Non-Hermitian Engineered TCC VCSEL for LIDAR Remote Sensing Technologies

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Abstract: We present the main aspects of a new approach to achieve a single mode operation in TCC-VCSEL array based on (1) increasing the spacing of the eigenfrequencies of supermodes, (2) *Q*-enhancing of the fundamental supermodes.

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Generally, a diode laser for deep space communications, demand to reliably operate in a stable, diffraction-limited beam at KW class power. For a reliable operation at such high powers, the main ingredient is to have a large emitting area with in-phase operation. Due to the perpendicular emission of VCSELs, two-dimensional arraying of VCSELs is used to obtain KW class output power but the coherency of the wavelength and phase are a severe problem when the number of lasers becomes too large [1]. Here we present a new method based on quality factor enhancing to achieve single mode operation in VCSEL array. The main aspects of this method are as follows: (1) single mode operation for the arrays with symmetric lasing profile, and (2) high power emission. In contrast to PT single mode lasers where in which one of the cavities is lossy [2,3] (and consequently does not lase), here all the cavities are lasing and none of them are lossy. This device concept can be utilized for a novel space LIDAR sensor that use small and high-efficiency diode lasers to measure range and surface reflectance of asteroids and comets.

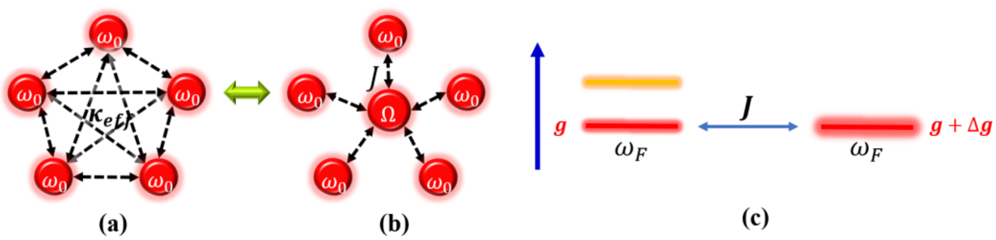

Fig. 1. *Schematic representation of N coupled cavities that are mutually coupled to each other. System in (a) supports two super modes ($\omega_0 - \kappa_{eff}$ and $\omega_0 + (N-1)\kappa_{eff}$). One can achieve such a coupled system via adiabatic coupling to a central cavity Ω and increasing its gain. (b) Schematic of Q-enhancing of the fundamental one through increasing the gain in central cavity.*

There are many different proposed lasers arrays like periodic, circular, centered polygonal arrays. Here, we present an array of adiabatically coupled cavities as illustrated in the Fig. 1. In this system every laser cavity ω_0, is assumed to be coupled to the central cavity Ω and κ is the coupling coefficient. The main idea here is to judiciously design the central cavity in such a way that the by pumping all lasers cavities the quality factor of the fundamental in phase mode increases and as a result reaches to the lasing threshold before all other out of phase modes. Fig. 1 (c) schematically shows that by adding extra gain (through optically or electrically pumping) to the central cavity one can suppress the lasing threshold of the in-phase mode. To study the behavior of the system we have solved the laser rate equations as follows:

$$\frac{\partial E_i}{\partial t} = \left(j\omega_i + \frac{G_i}{1+|E_i|^2} - \frac{1}{\tau_p} \right) E_i + jk(E_{i+1} + E_{i-1}) \quad (1)$$

In this equation E represents the normalized electric field in laser cavity and G_i and $\frac{1}{\tau_p}$ are the gain and loss in each cavity, respectively. One can clearly see that at system starts its lasing in out of phase and then reaches to the in-phase operation mode. Inset shows the mode pattern at different times. An attractive implementation approach is to build an array of transverse coupled cavity (TCC)-VCSEL [4-6], while all the VCSELs in the array, lase in the same phase and the output intensity at the focus of the emitted laser beam will be enhanced by a factor proportional to the square of the number of the individual elements constituting the array.

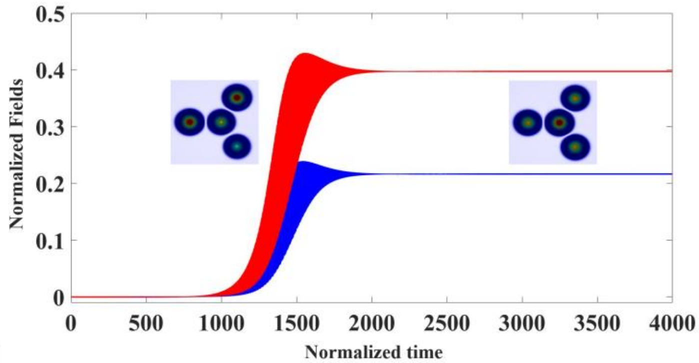

Fig. 2. *Filed evaluation of the laser system composed of three lasers cavities coupled to the central cavity which is slightly detuned with respect to* ω_0*. Here, k=1 is normalized coupling,* $\frac{1}{\tau_p}$*=0.1 and* G_i*=0.105 for each cavity and central cavity has higher gain (1.1*G_i*). This enhances the Q of the in-phase mode as a result decreases its threshold.*

Fig. 3(a) shows part of a unit cell in a TCC-VCSEL array. Each unit cell consists of three or five TCC-VCSELs. Fig. 3 (b) depicts the coupling between transverse cavities as a function of the middle width in the joint connection. 20 pairs of $AlGa_{0.92}As/AlGa_{0.16}As$ for the top mirror reflectivity and 40 pairs of $AlGa_{0.92}As/AlGa_{0.16}As$ for bottom DBR. The layer structure is designed to have a cut-off wavelength of 982.9 nm. In the design a combination of air and perfect matching layer (PML) is used as a boundary condition to totally absorb the electromagnetic radiation and prevent any back reflection. Fig.3 (c) represent a schematic of light coupling mechanism. Fig. 3 (d) plots the calculated intensity distribution of the coupling between transverse cavities by using a 3D film-mode matching method (FIMMWAVE Photon Design Corp.)

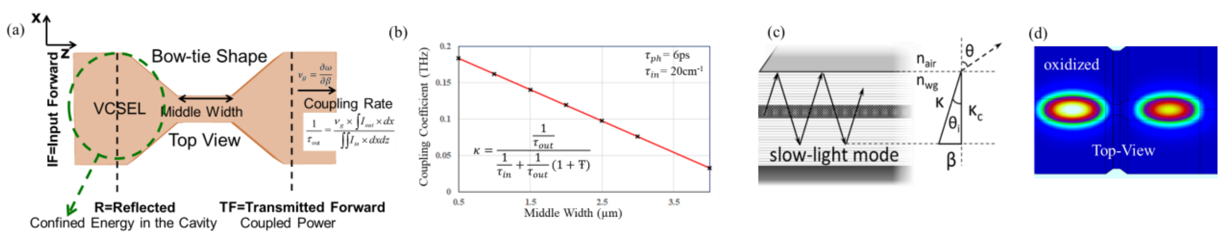

Fig.3. *(a) Schematic of a unit cell of our TCC-VCSEL array, (b) coupling coefficient between transverse cavities as a function of the middle width, (c) light coupling mechanism in TCC-VCSEL, (d) and plots the calculated intensity distribution of the coupling between transverse cavities.*

We have shown that the non-Hermitian engineering of the coupled laser array leads to the Q enhancement of the fundamental mode, which corresponds to lowest lasing threshold for in-phase operation of the system. This device concept is crucial for futuristic space LIDAR sensor to provide continues measurement and global coverage.

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