Radiation losses of wire lasers

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It has been shown that radiation of wire lasers, long lasers with transverse dimensions smaller than the wavelength, can be collected in a narrow axially sym-metric beam along the laser axes due to the interference of radiation from the sources along the laser waveguide [1]. The combination of a small aperture and a narrow beam is of great interest for many applications, such as arrays of individually tuneable tweezers and photonic integrated circuits. Despite the inspiring results obtained using terahertz quantum cascade wire lasers with periodic gratings [2,3], robust and reliable design of the end fire wire lasers is still an issue due to the generation of high quality parasitic modes with non-directional emission. An adequate account of the influence of the interference of radiation from the longitudinal distribution of sources in a wire laser waveguide within numerical mode analysis is very resource consuming, as it requires 3D simulation in a volume with a radius large compared to L^2/λ, where λ is the wavelength and L is the length of the laser. Here we use an analytical approach based on the method of equivalent currents in the volume of the laser waveguide [1], and an assumption that the mode field within the waveguide with a periodic longitudinal modulation can be described by a combination of Bloch waves. Interaction of the counter-propagating waves in the laser waveguide generally leads to a longitudinal modulation of their amplitudes [4]. However, in the stationary regime of laser generation, when amplification is compensated by losses, and the losses from the laser edges are relatively small, these amplitude modulations are relatively small. We show that only two longitudinal modes may produce a directive radiation along the laser axis with a uniform phase front, independently of the length of the laser, propagation constant and the shape of diffractive elements. The ratio of the radiative losses of the highest quality directive mode and the closest indirective longitudinal modes grows rapidly with advance away from the directive mode. It only weakly depends on the laser length and effective refractive index $n_{eff} >> 1$, and exceeds 10 dB for the closest indirective mode. Such rapid dependence of radiation losses imposes stringent requirements on the mode selection. Our model allows us to make a conclusion that that generation of the directive mode producing a narrow beam along the laser axis is possible when the mode selection provides the difference of the amplification coefficients for the longitudinal modes of the order of $(2L/\lambda)(\Delta\lambda/\lambda)$, where $\Delta\lambda$ is the width of amplification spectrum, or a band gap that covers the part of the amplification band next to the directive mode with $\lambda/(2nL)$ accuracy of the band edge position. For comparison, the ratio of the radiation losses for the longitudinal modes producing the conical beams under an angle to the longitudinal axes is close to unity and selection of one of such modes is not a problem.

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