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Divergence and polarisation of radiation of a wide-aperture chemical DF laser with an unstable resonator

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Abstract. **Influence of a plane-parallel plate, placed inside an unstable resonator and entirely overlapping the beam cross section, on the polarisation and divergence of wide-aperture DF-laser radiation is studied at various angles of plate inclination to the resonator axis. It is shown that the plate inside a resonator has no effect on the radiation divergence and only requires a corresponding shift of a convex mirror in order to keep the resonator confocal. A noticeable change in the radiation polarisation has been observed only at angles of plate inclination greater than 20°; at angles of above 45° the radiation becomes actually linearly polarised.**

Keywords: *unstable resonator, radiation polarisation, divergence, DF laser.*

As known, unstable resonators are widely used for obtaining high-quality beams in lasers with active media of large volume [1, 2]. An interest in the employment of unstable resonators for chemical lasers is also high nowadays (see, for example, [3, 4]). In solving some applied problems, in addition to strict requirements to beam divergence, the linear beam polarisation is needed. Several variants of complicated schemes were suggested in [5]. In [6, 7], a dielectric film polariser on a thin substrate was placed inside an unstable resonator. Our task was investigation of the influence of a 'non-thin' plane-parallel plate placed inside an unstable resonator, which completely overlaps the radiation beam, on the polarisation and divergence of radiation as a function of the angle between a plate surface and resonator axis.

Experiments on measuring the degree of radiation polarisation and divergence were carried out on a setup, which is schematically shown in Fig. 1. The source of radiation was a pulsed chemical photoinitiated $F_2 + D_2$ chain reaction laser. The spectral range of laser radiation was 3.7 – 4.2 μm and had a maximum near 3.9 μm. A length of the active medium was 80 cm at a light diameter of 100 mm. Laser cavity windows made of CaF_2 were placed at an angle of 4° to the resonator axis and had no effect on the beam polarisation. An unstable resonator of the laser comprised convex and concave mirrors with the reflection coefficients of above 99% and the ratio of focal lengths equal to 3. A distance between the reflecting surfaces was 246 cm. A near-field cross section of laser radiation looked like a ring with diameters of 33 and 100 mm. Laser radiation was directed by a plane mirror (*5*) to a spherical mirror (*6*) with a focal length of 18 m (at an incident angle of less than 3°). Then radiation was attenuated by almost three orders of magnitude due to reflections from wedges (*7*) and (*8*) and passed for recording the far-field intensity distribution to an array sensor (*10*) (Pyrocam III), in front of which additional damping filters were placed (IKS-3 and IKS-5). The angles of radiation incidence to wedges (*7*) and (*8*) were taken less than 3° in order to keep polarisation characteristics of the radiation undisturbed while reflecting from them.

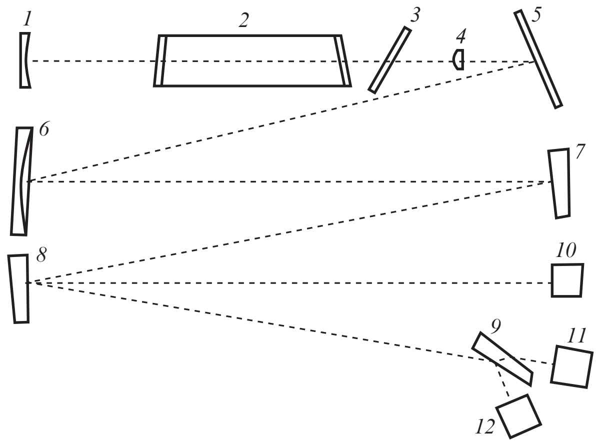

Figure 1. Scheme of the setup for measuring the degree of polarisation and observing far-zone radiation:
(*1*) concave mirror of the unstable resonator; (*2*) laser cell; (*3*) removable plane-parallel plate made of CaF_2; (*4*) convex mirror; (*5*) plane mirror; (*6*) spherical mirror with F = 18 m; (*7 – 9*) wedges made of CaF_2; (*10*) Pyrocam III array sensor; (*11, 12*) pyroelectric energy sensors.

Part of radiation reflected from the second surface of wedge (*8*) was used to control the polarisation. This radiation was directed to wedge (*9*) placed at the Brewster angle. The energy E_1 of radiation passed through the wedge, and energy E_2 of radiation reflected from the first wedge surface were measured by pyroelectric energy sensors (*11*) and (*12*), respectively. Let the total radiation energy in front of wedge (*9*) be $E = E_s + E_p$, where E_s is the radiation polarised normally to the plane of incidence; E_p is the radiation polarised in that plane; and $\eta = E_s/E$ is a part of s-polarised component in the radiation. In this case, we have

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$$\frac{\eta T_s + (1-\eta) T_p}{\eta R_s + (1-\eta) R_p} = \frac{E_1}{E_2},$$

where T_s and T_p are the transmission coefficients of the wedge for the s- and p-polarised radiation, respectively; and R_s and R_p are the corresponding coefficients of reflection from the front surface of the wedge. Transmission and reflection coefficients were calculated by the Fresnel formulae. By measuring energies E_1 and E_2 one can easily calculate a part of the s-polarised radiation component by the formula given above.

