Rate Equation Theory for Organic Diode Laser and Experimental Validation with Microcavity OLED

Rate Equation Theory for Organic Diode Laser and Experimental Validation

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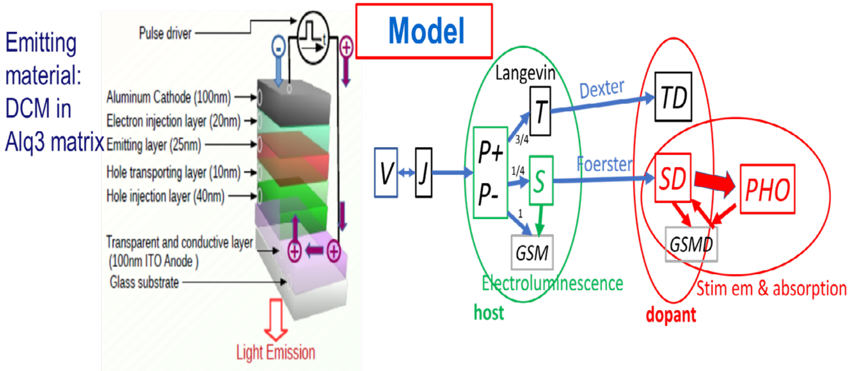
Abstract

We present a new model for an organic laser diode based on rate equations for polarons, singlet and triplet excitons, both in host and dopant molecules, and photon densities. The model is validated by comparing the calculated optical response with the measured light emission from a high-speed low-Q OLED submitted to a 20ns electrical pulse with current density of ~400 A/cm². The model confirms the feasibility of threshold-current density of ~500 A/cm² for OLEDs with Q>20K.

Model



$$\frac{d}{dt}N_P = \frac{J(t)}{ed} - \gamma N_P^2 - K_p N_p;$$ polarons $N_p^+ = N_p^- = N_p$

Host excitons

$$\frac{dN_S}{dt} = \frac{1}{4}\gamma N_P^2 + \frac{1}{4}\kappa_{TT}N_T^2 - (\kappa_{FRET}P_{0D} + \kappa_s + \kappa_{ISC})N_S - (\kappa_{SS}N_S + \kappa_{SP}N_P + \kappa_{ST}N_T)N_S;$$ singlets

$$\frac{dN_T}{dt} = \frac{3}{4}\gamma N_P^2 + k_{ISC}N_S - (\kappa_{DEXT}P_{0D} + \kappa_T)N_T - 2\kappa_{TP}N_T N_P + \frac{3}{4}K_{SS}N_S^2 - \frac{5}{4}\kappa_{TT}N_T^2;$$ triplets

Dopant excitons

$$\frac{d}{dt}N_{TD} = \kappa_{DEXT}P_{0D}N_T + \kappa_{ISCD}N_{SD} - K_{TD}N_{TD} - \frac{5}{4}K_{TTD}N_{TD}^2 - 2\kappa_{TPD}N_{TD}N_P;$$ triplets

$$\frac{dN_{SD}}{dt} = \kappa_{FRET}P_{0D}N_S + \frac{1}{4}\kappa_{TTD}N_{TD}^2 - (\kappa_{SD} + \kappa_{ISCD})N_{SD} - (\kappa_{SSD}N_{SD} + \kappa_{SPD}N_P + \kappa_{STD}N_{TD})N_{SD} - \xi P_{HO}(N_{SD} - W_\lambda N_{0D});$$ singlets

$$\frac{d}{dt}P_{HO} = \beta_{sp}\kappa_{SD}N_{SD} + (\Gamma\xi(N_{SD} - W_\lambda N_{0D}) - \kappa_{CAV})P_{HO};$$ photons

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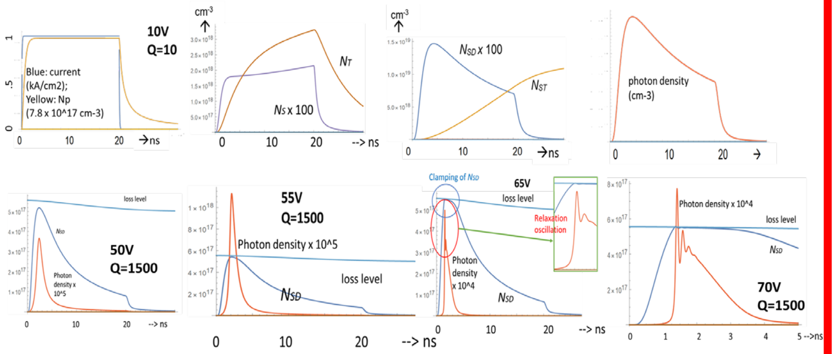
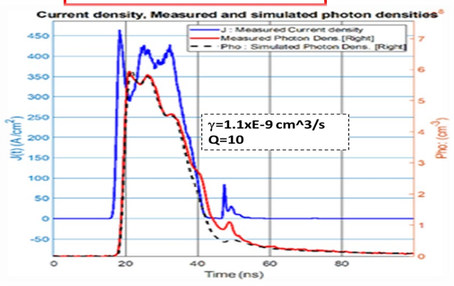
Dopant ground states $N_{0D} = N_{DOP} - N_{SD} - N_{TD};\ P_{0D} = \frac{N_{0D}}{N_{DOP}}.$

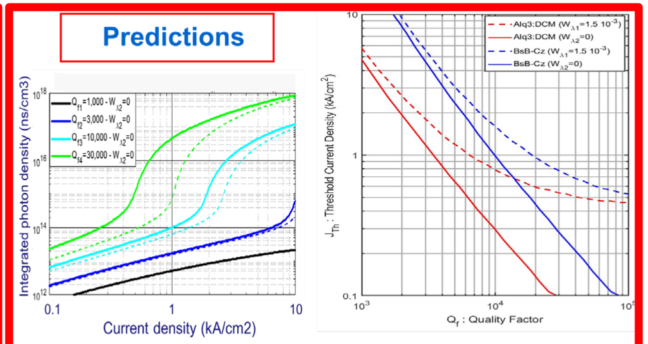
Simulations



Validation



Predictions



Discussion

Lasing in electrically injected organic diodes has not yet been demonstrated convincingly. Adachi [1] reports the first indication of lasing with a threshold at ~500A/cm2 in a high-speed high-Q µ-OLED. Our new rate-equation model explains how the build-up of triplet excitons quenches the gain for lasing. Therefore, lasing is possible only during a few ns and is characterized by pronounced relaxation oscillations.

Conclusion

Our validated theory predicts that lasing under electrical excitation is possible only under pulsed operation yielding laser pulses of <~2 ns duration. We confirm a threshold-current density of ~500A/cm2 in a high-speed µ-OLED, if the Q-factor ~20K and no residual absorption occurs.

[1] A. S. D. Sandanayaka et al., Appl. Phys. Express, vol. 12, no. 6, p. 061010, May 2019, doi: 10.7567/1882-0786/ab1b90, [2] A. Ouirimi et al, Organic Electronics, submitted 2020. [3] A. C. Chime et al., Organic Electronics, vol. 56, pp. 284–290, May 2018, DOI: 10.1016/j.orgel.2017.12.026.