Quantum Correlations and Laser Threshold

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We present laser models that include quantum correlations between the electromagnetic field and material population and polarization and show that these change the nature of the transition to lasing emission for any cavity size and emitter number. The photon number growth in the resonant cavity mode is driven by an increase in correlation between absorption and emission processes. In contrast to the predictions of semi-classical models, the onset of lasing requires fluctuation of the coherent field of finite amplitudes, and is associated to a discontinuous decrease of the correlation between absorption and emission processes. Furthermore, lasing and non-lasing emission can coexist in all lasers, but the parameter range in which these effects are observable decreases as the size of the laser increases. The difference between lasing and non-lasing solutions can be detected by measuring the first-order coherence, $g^{(1)}$, even if the coherence of the nonlasing solution steadily increases as the pump grows towards the laser threshold value. Our predictions are in remarkable agreement with nanolasers' first-order coherence measurements that have so far been explained only phenomenologically. For nanolasers, a consistent evaluation of different threshold indicators provides a tool for a correct interpretation of experimental measurements at the onset of lasing.