A Single-mode Dye Ring Laser with Output Coupler Using Frustrated Total Internal Reflection

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Details of a dye ring laser with an output coupler of adjustable transmission based on frustrated total internal reflection are reported. The construction allows optimization of tuning range or output power. Using appropriate intracavity etalons and a Fox-Smith reflector as mode selector reliable single-mode operation was observed with peak powers of 1 kW and bandwidths of 0.03 pm.

Prism ring cavities offer a convenient method of tuning the emission of an organic dye laser throughout the visible spectrum by prism rotation. For laser output bandwidths in the angstrom range, which are easily achievable with a set of 4 or 6 dispersively arranged prisms, it is possible to avoid any dielectric coatings within the cavity using an output coupler based on frustrated total internal reflection, FTIR [1]. In principal output powers in the megawatt range can be tuned without any danger of damaging coatings with intense laser light. In this note new experimental data on a 4 prism ring laser with an output coupler of variable transmission are presented. After insertion of additional wavelength selective elements such as interferometers and a longitudinal mode selector, reliable single-mode operation was obtained. The basis concept of wavelength selection by prism rotation has been previously discussed in references [2, 3].

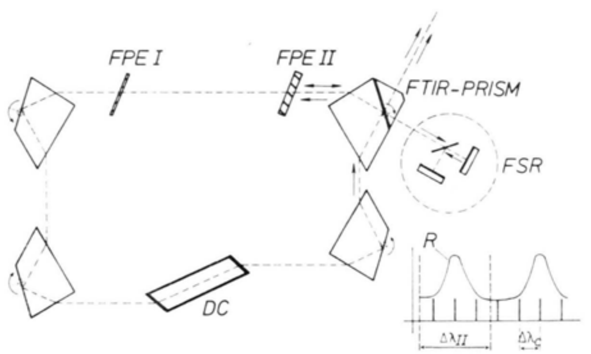

Fig. 1. Experimental setup of 4 prism ring laser. DC: dye cell, FTIR prism: outcoupling prism with variable transmission based on frustrated total internal reflection, FSR: Fox-Smith reflector, FPE: Fabry-erot etalon. Insert at lower right of schematic diagram shows longitudinal mode structure of laser cavity ($\Delta\lambda_c$), free spectral range $\Delta\lambda_{II}$ of FPE II and selective reflectivity R of Fox-Smith reflector.

Figure 1 depicts the laser setup with dye cell, optically pumped by the discharge of 20 J input energy through a 1.5″ long flashlamp (Xenon Corporation type N 598), 4 Abbé or Pellin-Broca prisms of constant 90° deviation and the attached FTIR-prism to extract power from the system. The prisms were mounted according to McClain's calculations [4, 5] in order to avoid a lateral translation of the deviated beam when the prism is rotated. The mounting consisted of placing the prism on its rotary table so that the axis of rotation passes through a point P lying one third of the way along the reflecting face, closest to the obtuse corner. Details of the outcoupling system are shown in Figure 2. The small 90°-prism was mounted in a distance Δx of approximately 600 nm from the Abbé prism by means of a 0.5 mm wide chromium boundary layer * and an adjusting screw. The ratio of reflected to transmitted light for a polarization parallel to the plane of incidence and an angle of incidence of 45° is given by the following equation [6, 7],

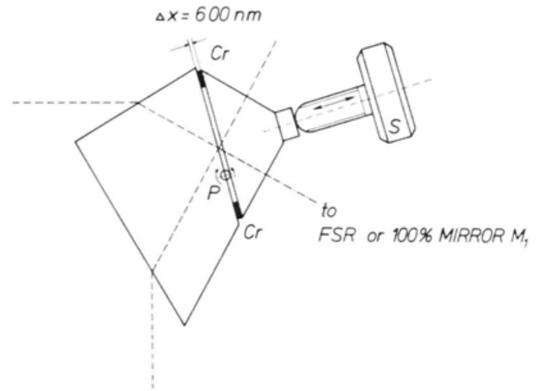

Fig. 2. Technical details of prism outcoupler. Δx air gap spacing, Cr: chromium layer, S: adjusting screw, P: axis of prism rotation.

