THIN-FILM LAYERS WITH DISTRIBUTED AMPLITUDE-MODULATED FEEDBACK

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A method of tuning the frequency of a thin-film laser with distributed feedback by producing periodic spatial modulation of the feedback in the film is proposed and experimentally realized.

Intensive investigations of optical phenomena in thin dielectric films [1] have recently led to the development of a thin-film laser with distributed feedback (DFB) [2]. The feedback in such a laser is the result of backward Bragg scattering of the light by periodic variations of the refractive index or of the gain of the amplifying medium itself. The emission wavelength of a laser with distributed feedback is given by

$$\lambda = 2n^* \Lambda ,$$

where n^* is the effective refractive index of the waveguide film and Λ is the period of the spatial modulation of either n^* or the gain k. By varying Λ or n^* it is possible to tune the frequency of such a laser. In tunable lasers with distributed feedback the feedback is usually produced by spatial modulation of the gain, by pumping with two coherent light beams that converge on the surface of the film at an angle 2θ [3]. The tuning is attained in this case by varying the angle θ, i.e., the period Λ.

The effective refractive index can be varied in several ways: by varying the thickness of the film, the refractive index of the substrate, etc. [1]. In [5], in particular, it was possible to tune the generation frequency in a film whose substrate was an anisotropic crystal. Variation of the direction of the generation relative to the crystal axis led to the change of n^* and consequently of the generation frequency.

In the present communication we propose to tune the frequency of a thin-film laser with distributed feedback by producing spatial modulation of the feedback in the film. As is well known [6], the magnitude of the distributed feedback is determined by the amplitude of the periodic changes Δn^* of the effective refractive index or Δk of the gain. If these amplitudes are spatially modulated with period $\Lambda' \gg \Lambda$, then there will be produced in the film, in addition to a lattice with period Λ, also lattices with periods $\Lambda_n = \Lambda(1 \pm n\Lambda/\Lambda')$, where $n = 1, 2, 3 \ldots$ If the emission wavelengths determined by these lattices fall in the amplification band of the film, then lasing at these wavelengths can occur at a suitable pumping level. The lasing frequency can be tuned in this case by varying the period Λ'.

To demonstrate the possibility of using the proposed tuning method, we performed an experiment in which we modulated the feedback, i.e., by two light beams interfering on the surface of the film. The experimental setup is shown in Fig. 1. The pump beam (λ = 0.347 μ, second harmonic of a Q-switched ruby laser) was split by a rectangular quartz prism, located ∿ 25 μ from the surface of the film. The film (thickness h = = 0.9 μ) of methylmethacrylate activated with rhodamine-6G (concentration 7.5×10^{-3} mol/l) was deposited on a substrate of fused quartz. A wire grid (Λ' = 40, 60, and 84 μ) was placed between the film and the prism and produced spatial modulation of the feedback. The laser radiation emerged through the tapered edge of the film and was registered with a DFS-8 spectrograph. Figure 2 shows the spectral composition of the radiation of a thin-film laser for different grid periods (60 and 84 μ).

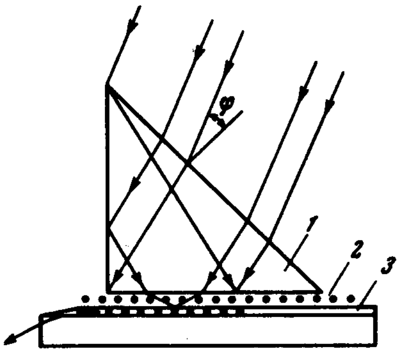

Fig. 1. Experimental setup: 1 — prism, 2 — wire grid, 3 — activated film.

In our case, the pump-like modulation had a rectangular character, so that one should expect the appearance of at least three frequencies (for n = 0 and ± 1). More frequently, however, there were actually only two

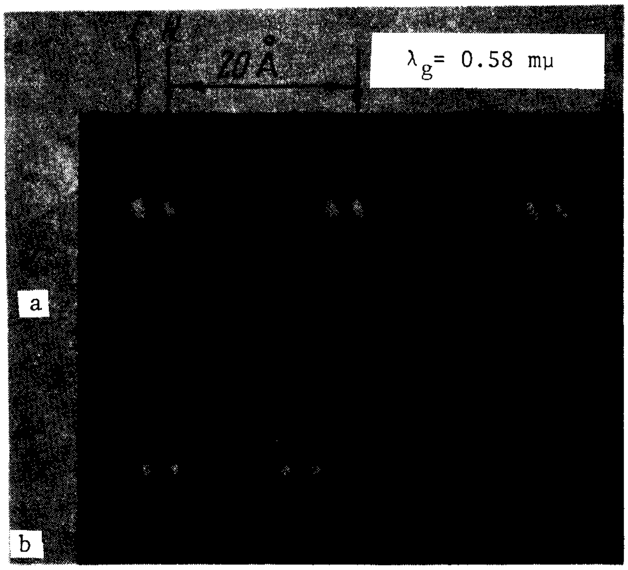

Fig. 2. Generation spectra of thin-film laser.

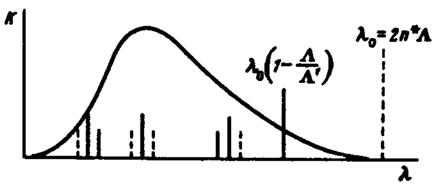

Fig. 3. The solid vertical lines denote the generation wave lengths.

frequencies, because the lattices with shifted periods (n = ± 1) had lower amplitudes approximately 1.5 times smaller than the main lattice (n = 0), because of the frequency dependence of the gain, and because of the pump level. Figure 3 shows schematically the gain contour in the film, the relative amplitudes of the lattices, and the generation wavelengths. At the center of the luminescence band, at low pump levels, lasing is at one frequency, while on the right and left of the center there are two frequencies. At high pump levels, immediate lasing at three and more frequencies can be obtained.

Figure 2a shows the generation spectrum realized in the shortwave region of the luminescence band, the third frequency corresponding to generation on a lattice with a period $\Lambda_2 = \Lambda(1 + 2\Lambda/\Lambda')$. Figure 2b shows the generation spectrum obtained by rotating the wire grid (Λ' = 60 μ) through an angle $\psi = 45°$ relative to the generation direction. This experiment demonstrates the possibility of smoothly tuning the generation frequency by rotating the wire grid, which is equivalent to increasing the period $\Lambda'_\psi = \Lambda'/\sin\psi$. To obtain a single-frequency operation of the tunable laser (by single-frequency we mean here simultaneous generation of E and H waves), it is necessary to choose the principal lattice period Λ in such a way that the corresponding frequency does not fall in the amplification band (Fig. 3), and the period Λ' must be sho chosen that the mixed frequency lies inside this band.

It is shown in [7] that for a corrugated film whose thickness varies periodically, $h = a_0[1 + \mu\cos(2\pi/\Lambda')x]$, the proper solution is the superposition of spatial harmonics whose phase constants are determined by the relation

$$\beta_n = \beta \pm n\frac{2\pi}{\Lambda'},$$

where n = 1, 2, 3 ...

Obviously, if we produce distributed feedback in such a waveguide we can obtain simultaneous generation on several frequencies, and everything stated above concerning the frequency of tuning can be applied to this case.

In the future it is desirable to be able to tune electrically the generation frequency of a thin-film laser with distributor feedback by using, e.g., acousto-optics, and apparently the principle of feedback modulation can serve as the basis for further research on electronic laser tuning.

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