

З СЕКЦІЯ «НАНОЕЛЕКТРОНІКА ТА ІНФОРМАЦІЙНО-ВІМІРЮВАЛЬНІ ТЕХНОЛОГІЇ»

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ELECTROMAGNETIC ANALYSIS OF THRESHOLD CONDITIONS OF GOLD FILM WITH DBR MICROLASER CONFIGURATION

A laser typically comprises an open resonator, or cavity, and an active region containing a gain material. In solid-state and fiber lasers, the gain material is usually glass, transparent ceramics, or crystal doped with rare earth elements [1]. Lately, the selection of the active medium host material and its proportion into the cavity have been investigated in [2]. This work consider a reduced to a 1-D configuration of microlaser made of active cavity with gold film superstrate and distributed Bragg Reflector substrate as depicted in Fig.1.

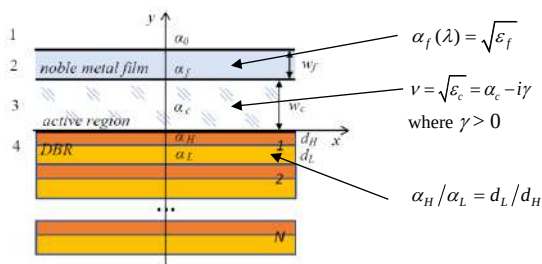


Figure 1 – Considered 1-D microlaser configuration geometry

We simplify the laser emission consideration by neglecting all non-electromagnetic effects. The source-free linear set of Maxwell equations with corresponding boundary and radiation conditions can then be used for further electromagnetic field analysis. Such approach is called the Lasing Eigenvalue Problem (LEP) and can be found in more details in [2, 3]. The active region cavity is assumed uniformly active, so that $\text{Re } \nu = \alpha > 0$ is the known refractive index of the chosen gain material, e.g. for Nd:YAG has $\alpha_c = 1.81$, and $\gamma = -\text{Im } \nu > 0$, is unknown gain index threshold value. Then, in LEP, we are looking for a scalar function E_z field component with the eigenvalues as real number pairs (λ_m, γ_m) ,

the first is a mode emission wavelength and the second is correlated threshold values of the gain index. Here, all the geometrical parameters and refractive indices, including α_c , are assumed known values.

To derive the characteristic equation for the modes in the presented structure with DBR substrate, we can apply the transmission matrix method (TMM). On the substitution of the field expressions into the specific boundary conditions, using TMM and certain algebra, the considered LEP can be reduced to the following transcendental equation:

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

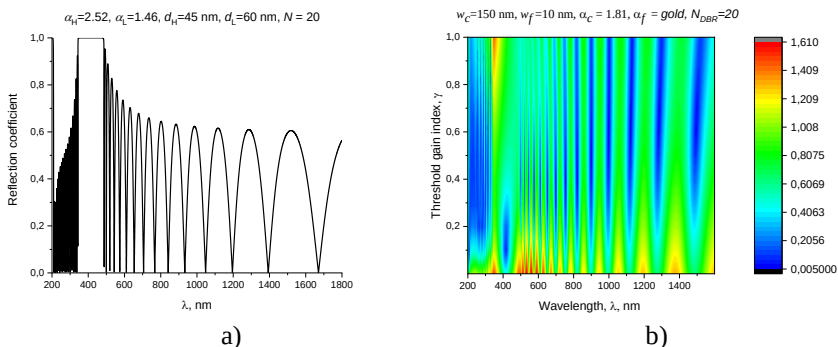
where $R_{jp} = (\alpha_j - \alpha_p)(\alpha_j + \alpha_p)^{-1}$, $j \neq p$, are the reflection coefficients from the interfaces between the domains, and R_{DBR} is the reflection coefficient of DBR (Fig.2a).

We look for the LEP eigenvalues which are the roots of (1). For this we find the initial-guess values from the analysis of the absolute value of the left-hand part of (1), $|\Phi(k, \gamma)|$, as a function of its arguments.

The plot in Fig. 2a shows the reflection coefficient in the visible and near infra-red ranges for the DBR with 20 pairs of dielectric layers with $\alpha_L = 1.46$ and $\alpha_H = 2.52$ and layers thickness in the corresponding material, so that. $w_L = 60$ nm and $w_H = 45$ nm. As one can see, there is a band gap with a centerline around 420 nm, where the DBR-caused modes cannot exist.

The result presented in Fig. 2b highlights the influence of the gold film thickness and DBR parameters on the characteristics of the lasing modes. Specifically, the position of the DBR's reflection band dictates the cavity's lowest-threshold mode (can be seen as blue spots). Furthermore, it should be noted that the threshold can be gradually reduced by increasing the thickness of the gold film. Additionally, the DBR initiates multiple high-threshold so-called “parasitic” modes, which arise from the DBR layers acting as additional cavities. These higher-order modes, with wavelength in the violet and ultraviolet ranges where gold bulk losses are significant, exhibit a more complex interplay between radiation and ohmic losses.

All in all, the parametric analysis of the LEP eigenvalues was presented, where we have found if the working mode lies in the band gap of DBR, its gain index threshold decreases significantly. We have also demonstrated that the impact of the DBR extends beyond the formation of band gaps, contributing to the presence of numerous “parasitic” modes likely associated with the DBR layers acting as “parasitic cavities.” The number of these modes is directly proportional to the number of high- and low-refractive-index layer pairs in the DBR.



a) – Refractive coefficient of the DBR; b) – Colormap of the absolute value of (1).
Figure 2 – Influence of the gold film and DBR substrate of 20 pairs of alternating TiO_2 and SiO_2 layers on the microlaser cavity modes

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