They are still relatively primitive devices, comparable to the 1910 models of airplanes or crystal-set radios. They began as a scientific curiosity but rose quickly to the eminence of useful tools. And Rice is the only place in Texas where scientists have developed and are working with

TUNABLE LASERS

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EFFORTS to design a tunable laser on the Rice campus began in the fall of 1968. Fifteen months later we became one of the first groups in the world actually to operate such a device. And in the winter of 1971 Rice still had the only tunable lasers in Texas.

Our research and development of the tunable laser was made possible through grants from two government agencies. Rice's competitors in the search for tunable lasers were scientists of the much larger facilities of Bell Telephone Laboratories and Stanford University.

By now probably everyone knows that a laser is a light source of a new kind capable of producing light with special properties in and near the visible portion of the electromagnetic radiation spectrum. The light is extremely intense and "coherent" or directional and of a single frequency or wavelength. These disciplined qualities make the laser more attractive than ordinary "incoherent" light sources such as incandescent or fluorescent lamps or the sun.

A laser consists of three basic components: a laser substance with suitable energy levels; some source of energy activating the laser material, which can be either optical, electrical, or chemical; and an optical enclosure to provide a strong interaction between radiation and the material.

The original suggestion for meeting these basic requirements was made in 1958 based on concepts already formulated as early as 1917 by Albert Einstein. The first laser to operate successfully was constructed in July 1960 by Theodore Maiman, then with the Hughes Research Laboratory. This laser used a synthetic ruby crystal as the active medium. The flat and parallel end surfaces were silver-coated to form the reflecting surfaces of an optical enclosure. Maiman's particular contribution was the discovery that a conventional electronic flash tube of the kind used by photographers would supply adequate excitation to induce laser emission in the ruby crystal. The first lasers had limited usefulness but today, a decade later, pulsed and continuous lasers of all types —solid state, glasses, semiconductors, liquids, gases, plastics, and even gelatin—have been developed at thousands of single wavelengths or frequencies all the way from 1500 Angstroms in the ultraviolet to almost 8 million Angstroms in the infrared. Peak powers of ten thousand billion watts as brief as one trillionth of a second and continuous powers of almost 100,000 watts (instead of 100 watts from a light bulb) in a beam whose cross section is less than a half inch in diameter and with divergence angles as small as one hundredth of a degree have been reported.

For many new applications of laser light it is highly desirable to be able to tune or vary the frequency of the coherent output radiation in a manner similar to tuning to a specific station on a radio. It is sometimes possible to vary the laser wavelength over a small tuning range, of about 1%, by changing the temperature of the medium or by applying either pressure or a magnetic field to it. However, a laser is essentially a fixed-frequency device. Hence, the development of a light source possessing all the characteristic features of the laser with the added feature of tunability seemed to us a challenging technical problem. At the time we started our research two approaches appeared feasible—dye lasers and parametric oscillators. Although each appeared to have its own advantages, we decided to pursue the idea of an optical parametric oscillator. The parametric oscillator makes use of the nonlinear response of certain optical crystals, while the dye laser makes use of the broad energy bands that are associated with molecular spectra to convert laser light of a fixed frequency into variable-frequency light.

A wide variety of industrial and scientific applications of coherent light are being explored all over the world. In fact, lasers have become a $300 million a year industry in the United States alone. Some of the more common applications include optical communications, information processing (holography), ranging, monitoring of pollution, medicine, and pure science. The most direct applications do not require a tunable laser since they make use only of the tremendous energy or power capability of a laser beam to heat, melt, or vaporize materials in welding, drilling, machining, and surgery. For this purpose, the neodymium glass, yttrium aluminum garnet, or gaseous carbon dioxide laser are most frequently used.

Current research at Rice involves a wide range of laser and laser-related projects that benefit from tunable lasers. Together with Professor Robert F. Curl of the Chemistry Department we plan to apply the high power, narrow-band output from a tunable laser to microwave and optical spectroscopy with the possibility of achieving unprecedented resolution. This is an innovative approach toward the investigation of the molecular structure of chemical compounds.

