tunable lasers-the tools of the trade

SIDEBAR 2:

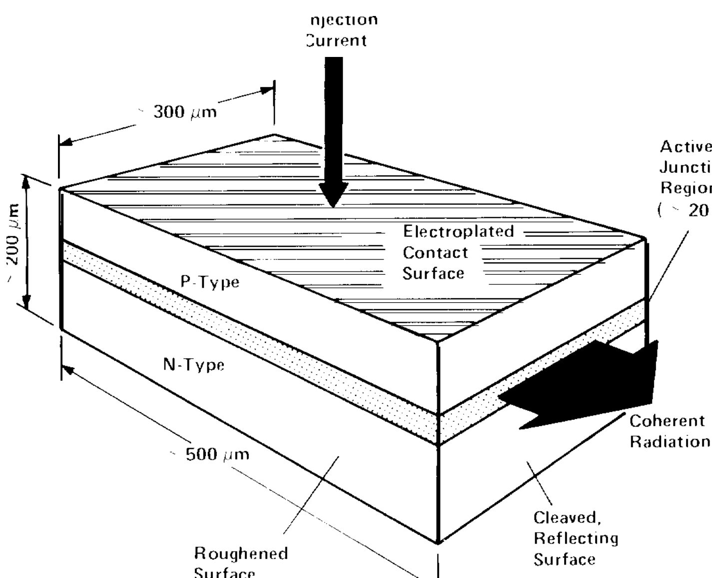
Molecular spectroscopy has undergone its modern revolution to the tune of lasers whose frequencies can be varied continuously over portions of the infrared spectrum. The most widely useful of such lasers are semiconductor diode lasers, which are similar to the light-emitting diodes familiar from so many display applications. These lasers are characterized by highly monochromatic and widely tunable output frequencies. They are also inexpensive and, although requiring cooling to very low temperatures, simple to operate.

The lasing medium of these devices is a D-n junction diode formed in a small crystalline semiconductor. The crystal itself, no bigger than a grain of sand, is mounted on a copper base that serves as an electrical ground and as a thermal connection to a liquefied gas. An injection current applied across the diode causes migration of conduction-band electrons from the n-type material and of holes (valence-band electron vacancies) from the p-type material into the junction region. There the conduction electrons combine with the holes and emit photons whose frequency depends on the energy difference between the valence and conduction bands of the semiconductor.

The diode lases spontaneously on wavenumbers ranging over several tens of reciprocal centimeters. Within this interval particular wavenumbers (cavity modes) can be amplified by constructive interference within an optical cavity. Such an optical cavity is conveniently at hand in the form of the optically flat and parallel cleaved faces of the crystal. The lasing frequency is thus determined by the index of refraction and length of the crystal Because these parameters are temperature dependent, the laser can be tuned by varying the temperature of the crystal. In practice this is accomplished by varying the injection current and hence the electrical energy dissipated within the crystal. A semiconductor diode laser can be continuously tuned in this manner over an interval of about 1 cm^{-1}. Adjacent intervals can be accessed by changing the crystal's thermal or magnetic environment, both of which alter not only the index of refraction and length of the crystal but also the diode's spontaneous emission frequency. With these techniques some semiconductor diode lasers can be quasi-continuously tuned over intervals of 100 cm^{-1} with a linewidth of 10^{-5} cm^{-1} or better. However, achieving such a broad tuning range and narrow linewidth requires great care in the fabrication of the diodes, a process involving sophisticated masking and epitaxial growth techniques.

Particularly useful for infrared spectroscopy are semiconductor diode lasers whose spontaneous emission frequency can be varied by altering the chemical composition of the semiconductor from which they are fabricated. For example, lasers made from the semiconductor $Pb_{1-x}Sn_xTe$ (where $0 \leq x \leq 0.28$) can be tailored to emit between 6.6 and 33 µm (between 1520 and 300 cm^{-1}).

This brief account of semiconductor diode lasers has overlooked certain of their faults. Generally, the simultaneous lasing of several different cavity modes, separated by about 1 cm^{-1}, requires the use of a grating spectrometer to select a single mode. Also, competition between the different cavity modes sometimes causes discontinuous frequency jumps, called mode hops, during a scan. Nevertheless, no other laser is so generally useful for high-resolution spectroscopy throughout a very interesting portion of the infrared region. ■



Simplified diagram of a semiconductor diode laser. These tunable lasers have become the workhorses for molecular spectroscopy because of their broad coverage of the infrared region in which rotational-vibra tional transitions occur.