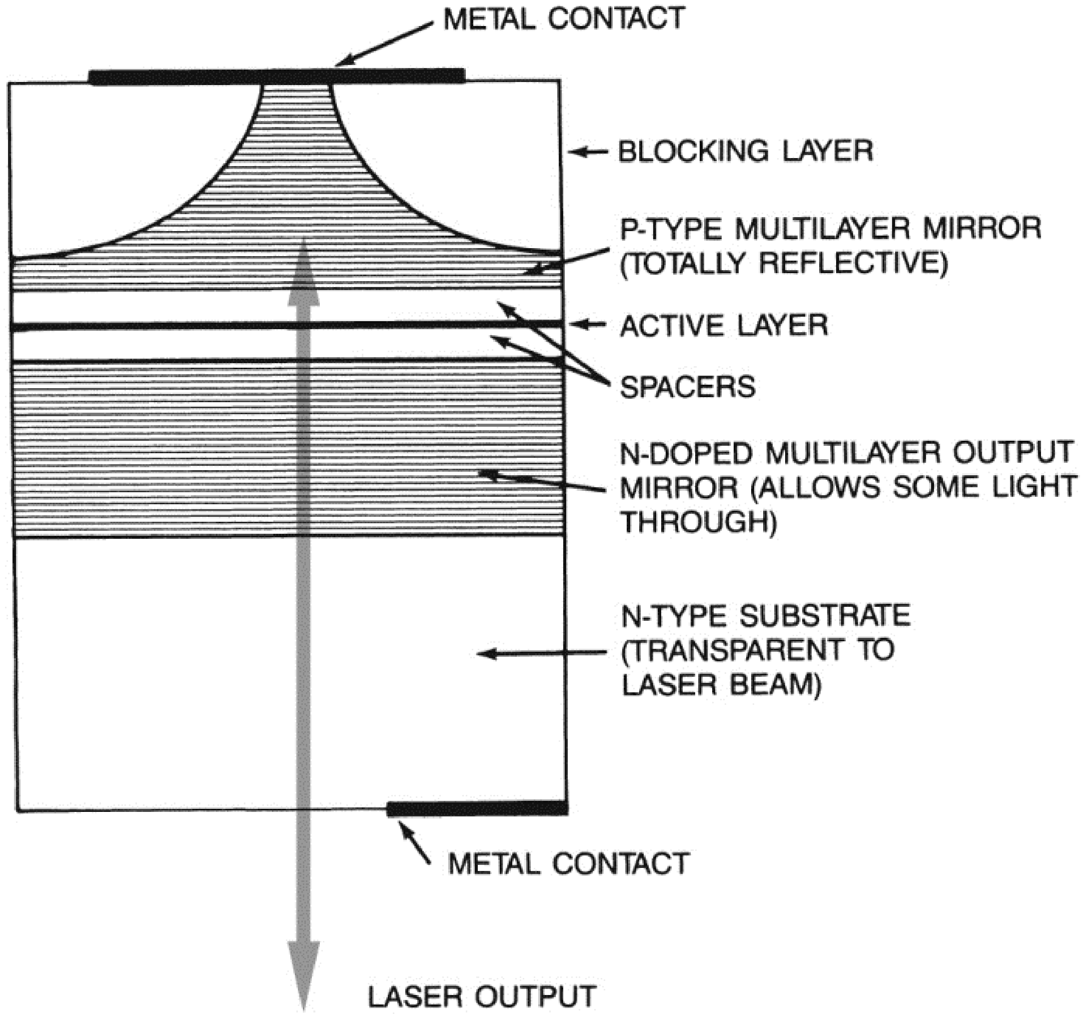


Figure 3-34 *Cross-section of a VCSEL, showing the layering of mirrors*

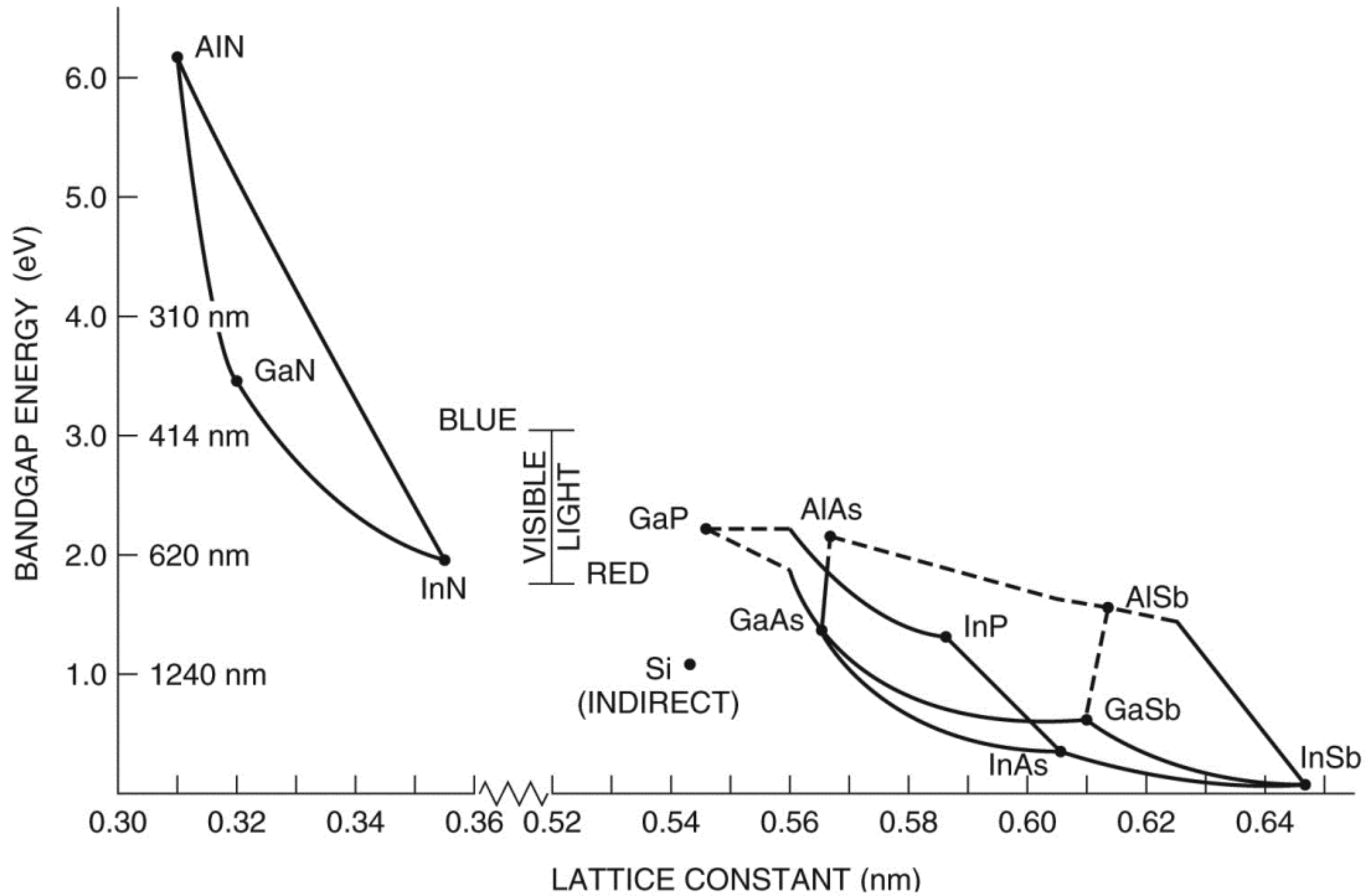


Figure 3-35 *Bandgap energy (in electron volts and wavelength) and lattice constants for selected III–V semiconductors, with silicon included for comparison. Dashed lines show compounds with indirect bandgaps.*

