Threshold Conditions Analysis of Microlaser Configuration with Gold Film and DBR

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ABSTRACT - This work dedicated to the analysis of the threshold conditions for a layered microlaser model made of a gain-material cavity, sandwiched between golf film, and distributed Bragg reflector (DBR). The Lasing Eigenvalue Problem (LEP) based on a source-free linear set of Maxwell equations is used for electromagnetic analysis. Within this approach, we look for a scalar function of electrical field component with the eigenvalues as real number pairs of a mode emission wavelength and correlated threshold values of the gain index.

Eigenvalue problem formulation

Within LEP, we consider the laser modes, which are on the threshold of stationary, i.e. not attenuating in time, emission as natural modes of the open resonators with the real-valued natural frequencies. Therefore, we search for them as a solutions of the source-free time-harmonic Maxwell equations in infinite spatial domain, with the boundary and radiation conditions.

One-dimensional (1-D) configurations having the same cavity of the thickness w_c, shown in Fig. 1, fully filled in with the gain material and sandwiched between the noble metal superstrate film as the upper reflector and a DBR substrate.

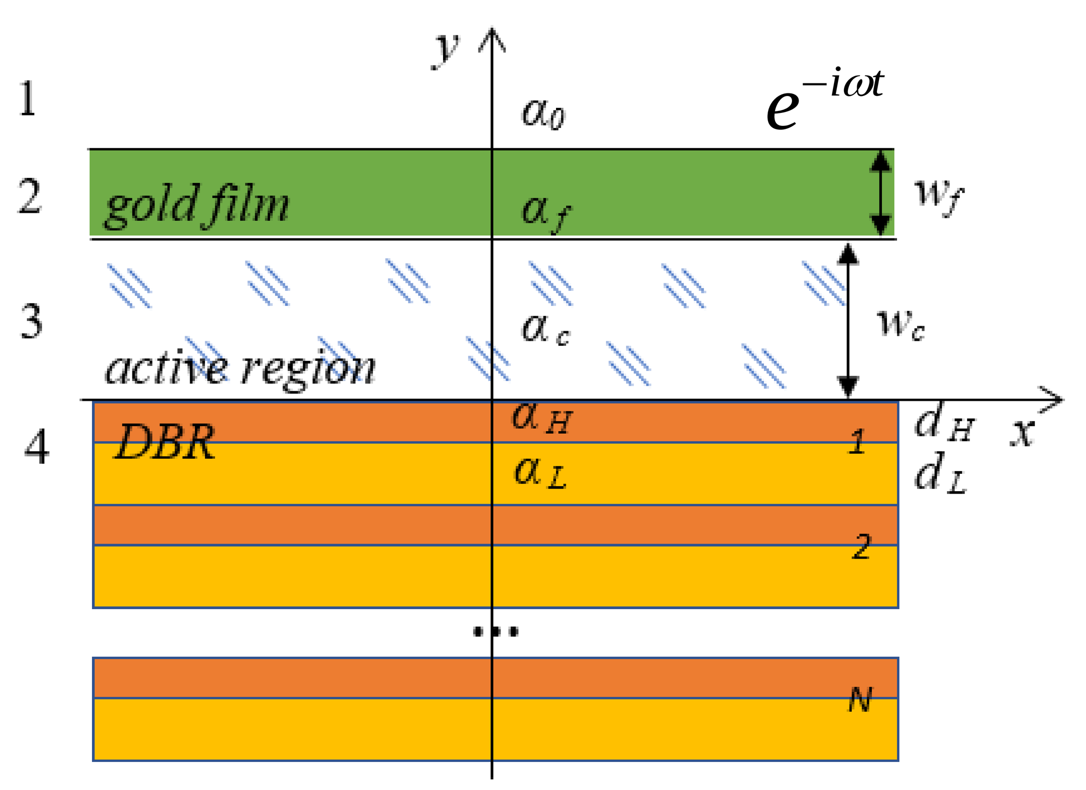

Fig. 1 Microlaser cavity geometry

Active material description

The gain material is assumed to have a complex relative dielectric permittivity, $\varepsilon_c = \varepsilon' + i\varepsilon''$ with negative imaginary part, while all materials are nonmagnetic.

Traditionally for laser science, the gain material can be equivalently characterized with the aid of its refractive index, $\nu = \sqrt{\varepsilon_c} = \alpha_c - i\gamma$ where $\gamma > 0$.

Here, $\mathrm{Re}\,\nu = \alpha > 0$ is the known refractive index of the chosen material, and $\mathrm{Im}\,\nu = \gamma > 0$ is unknown threshold value of the gain index.

In addition, for such layered structure we apply the transmission matrix method (TMM) , use Maxwell equations without source, and obtain transcendental equation. The roots of this equation are LEP eigenvalues, namely a frequency and a threshold.

$$\Phi(k,\gamma) = e^{-i2k(\alpha_c - i\gamma)w_c} - \frac{R_{DBR}\left(e^{i2k\alpha_f w_f} R_{12} - R_{32}\right)}{e^{i2k\alpha_f w_f} R_{12} R_{32} - 1} = 0$$

where, $R_{jp} = \dfrac{(\alpha_j - \alpha_p)}{(\alpha_j + \alpha_p)},\ j \neq p$

Then, we look for the roots of transcendental equation, which correspond to the LEP eigenvalues.