$$\frac{R_p}{T_p} = \frac{(n^2-1)^4}{4\,n^2(n^2-2)} \cdot \sinh^2\left[\frac{2\,\pi\cdot\Delta x}{\lambda}\sqrt{\frac{n^2-2}{2}}\right]. \qquad (1)$$

Polarization of the laser light parallel to the plane of incidence is secured by the Brewster angled dye cell and the mounting of the 4 prisms at Brewster angle. For $\Delta x \approx \lambda/2$ a transmission of 50% is to be expected, for $\Delta x \approx \lambda/4$, 80% and for $\Delta x \approx \lambda$, 10%. In order to obtain a broad range of transmission, an

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* The coated FTIR-prism was kindly provided by Dr. F. Zaraga, Istituto di Fisica del Politecnico, Milano, Italy.

air gap spacing of about λ was chosen which could be compressed by elastic deformation of the prism combination and the chromium layer with the adjusting screw. Under optimal conditions, the same layer allowed a reproducible variation of the transmission of the output coupler between 3% and 80%. The actual transmission could be measured by means of the outcoupled light from an alignment He-Ne-laser. Figure 3 shows the tuning curves for increasing

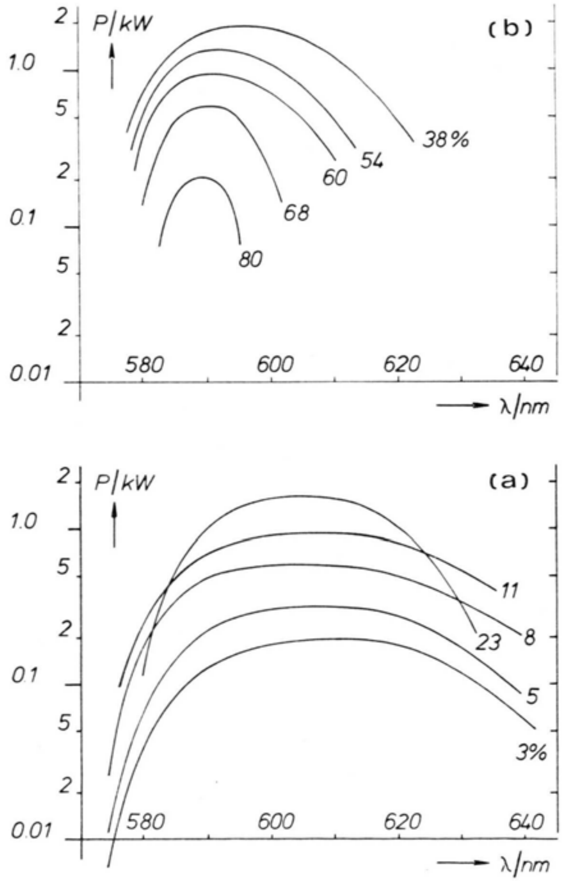

Fig. 3. Output spectra of ring laser with transmission of outcoupler varying from 3% to 23% (a) and 38% to 80% (b). Note the blueshift of maximum peak output power with increasing transmission.

transmission of the outcoupler, taken with a $2.5 \cdot 10^{-4}$ molar solution of Rhodamine 6 G in water containing 8% Ammonyx. The broadest tuning range (575 nm – 645 nm) was obtained for the lowest transmission of 3%. Peak output power increased to 2 kW for 38% transmission. Figure 4 summarizes the results of laser output optimization in a plot of peak output power versus transmission of the outcoupler. All measurements for the ring laser were taken under traveling wave operation conditions, by feeding back onto itself the clockwise traveling wave with the broadband high reflectivity mirror M_1. The tuning curves of Fig. 3 have not been corrected for the