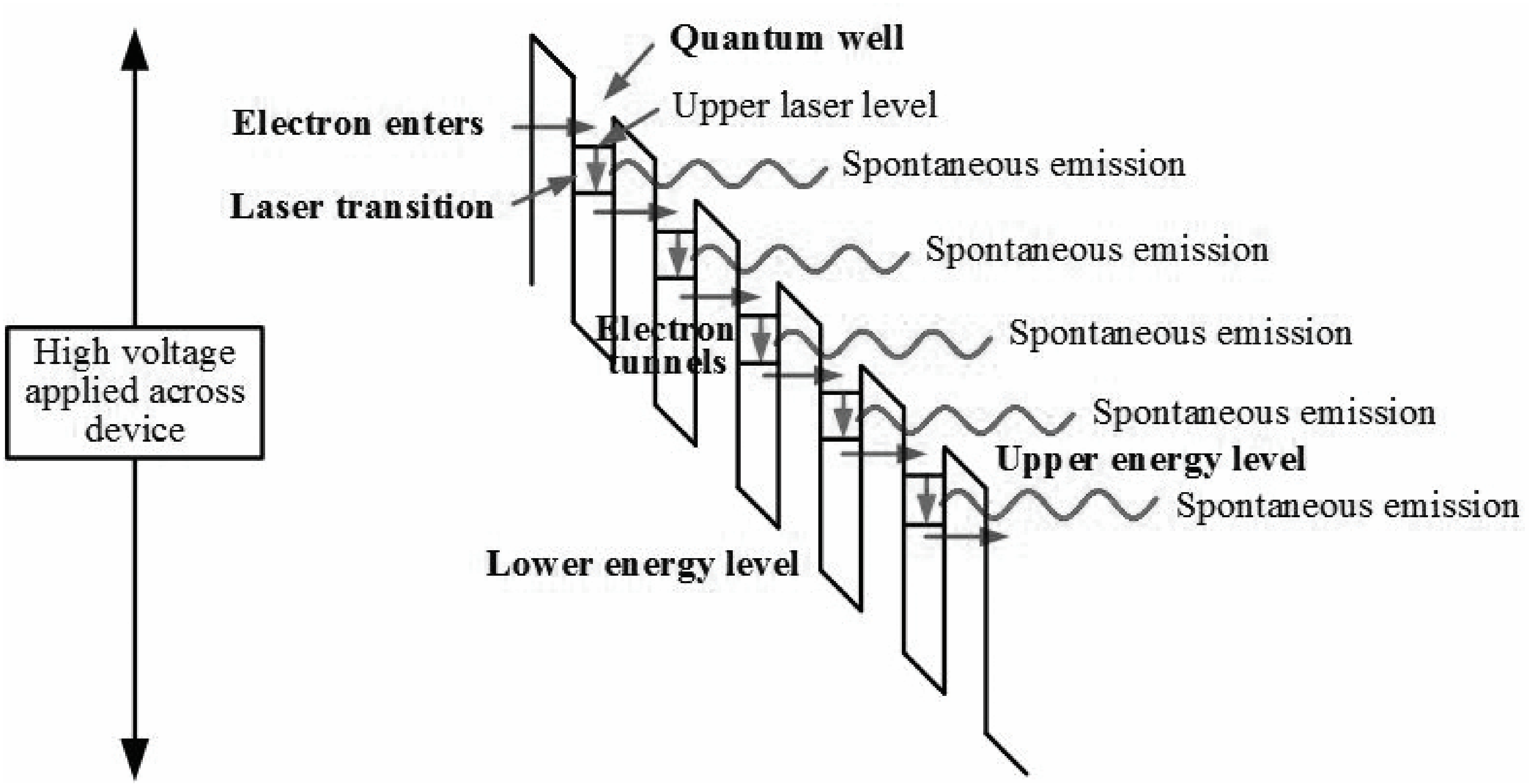


Figure 3-36 *Operation of a quantum cascade laser, with a single electron emitting a series of photons as it drops through a series of quantum wells*

