Analysis of Lasing in COILs with Positive and Negative Branch Unstable Resonators Using a Simple Geometrical-Optics Model

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A simple geometrical optics model is developed that describes the power extraction in chemical oxygen-iodine lasers with unstable resonators. The off-axis positive and negative branch unstable resonators with cylindrical mirrors that were recently used in the COIL are studied. The optical extraction efficiency and intensity spatial distributions in the flow direction for both kinds of resonators are calculated.

The small signal gain in the chemical oxygen-iodine lasers (COILs) is typically <1.5%/cm. Hence, to exceed the mirror losses, stable resonators with large Fresnel numbers are usually used and many transverse modes oscillate resulting in poor quality and large divergence of the extracted beam. To improve the beam quality, COILs with different kinds of unstable resonators were recently tested [1, 2]. High optical extraction efficiency and small beam divergence close to the diffraction limit in the flow direction were obtained. To determine the optical extraction efficiency η_{ext} and spatial distribution of the intensity I rather complex procedure for calculating the three-dimensional mode pattern by solving the paraxial wave equation and taking into account a nonuniform, transversely flowing, saturable gain medium was applied by different authors [3, 4].

However, due to the large Fresnel number a much more simple geometrical optics approach can be used. For a weakly amplifying medium the resonator magnification M should be close to unity. In this case under the geometrical-optics approximation the spatial distribution of the intra-resonator intensity I in the flow direction x for the positive branch cylindrical unstable resonator can be found by solving a very simple ordinary differential equation $x(dI/dx) = (g/g_{th} - 1)I$, where x is the distance from the optical axis, g and $g_{th} = \ln M/2L$ are the saturated and threshold gains, respectively, and L is the gain length [5]. We showed that for the negative branch unstable resonator I is determined from the same equation, where g is replaced with $[g(x) + g(-x)]/2$. The loaded gain was found by solving the kinetic equations for different species in the COIL taking into account the stimulated emission as described in [5]. Using this procedure we found η_{ext} for the negative and positive branch cylindrical unstable resonators as a function of g_{th}/g_0, where g_0 is the gain at the resonator inlet, and of the ratio γ_0 between the residence time of the gas in the resonator and the $O_2(^1\Delta)$ energy extraction time. A very important case of the off-axis positive branch resonator where the flow inlet is located at the optical axis and the radiation is coupled out from the single aperture, located near the flow outlet from the resonator, was studied. This case was not considered in [5] where we found η_{ext} for the positive branch resonators in the case of the finite mirror aperture length lying upstream of the optical axis. The optimal ratio r between the sections of the mirror aperture lying downstream and upstream of the optical axis, corresponding to the maximum η_{ext} is found in this paper. For the negative branch resonator analytical expressions for η_{ext} are derived. In particular, near the threshold of the population inversion, $\eta_{ext} = 1 - (g_{th}/g_0)^2$. It appears that for the positive branch resonator I decreases monotonically in the flow direction, whereas for the negative branch resonator $I(x)$ is symmetrical with respect to the optical axis.

[1] J. Handke, W. O. Schall, T. Hall, F. Duschek and K. M. Grünewald, Appl. Opt. **45**, 3831 (2006)

[2] C. Pargmann, T. Hall, F. Duschek, K. M. Grünewald and J. Handke, Appl. Opt. **46**, 7751 (2007)

[3] E. A. Sziklas and A. E. Siegman, Appl. Opt. **14**, 1874 (1975)

[4] D. Yu, F. Sang, Y. Jin and Y. San, Opt. Eng. **41**, 2668 (2002.

[5] B. D. Barmashenko and S. Rosenwaks, Appl. Opt. **35**, 7091 (1996)

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