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Rate-Equation Analysis for an Integrated Coupled-Cavity Laser with MMI Anti-Phase Coupler

Daan LENSTRA
Eindhoven University of Technology, P.O.Box 513, 5600MB, The Netherlands
* d.lenstra@tue.nl

In this paper a dynamical theory is reported for the coupled-cavity laser (CCL) with a multi-mode interference (MMI) coupler, which provides an excellent description of the locking and other operational aspects of the laser realized by D'Agostino et al. in 2015 [1]. The revived interest in CCLs as widely tuneable lasers for sensing and other applications is due to the specially designed MMI anti-phase coupler as described in [1]. The theory explains if, why and how the two individual isolated constituent modes combine to one single "super mode", a situation referred to as locked state. A comprehensive formulation of the model and derivation of the rate equations for the CCL with quantum-well active material can be found in [2].

We consider two Fabry-Pérot (FP) lasers that are very similar except they differ 5–10 % in length and couple by a reflective MMI coupler. The amplitudes indicated (Fig.1) are evaluated at the point where each laser touches the MMI-coupler. Note that the coupling parameters have been designed in such a way that C_{bar} and C_x are 180 degrees out of phase and the sum of their absolute values equals unity. This is a property of the 3x3 reflective coupler in which only the two outer ports are used [1,2]. The ideal theoretical values for the coupling coefficients are C_{bar}=0.79 and C_x=-0.21 [1,2]. This implies that if the amplitudes E_1 and E_2 are equal and opposite, the coupler behaves as a 100% reflector for both lasers. Due to small deviations from growth specifications the ideal values for the coupling coefficients can very well be somewhat different. In fact, we found that best agreement with experimental data was achieved by taking smaller values for C_{bar}, i.e. 0.75 instead of 0.79, and for $|C_x|$, i.e. 0.18 instead of 0.21.

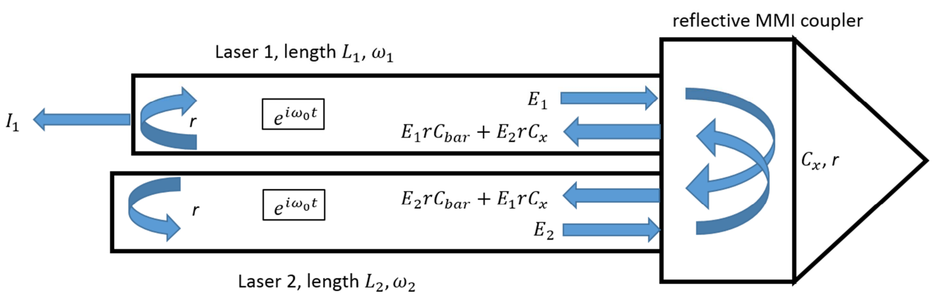

Fig. 37. Sketch of two FP-lasers coupled by a reflective MMI coupler with designed coupling parameters C_{bar} and C_x. The slowly-varying amplitudes are relative to the exponential time factor as indicated, where ω_0 is the locked frequency. ω_1 , ω_2 are the frequencies of the isolated lasers, i.e. when C_x=0.

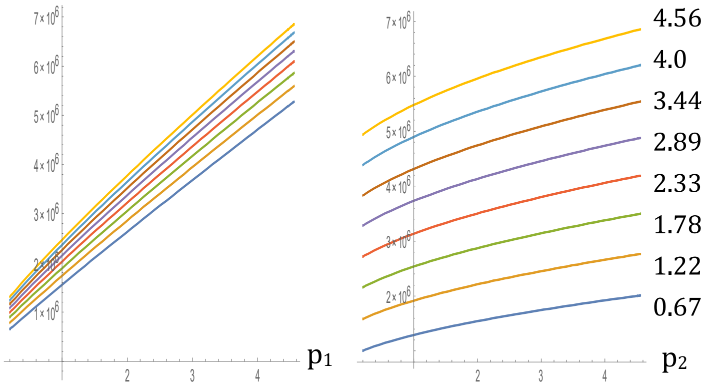

Fig. 2. Left: Intensity I_1 versus p_1, at fixed p_2 = {0.67, 1.22, 1.78, 2.33, 2.89, 3.44, 4., 4.65}. Right: intensity I_1 versus p_2, with fixed p_1 = {same values}; optimized detuning assumed. The shapes of the curves hardly depend on the precise value of α . The values for C_{bar} and C_x as in table 1 were taken so as to optimize the qualitative and quantitative proportionality agreement with the measured curves in [1].

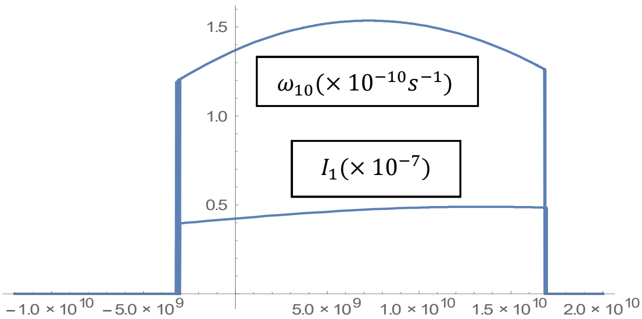

Fig. 3. Intensity $I_1(\times 10^{-7})$ and operation frequency shift $\omega_{10}(\times 10^{-10})$ versus detuning $\omega_{21} \equiv \omega_2 - \omega_1$ within the locking range. The pump strengths are $p1$=4, $p2$=2.

Fig. 2 left shows the output-intensity curves of laser 1 versus its pump strength for various values of the pump strength of laser 2; Fig. 2 right shows the output intensities versus the pump strength of laser 2 with the pump strength of laser 1 as parameter. Here we define for j=1,2 the pump strengths as $p_j \equiv \Delta J_j / J_{thr,j}$ where ΔJ_j is the injection current w.r.t. the threshold current $J_{thr,j}$ (i.e. when each laser stands on its own, that is, without any coupling. The shapes of the curves agree well with the measured curves in [1]. Fig. 3 shows numerical results for the output intensity of laser 1 and the operation frequency within the locking range.

References

[1] D. D'Agostino,* D. Lenstra, H. P. M. M. Ambrosius, and M. K. Smit, "Coupled cavity laser based on anti-resonant imaging via multimode interference", OPTICS LETTERS, vol. 40, pp. 653-656, February 2015.

[2] D.Lenstra,"Rate-equation analysis for the coupled-cavity laser with MMI anti-phase coupler", DOI: 10.13140/RG.2.1.2747.6245, February 2016.