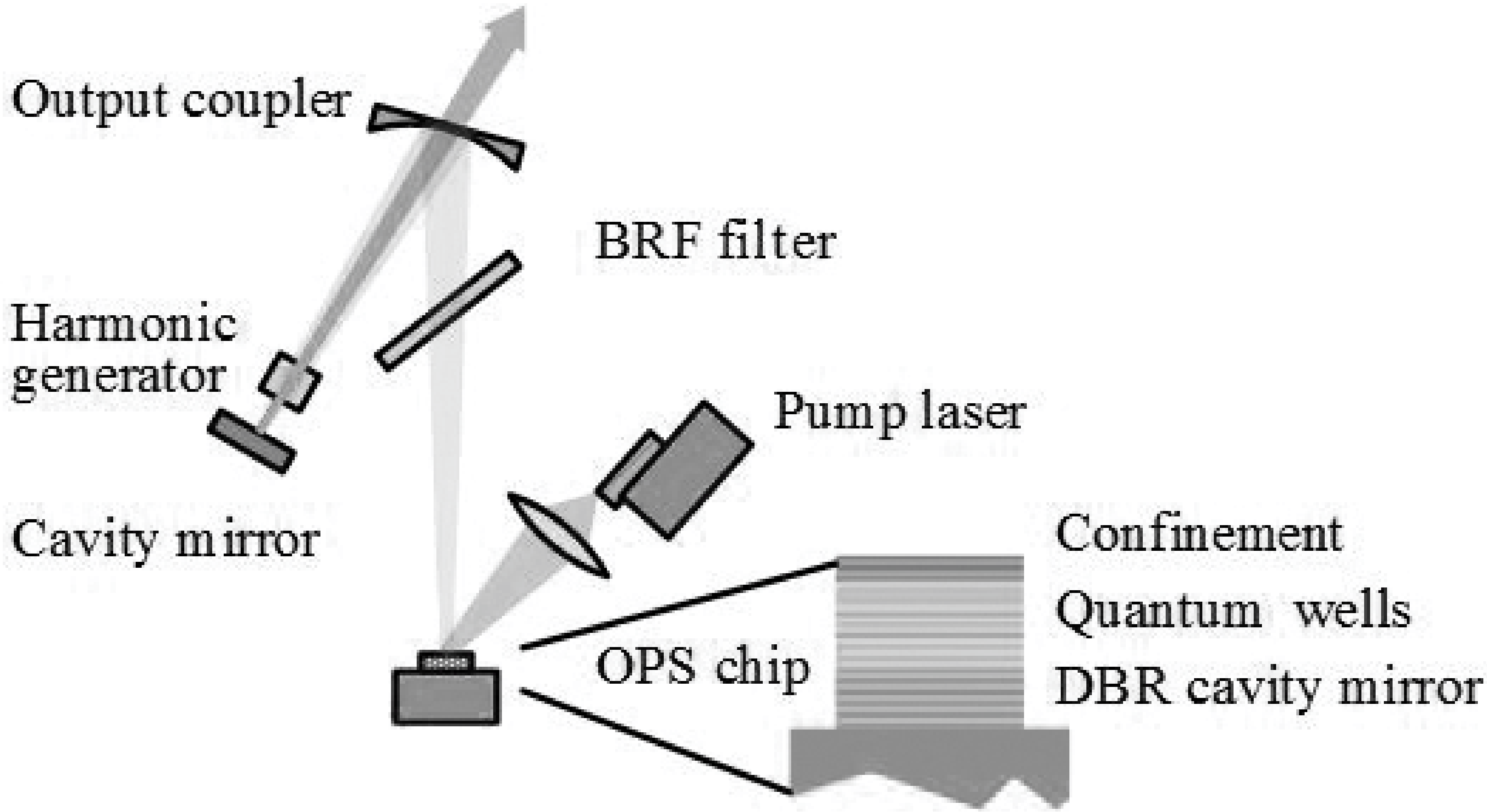
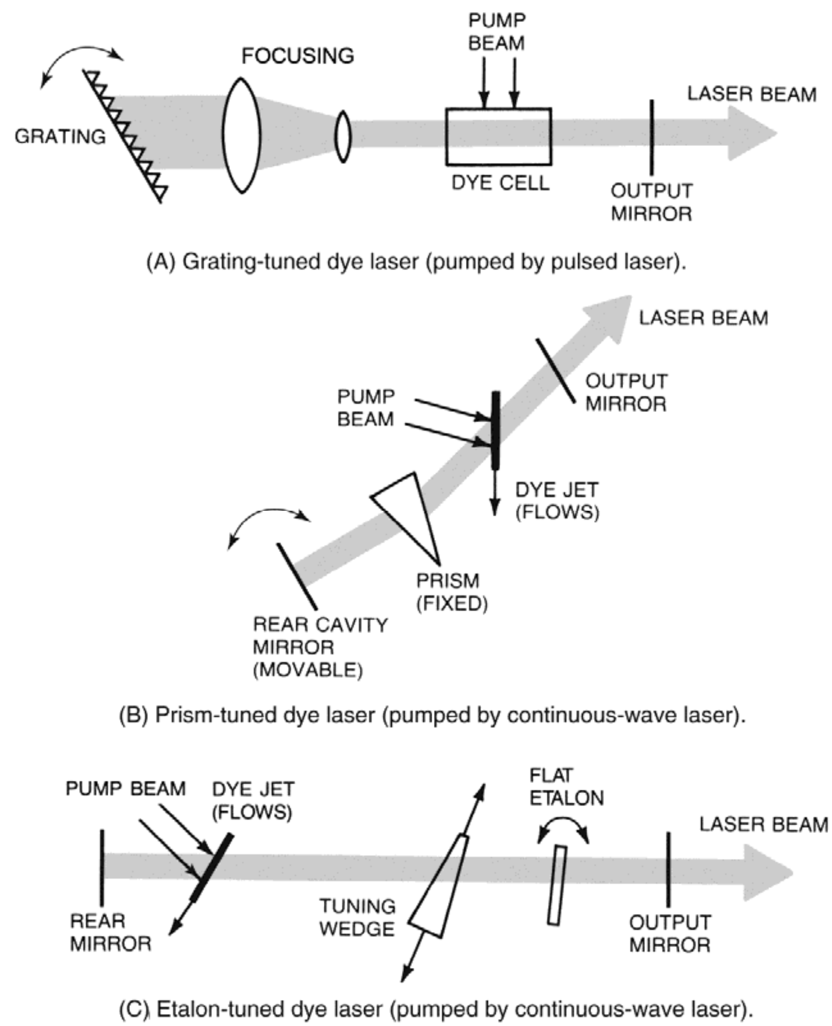