Conclusion

Overall, the parametric analysis of the LEP eigenvalues was presented. The obtained numerical results show how one can control both the emission frequency and the gain index threshold by changing the metal superstrate film thickness and DBR parameters. Additionally, we have shown that the effect of DBR is not only in the appearance of the band gaps but also in the existence of many “parasitic” modes associated, apparently, with the DBR layers as “parasitic cavities”.

Numerical results

The Fig. 2 shows the colour maps of laser eigenvalue modes for microlaser based on Nd crystal (ε=1.81) with two quantities of pair (N_{DBR}=2 and N_{DBR}=20) in the distributed Bragg reflector made of TiO_2 and SiO_2 layers and gold film of 10 nm thickness.

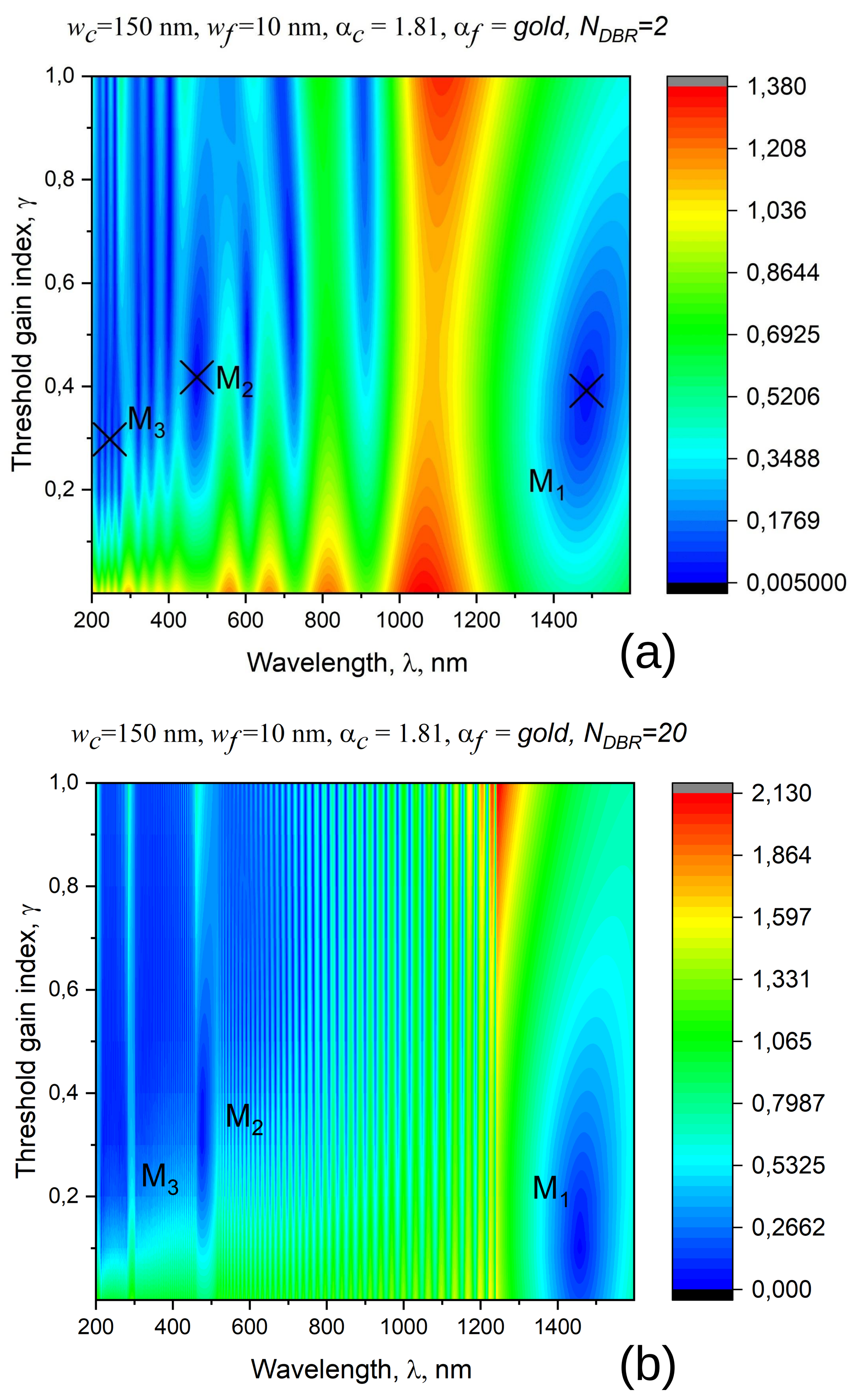

Fig. 2 Laser eigenvalue modes

As one can see, the threshold gain index of modes (denoted by crosses) is dropped in the lower colour map for the larger number of DBR layers. That happened due to the mode is in the band gap of the DBR. Also, the blue stripes correspond to so-called “parasitic” modes caused by dielectric layers of DBR, so their number grows with the increase of the number of layers. Besides, the influence of the gold film thickness is investigated as well, and it shows a similar behaviour; the thicker the film, the lower the threshold.