# Low-threshold Coherently-coupled Organic VCSEL

J. R. Tischler, E. R. Young, D. G. Nocera, V. Bulović
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Here we report observation of extremely low-threshold lasing in organic VCSELs when the excitons are coherently coupled non-radiatively to each other. Non-radiative coupling between excitons can enhance the emission cross-section of a gain material and lead to laser action at considerably lower excitation densities [1]. The coupling strength associated with the excitonic interaction is proportional to the number of excited molecules at any given time; hence the effect necessitates creating the exciton population quickly relative to the excited state decay time. This phenomenon is often referred to as superradiance [1], [2]. In organic semiconductor VCSELs, this effect leads to a 95% reduction in threshold when sub-psec non-resonant excitation is utilized to create the exciton population, instead of a longer nsec duration pump pulse. The VCSELs consist of a thermally evaporated gain layer composed of the laser dye DCM doped (2.5 % v/v) into an $Alq_3$ host matrix, which is situated between a metal mirror and a dielectric Bragg reflector (DBR). In VCSELs where the gain layer is "λ/2n thick", i.e., 156.7 nm, an extremely low threshold of 4.9 μJ/cm² is observed. This marks the first time lasing from organics has been reported in a metal/DBR half-wavelength thick microcavity, despite the rather modest resonator quality factor of $Q < 200$. Lasing is confirmed by supra-linear input-output power dependence and by spectral and spatial line-narrowing above the threshold. Moreover, when the optical excitation is polarized, the emission above the threshold strongly follows the polarization of the pump light. All prior demonstrations of laser action in solid-state organic VCSEL structures have utilized either gain layers of at least 3 times the thickness [3] or have relied on higher finesse of all dielectric microcavities [4]. The observed laser threshold of 4.9 μJ/cm² in the half-wavelength thick microcavity corresponds to excitation of at most 3.2% of the DCM molecules.

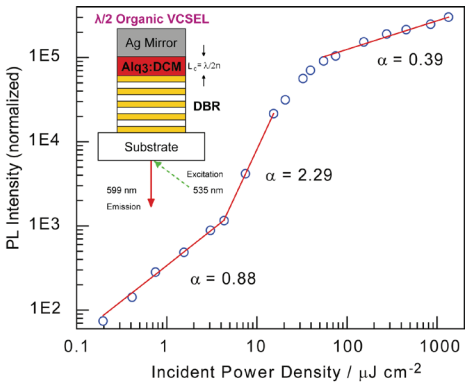


**FIGURE 1:** Input/Output power dependence upon direct DCM excitation ($l_{ex}$ = 535 nm) shows the lasing threshold at 4.9 μJ/cm² incident power and superlinear slope α = 2.29 when fit to power law, $y = mx^{\alpha}$. Inset: Device design consists of a dielectric Bragg reflector (DBR), organic semiconductor gain layer, and silver mirror. The sample is excited at q = 60° from normal using TM polarized laser light focused down to a spot size of 0.001 cm² as measured on the sample plane.

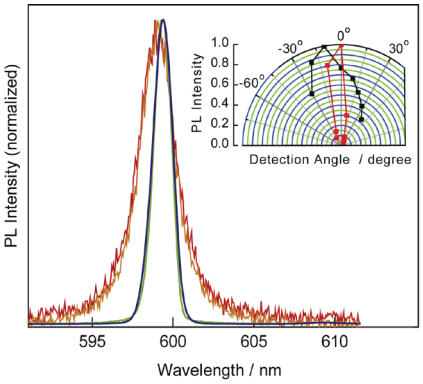


**FIGURE 2:** Emission spectra of OVCSEL at different power levels above and below the threshold show linewidth narrowing from 2.5 nm for excitation below threshold (, 3.25 μJ/cm²; , 8 μJ/cm2) to 1.1 nm above threshold (, 15 μJ/cm²; , 250 μJ/cm²). Inset: Emission cone spatially narrows from from Dq = ± 30° to Dq = ± 5° as measured at the emission peak.

## REFERENCES

[1] L. Moi, P. Goy, M. Gross, J. M. Raimond, C. Fabre, and S. Haroche, "Rydberg-atom masers. I. A theoretical and experimental study of super-radiant systems in the millimeter-wave domain", Physical Review A, vol. 27, pp. 2043-2064, April 1983.

[2] R. H. Dicke, "Coherence in Spontaneous Radiation Processes", *Physical Review*, vol. 93, pp. 99-110, January 1954.

[3] V. Bulović, V. G. Kozlov, V. B. Khalfin, and S. R. Forrest, "Transform-limited, narrow-linewidth lasing action in organic semiconductor microcavities", *Science*, vol. 279, pp. 553-555, January 1998.

[4] M. Koschorreck, R. Gehlhaar, V. G. Lyssenko, M. Swoboda, M. Hoffmann, and K. Leo, "Dynamics of a high-Q vertical-cavity organic laser", *Applied Physics Letters*, vol. 87, pp. 181108:1-3, October 2005.