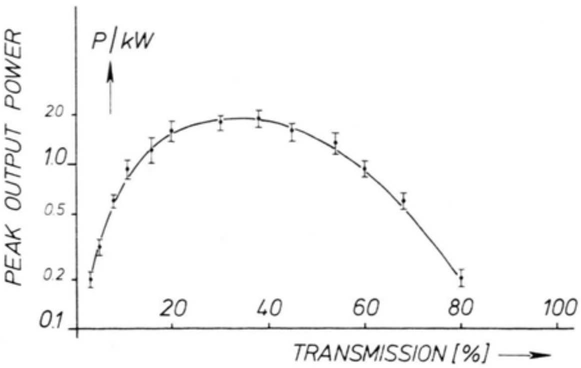

Fig. 4. Dependence of peak output power on transmission of output coupler for a $2.5 \cdot 10^{-4}$ molar solution of Rhodamine 6 G in water plus 8% Ammonyx as detergent to prevent dimerisation.

wavelength dependence of the ratio R_p/T_p. The bandwidth (fwhm) of the laser emission was 2 Å, the divergence 2 mrad and the pulse duration 300 ns.

The bandwidth of the system could be considerably reduced by insertion of two solid state quartz Fabry-Perot etalons (FPE I + FPE II) of 0.25 and 4 mm thickness covered with a broadband reflection coating of 60% reflectivity. At 20 J input energy typically 3 longitudinal cavity modes were oscillating with a mode spacing of 0.65 pm corresponding to an effective cavity length of 55 cm. Three mode operation resulted in total bandwidth of 2 pm.

Replacing the reversing mirror M_1 by the Fox-Smith reflector (FSR) of the selective reflectivity [8, 9] as shown in Fig. 1, reliable single-mode operation was obtained, provided the transmission of the output coupler exceeded 20% and clockwise and counterclockwise traveling waves were fed back with interferometric precision. Using an analyzing interferometer of 2.25 pm free spectral range at 600 nm, a bandwidth of 0.03 pm was measured in this case of single-mode operation. This value is not corrected for the finite resolving power of the interferometer. Taking into account the reduction of pulse width to 100 ns, the actual bandwidth may have approached the transformlimited value [10] which is approximately 0.006 pm for a pulse of 100 ns duration. As long as the two intracavity interferometers were inserted in near vertical position, the peak output power was reduced by a factor 2. With 38% transmission of the output coupler up to 1 kW peak power were observed in single-mode operation of the ring laser.

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[1] R. Polloni, IEEE J. Quant. Electr. **QE-8**, 428 [1972].
[2] G. Marowsky, L. Ringwelski, and F. P. Schäfer, Z. Naturforsch. **27 a**, 711 [1972].
[3] G. Marowsky, IEEE J. Quant. Electr. **QE-9**, 245 [1973].
[4] W. M. McClain, Appl. Opt. **12**, 153 [1973].
[5] J. Reader, Appl. Opt. **12**, 1405 [1973].
[6] E. L. Steele, W. C. Davis, and R. L. Treuthart, Appl. Opt. **5**, 6 [1966].
[7] M. Born and E. Wolf, Principles of Optics (Pergamon, New York, 1970).
[8] P. W. Smith, Proc. IEEE **60**, 422 [1972].
[9] G. Marowsky, Rev. Sci. Instrum. **44**, 890 [1973].
[10] E. G. Arthurs, D. J. Bradley, and A. G. Roddie, Appl. Phys. Letters **19**, 480 [1971].

BERICHTIGUNG

W. Muschler: „Gleichzeitige Bestimmung von Elektronenkonzentration und Elektronenstoßzahl in einem örtlich langsam veränderlichen Magnetoplasma (Teil II)", Z. Naturforsch. **29 a**, 75 ff. [1974].

Die Formel (3.16) muß richtig heißen:

$$\partial Z/\partial \beta = -q(\sin\beta)\,|\varrho|\,(|\varrho|^2+1)\,[4\,|\varrho|^2\cos^2\beta-(|\varrho|^2-1)^2]/Q_3\,, \qquad (3.16)$$