Ultralow Lasing Thresholds of VCSEL-type Resonators with Periodically Structured Quantum Wells

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Widely used in photonics vertical cavity surface emitting lasers (VCSEL) commonly have quantum wells as active regions. Besides many advantages of that model we propose enhancing its properties by replacing a quantum well with periodically structured quantum wires. Thus the properties of specific high Q-factor grating resonances of the grating consisting of periodically placed circular cylinders [1,2] can be combined with those of a VCSEL-type resonator. In the latter device, two distributed Bragg reflectors (DBR) sandwiching a cavity in the middle forge a high-intensity field in the cavity. First time the grating resonances were explained in [1]. Then we investigated in [2] the natural grating-type modes of similar structure made of quantum wires, in the framework of the Lasing Eigenvalue Problem (LEP) with two parameters (σ, γ). The first is the normalized by period lasing frequency and the second is the material gain necessary to bring the mode to lasing. Therefore it is interesting to find geometrical and material parameters which lead to the lowest lasing threshold. In the previous study, besides other interesting facts it was discovered that, if the quantum-wire grating in the free space becomes sparser, the lasing thresholds decrease in exponential manner and can reach the values $\gamma \approx 10^{-3}$ if the period is ten times larger than the wire diameter.

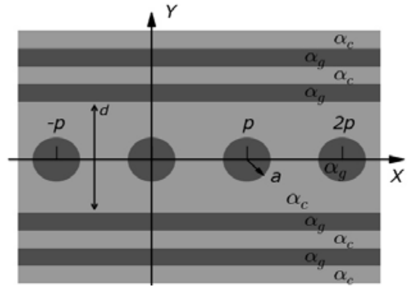

Fig.1 The cross-sectional geometry of a periodically structured optical resonator.

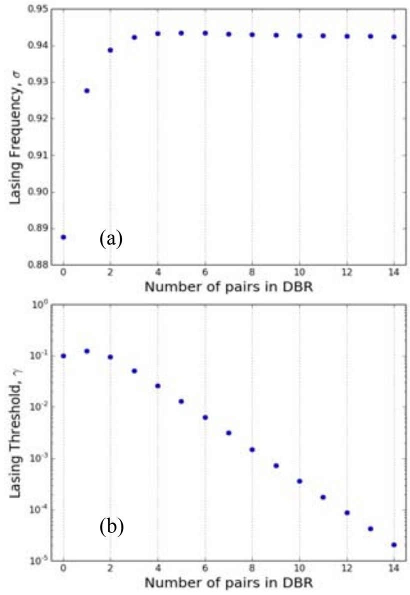

Fig.2 Dependences of the lasing frequency (a) and threshold (b) on number of pairs in DBR in the resonator with $\alpha_C = 1.4$, $\alpha_G = 2.0$, $d = p = 4a$. H-polarization.

Here a VCSEL-like model is considered (see Fig. 1) or a dielectric cavity with refractive index $\alpha_C = 1.4$ with an embedded infinite grating of nanowires with $\alpha_G = 2.0$ placed in the middle between two DBRs. Each DBR consists of N pairs of two planar layers of the refractive indices α_G and α_C and the width that corresponds to the quarter wavelength. Reflectance of the DBR tends to 1 with increasing the number N while the field intensifies inside the cavity. Fig. 2 shows dependences of the lasing frequency (a) and lasing threshold (b) on the number of DBR pairs. As we can see, the lasing frequency does not vary essentially if $N > 4$ while the lasing threshold keeps getting down to the level $\gamma \approx 10^{-5}$. The shown here results prove that adding DBR can dramatically decrease the lasing thresholds even for relatively small values of the ratio of the grating period to wire radius.

[1] R. Gomez-Medina, M. Laroche, J.J. Saenz, “Extraordinary optical reflection from sub-wavelength cylinder arrays,” *Optics Express*, vol. 14, no 9, pp. 3730-3737, 2006.
[2] V.O. Byelobrov, J. Ctyroky, T.M. Benson, *et al.*, "Low-threshold lasing modes of an infinite periodic chain of quantum wires," *Opt. Lett.*, vol. 35, no 21, pp. 3634-3636, 2010.