Figure 3-37 *An optically pumped semiconductor laser (OPSL) in a reflective cavity. The OPSL is a thin disk containing a stack of quantum wells and a reflector, but it does not contain a diode junction or current guiding structures. The folded cavity can include a harmonic generator, to double the OPSL's near-infrared fundamental output to visible wavelengths.*



(A) Grating-tuned dye laser (pumped by pulsed laser).

(B) Prism-tuned dye laser (pumped by continuous-wave laser).

(C) Etalon-tuned dye laser (pumped by continuous-wave laser).

Figure 3-38 *Simple, low-power, tunable dye lasers*

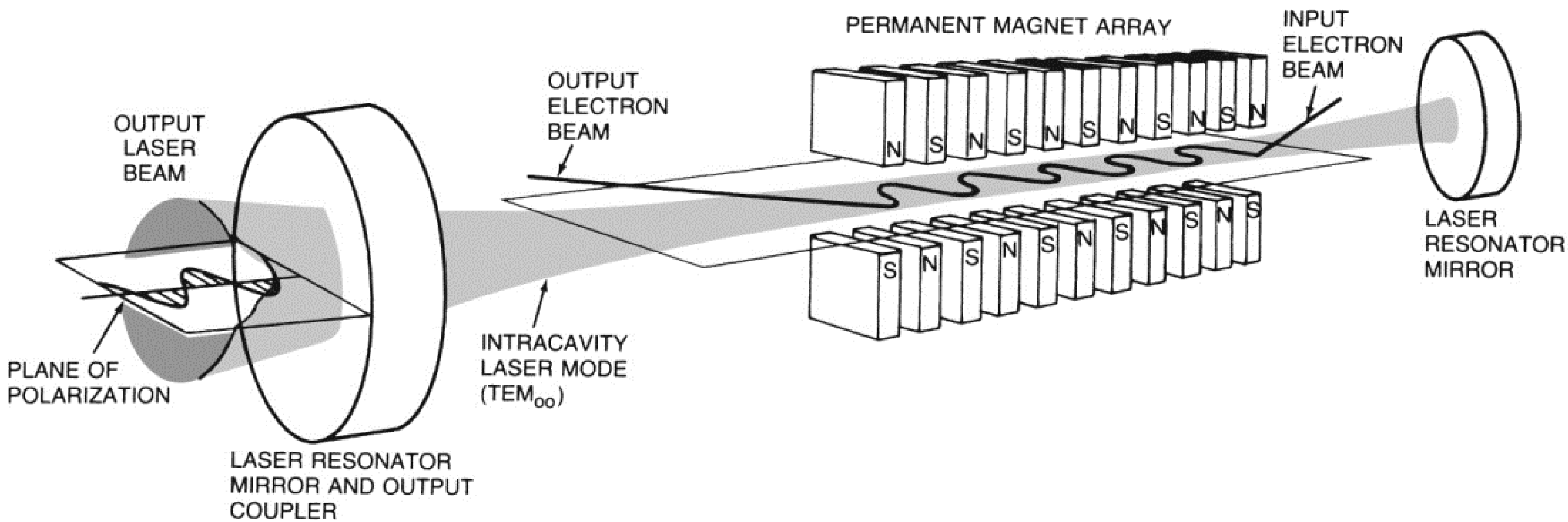


Figure 3-39 *Operation of a free-electron laser. High-speed electrons pass through an array of magnets, which bend the beam back and forth. The electrons radiate light when their paths are bent, as shown in the inset, producing a laser beam. (Courtesy of University of California at Santa Barbara Quantum Institute.)*