Professors Ronald F. Stebbings and G. King Walters of the Space Science and Physics Departments, respectively, are concerned with astrophysics on a laboratory scale. They propose to study the spectrum of gases found in the upper atmosphere and in outer space with a tunable dye laser whose output is transformed to the ultraviolet by utilizing the nonlinear response of certain transparent crystals to incident radiation fields.

With Professor Stebblings we also plan to use laser radiation for detecting and measuring air and water pollutants through their characteristic absorption and Raman spectra. Measurements of these spectra not only permit identification of various pollutants, since no two molecules have exactly the same Raman spectra, but also measure their abundance quantitatively. Furthermore, it should be possible to monitor water and air pollution instantaneously and remotely. For example, this technique can be extremely useful in detecting even distant pollution from industrial chimneys.

In the Chemical Engineering Department Professor Riki Kobayashi and his colleagues use light-scattering measurements to examine the thermodynamic properties of fluids near a certain pressure and temperature called the "critical point."

With Professor Thomas L. Estle's group in the Physics Department we are investigating the feasibility of recording and retrieving information in optical form. Use is made of the basic concept of holography, which was invented 23 years ago by this year's Physics Nobel Laureate, Dr. Dennis Gabor. In a way this is similar to the photographic process. It involves the making and reconstructing of a coded record of an object by means of the interference and diffraction of coherent light. We found that instead of using photographic film or plates, it is possible to store a large amount of digital information for a long time in optical crystals which can be read and erased at will. This offers the possibility to cram the amount of information contained in one volume of the *Encyclopedia Britannica,* comparable to 10 million characters, into a cube of lithium niobate of five millimeters to a side corresponding to a density of one billion bits per square centimeter capacity and random access time as short as one billionth of a second. Provost Frank E. Vandiver, Harris Masterson, Jr., Professor of History, and others have considered the possibility of using such a high-capacity optical holographic information storage system in developing a central library for certain special subjects which would become easily accessible to subscribers by means of an electronic and optical link. Another problem that intrigues us is the possibility of a three-dimensional color display when combining tunable lasers with a suitable holographic crystal.

Together with Professor Thomas A. Rabson of the Electrical Engineering Department we are currently engaged in developing a source capable of producing extremely short tunable light pulses which, for example, will be useful in optical radar applications. Pulses of this type can bring about thermonuclear fusion, since the spectral intensities associated with them are a million billion times those of an equivalent area of the sun.

We are also interested in the effect of intense optical radiation on living organisms. For example, we are able to produce functional abnormalities in the central nervous system of spiders by irradiating them with laser radiation and observing the changes in the webs which the spiders then produce. Tunable laser light would be a very useful tool for studying the not yet completely understood photochemical processes involved in color vision in the range of 3800 Angstroms to 7600 Angstroms.

Among the numerous potential applications of tunable lasers are optical communications in which tunable coherent high-frequency sources can provide enhanced spectrum coverage and larger bandwidth and information capacity than existing communications systems. A tunable laser with a line width of about one Angstrom centered at 7000 Angstroms when properly used, should lead to a bandwidth for transmission of information of about 50 billion cycles. This bandwidth corresponds to 10,000 television channels or some 1.7 million radio channels. Systems of this sort are quite feasible, but are as yet uneconomical when compared to the lower frequency systems presently used. However, for space communications without absorbing atmosphere, optical wavelengths appear most promising since their directivity is so excellent.

Tunable lasers are still relatively primitive devices at the crystal-set stage of radios, or airplanes around 1910. Therefore, it is reasonably certain that once tunable lasers become readily available other new and exciting applications in many areas of scientific and industrial endeavors will be found.

Author Tittel is shown on opposite page with one of Rice's tunable lasers. Tuning such a device is "similar to tuning to a specific station on a radio," writes Tittel.