Measurements of radiation divergence were performed with plate (*3*) placed at the Brewster angle inside the resonator or without the plate. In the first case, the convex mirror should be moved aside (thus, increasing the resonator base) by 8 mm and shifted horizontally by 7.5 mm. In both cases, almost undistinguishable images of the energy density distribution in the far zone have been observed (Fig. 2).

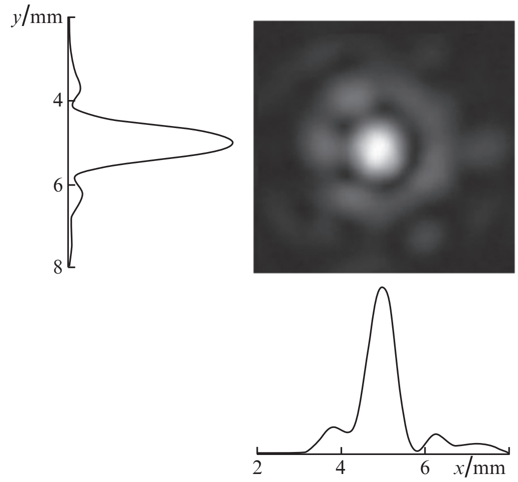

Figure 2. Image of radiation energy density distribution in the far zone and profiles of the energy density distribution along the *x* and *y* axes.

A diameter of the first dark ring in Fig. 2 is 1.7 mm. A diameter of the zone, into which 50% of radiation energy passes, is 1.35 mm; this corresponds to the divergence (at half the maximal energy) of 7.5×10^{-5} rad. Note that divergence of an ideal emitter with a ring of such a diameter is 5.6×10^{-5} rad. Thus, a pulsed chemical laser with the unstable resonator having magnification 3 provides a divergence that slightly (by 34%) exceeds the theoretically admissible value. Introduction of a non-thin (δ = 15 mm) plane-parallel plate into such a resonator at large angle (the Brewster angle in our case is 54.7°) does not affect the divergence and only requires additional adjustment of the resonator to maintain it confocal.

In Fig. 3a one can see results of measuring the degree of polarisation η versus the turn angle ϕ of a plane-parallel plate (*3*) made of CaF_2 relative to the resonator axis. At $\phi < 10°$, the value of η is ~0.5, which corresponds to unpolarised radiation or circularly polarised radiation. One can see that a noticeable change of radiation polarisation only starts from $\phi > 20°$, and at $\phi > 45°$ the radiation is mainly linearly polarised ($E_p/E_s > 125$). In [8], linearly polarised radiation was obtained by introducing a plane copper mirror inside a resonator, which had a reflection coefficient for s-polarised light exceeding that for p-polarised light by only 0.72%.

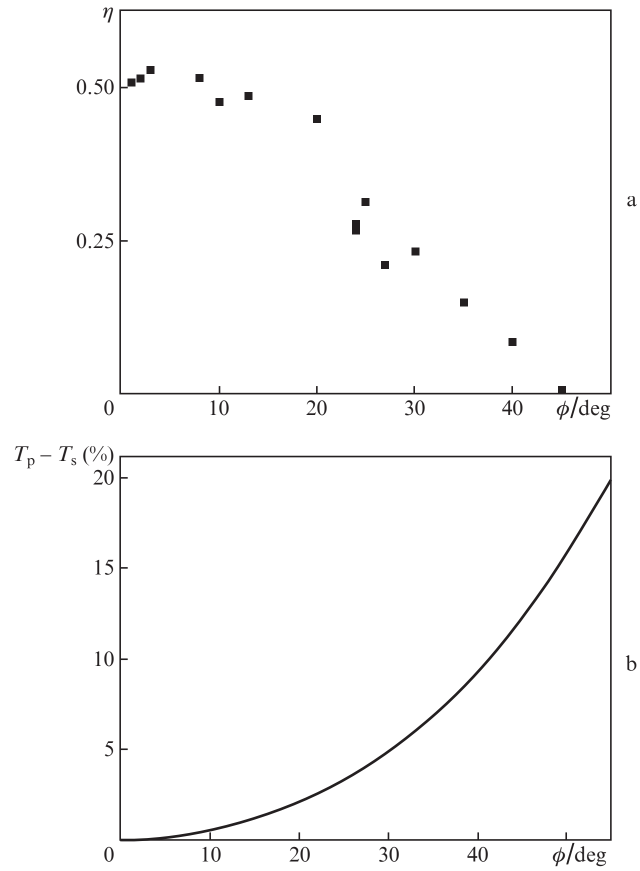

Figure 3. (a) Measured degree of polarisation η vs. the inclination angle of a CaF_2 plane-parallel plate placed inside the resonator and (b) difference of transmission coefficients of the same plate for p- and s-polarisations.

To compare with these data, in Fig. 3b we present the dependence of ϕ on the difference of transmission coefficients of the CaF_2 plate for different polarisations. In our experiments, actually perfect linear polarisation is reached at the difference of 12% between the transmission coefficients for s- and p-polarisations. So large a discrepancy between our results and [8] is, seemingly, related to different amplifying properties of the active media: in [8], the gain per round trip in the resonator was ~4, whereas in our laser it was ~900.

Thus, we have shown that introduction of a plate inside a resonator requires only a corresponding shift in the convex mirror position and does not affect radiation divergence. The degree of polarisation starts to change noticeably only at inclination angles of a CaF_2 plate to the resonator axis greater than 20°; at angles of above 45°, the laser radiation is mainly linearly polarised.

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