Figure 3-40 *Laser guide star from the Keck-2 telescope on Mauna Kea, Hawaii. The stars moved noticeably during the three-minute exposure needed to record the laser beam.*

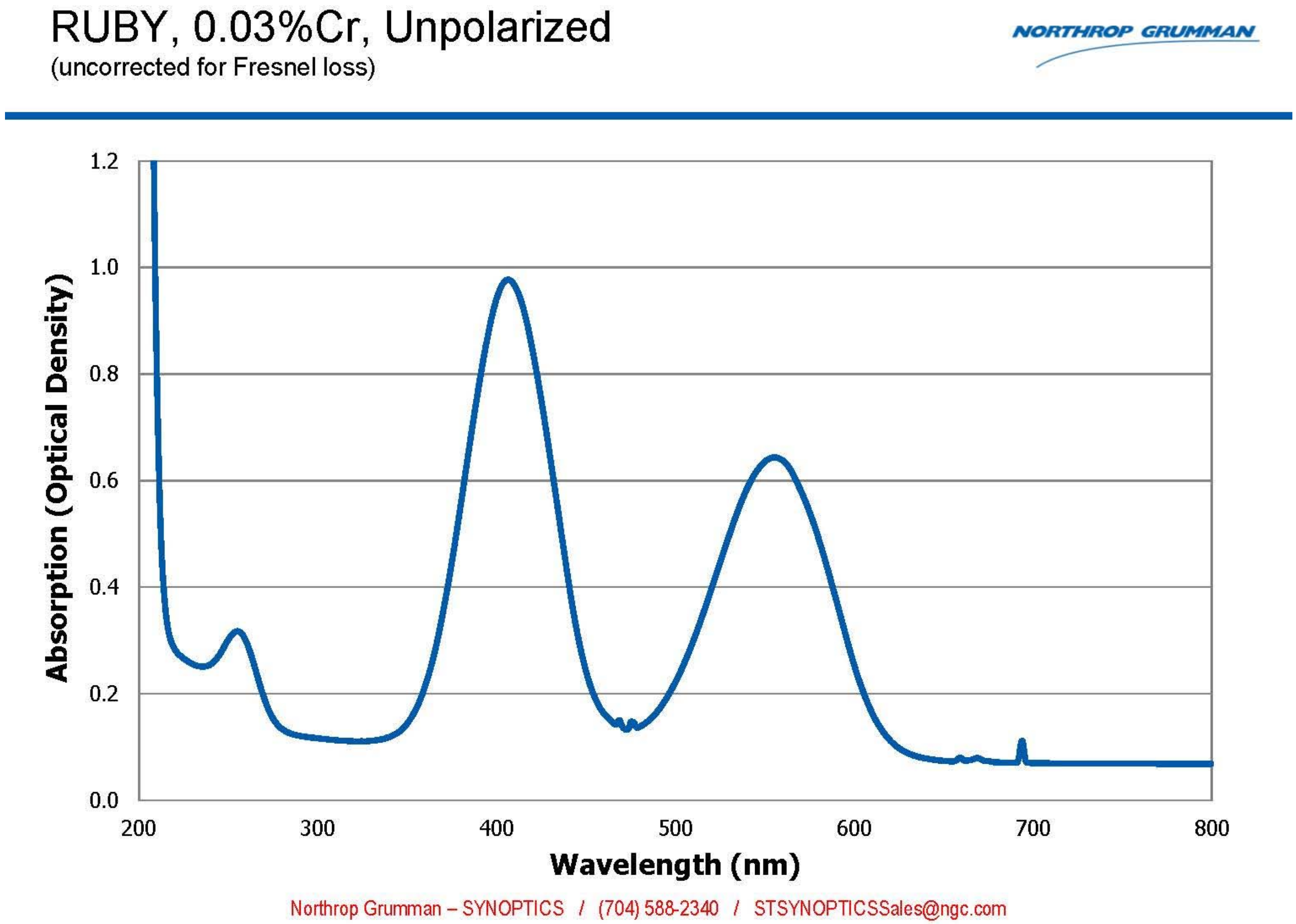


Figure 3-41 *Ruby Crystal Absorption Data*
(Image Courtesy of Northrop Grumman Corporation)