Novel geometry for single-mode scanning of tunable lasers

Karen Liu and Michael G. Littman

Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, New Jersey 08544

Received November 24, 1980

We describe a geometry that allows for the single-mode scanning of lasers that use a diffraction grating as the dispersive element. It is observed that under the right conditions a rotation of the tuning element can provide changes simultaneously in cavity length and diffraction angle that exactly match the requirements needed for continuous single-mode scanning. As a case study, the method is applied to the grazing-incidence pulsed dye laser.

In this Letter we describe a novel tuning method that is applicable to single-mode lasers that incorporate a diffraction grating as the dispersive element. Even though the scheme is general, for the sake of simplicity we describe the method only as it applies to the grazing-incidence pulsed dye laser.[1–4]

The basic geometry of the single-longitudinal-mode grazing-incidence dye laser is given in Fig. 1. Tuning is accomplished simply by rotating a mirror. In an earlier publication it was suggested that by careful selection of the pivot point about which the tuning mirror is rotated, one could scan simultaneously the cavity length and the grating feedback angle, thereby permitting a continuous single-mode scan over a limited range.[3] We have determined that it is possible to define a pivot point that satisfies this tracking condition *exactly* over the entire tuning range of the grating.

In order to achieve tracking it is necessary to satisfy the following two equations, which together determine the laser wavelength:

$$\lambda = \frac{2}{N} L(\phi) = \frac{2}{N} [l_f + l_t(\phi)], \qquad (1)$$

$$\lambda = \frac{x}{m} (\sin\theta_0 + \sin\phi). \qquad (2)$$

Here $L(\phi)$ is the optical cavity length [l_f is the optical distance between the grating and the fixed mirror and $l_t(\phi)$ is the optical distance between the grating and tuning mirror], N is the mode number, x is the grating period, m is the diffraction order, θ_0 is the incidence angle, and ϕ is the diffraction angle. Equation (1) is simply a statement that the cavity length corresponds to an integral number of half-wavelengths. Equation (2) is the master grating relationship. If we choose the pivot axis to be the intersection of the surface planes of the grating and tuning mirror, and designate the distance between the grating center and pivot axis by l_p, then $L(\phi)$ is just

$$L(\phi) = l_f + l_p \sin\phi.$$

Substituting this result in Eq. (1) gives

$$\lambda = \frac{2}{N} (l_f + l_p \sin\phi). \qquad (3)$$

Comparison of Eqs. (2) and (3) reveals that, if

$$\frac{2}{N} l_f = \frac{x}{m} \sin\theta_0$$

and

$$\frac{2}{N} l_p = \frac{x}{m},$$

then tracking is achieved exactly for all accessible wavelengths. (Note that if the optical length of the dye cell is equal to its physical length, then the pivot axis is defined uniquely by the intersection of the surface planes of the grating and cavity end mirror.) For the grazing-incidence case we have the additional condition $\sin\theta_0 \approx 1$, so that the pivot is located at a distance $l_p \approx l_f$. For a typical grazing-incidence laser, $l_p \approx l_f \approx 9$ cm, $x = (2400 \text{ lines/mm})^{-1}$, $m = 1$, and $N = 4.5 \times 10^5$. This laser thus can be scanned in a single mode over the wavelength range $\lambda = 416$–833 nm.

The proposed laser-scanning scheme does impose severe requirements on the rotation mount used for the tuning mirror. In particular, a mechanical runout of as little as a half-wavelength will result in a mode hop. (This runout can be compensated for by use of a piezoelectric transducer on the cavity end mirror.) Care must be taken to set the pivot location correctly. An

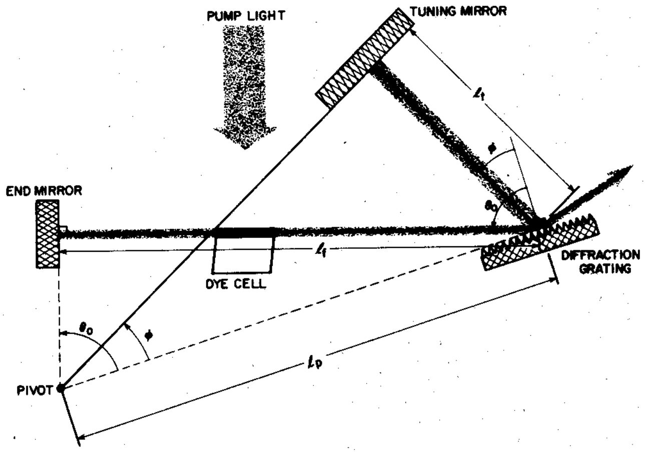

Fig. 1. Grazing-incidence pulsed dye laser with self-tracking geometry. (The pivot position as shown is correct only if the optical path length of the dye is equal to its physical length.)

0146-9592/81/030117-02$0.50/0

error in its position of as little as 0.1 mm reduces the tracking range from 416 to 11 nm.[5]

In principle, the described scanning system can be used with many other types of tunable lasers, especially in high-gain systems, such as color-center lasers. An approximate tracking also can be achieved by using a prism instead of a diffraction grating. This would be useful especially in lower-gain systems, such as cw dye lasers. In addition, an analogous geometry exists for use with Littrow gratings. A grazing-incidence prototype laser that incorporates the single-mode scanning geometry is being constructed.

We thank Richard Miles, Stuart Crampton, and John French for helpful discussions. This work was supported by research initiation funds from the Department of Mechanical and Aerospace Engineering, Princeton University.

References

1. M. Littman and H. Metcalf, Appl. Opt. **17,** 2224 (1978).
2. I. Shoshan, N. Danon, and U. Oppenheim, J. Appl. Phys. **48,** 4495 (1977).
3. M. Littman, Opt. Lett. **3,** 138 (1978).
4. S. Saikan, Appl. Phys. **17,** 417 (1978); T. Chang and R. Y. Li, Appl. Opt. **19,** 3651 (1980).
5. K. Liu, "Scanning system for single-mode tunable dye laser," undergraduate research report, Princeton University, Princeton, N.J., 1980 (unpublished).