Frequency-Comb-Assisted Swept-Wavelength Interferometry

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Swept-wavelength interferometry (SWI) is a highly sensitive and versatile technique implemented in a diverse array of industrial and scientific applications. SWI uses a continuously tunable laser to capture the magnitude and phase response of a device under test (DUT). The prevalent non-linear tuning of the laser calls for an auxiliary interferometer for the calibration of the laser frequency on the fly [1]. However, this approach is susceptible to environmental perturbations, and the inherent dispersion of the interferometer introduces systematic errors. Laser frequency combs can be used as optical rulers against which to calibrate tunable lasers with high- precision and, when self-referenced, with high accuracy [2]. Here, we apply this comb-based calibration approach in the context of SWI for the first time and illustrate its relevance for the characterization of high-Q microresonators.

The experimental setup depicted in Fig. 1a consists of two sub-sections: the swept-wavelength interferometer and the calibration unit. The latter serves to calibrate the optical frequency axis with the aid of a commercial self-referenced mode-locked fiber laser frequency comb, following a procedure similar to [2]. In SWI, the DUT is arranged in one of the arms of an unbalanced interferometer. After offline processing, the interferogram is mapped from time to frequency axis, and its Fourier analysis allowed the retrieval of the DUT phase profile. The amplitude profile of the sample is obtained by direct absorption spectroscopy by tapping off light from the DUT arm in the interferometer.

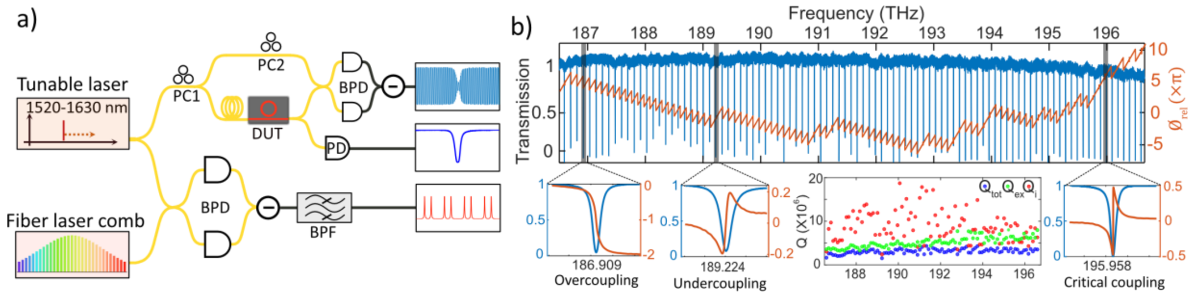

Fig. 1 (a) Simplified measurement setup for acquisition of calibrated interferogram and transmission trace. (b) Magnitude and phase response and Q-plot of the resonances (zoom in of the different coupling resonances at the bottom).

Direct comb-based laser spectroscopy has been applied to the measurement of high-Q microresonators [2]. Using a self-referenced comb for calibrating the nonlinear tuning of the laser allows for resolving the frequency location of the longitudinal modes of different mode families with great accuracy, which in turn allows for quantifying the microresonator's dispersion. SWI allows for, in addition, accessing the phase profile within the resonances and univocally distinguishing the coupling condition. This information is often simply assumed based on the design of the coupling region. An illustration is given in Fig. 1b, where we show measurements of a high-Q Si_3N_4 microresonator (fabrication process details in [3]) over the C & L bands. The two zoomed plots at the bottom left in Fig. 1b have similar transmission response. The phase profiles, however, are distinct and correspond to the overcoupling and undercoupling cases. Likewise, the bottom right plot has zero transmission at the resonance location and an abrupt π-phase transition, which is indicative of critical coupling. The Lorentzian linewidth model was used to fit the spectrum for individual resonances and extract the full width half maximum ($\Delta\omega_{\mathrm{FWHM}}$) and extinction ratio ($\mathrm{P_{min}}$) parameters. The numerical solution of the equations $\Delta\omega_{\mathrm{FWHM}} = 2c(1-ar)/n_g L\sqrt{ar}$ and $\mathrm{P_{min}} = (1-ar)^2/(a-r)^2$ [4] resulted in amplitude transmission per round trip (a) and self-coupling coefficient (r) values. We chose the correct value, $a > r$ for the overcoupling and $a < r$ for the undercoupling condition according to the phase distribution. These evaluated coefficients were used to estimate the $\Delta\omega_{\mathrm{FWHM}}$ in the absence of propagation loss/coupling loss to calculate an extrinsic ($\mathrm{Q_{ex}}$)/intrinsic ($\mathrm{Q_i}$) quality factor (scatterplot in Fig. 1b) using $\mathrm{Q} = \omega/\Delta\omega_{\mathrm{FWHM}}$.

References

[1] B. J. Soller, D. K. Gifford, M. S. Wolfe, and M. E. Froggatt, "High resolution optical frequency domain reflectometry for characterization of components and assemblies," Opt. Express **13**(2), 666 (2005).

[2] P. Del'Haye, O. Arcizet, M. L. Gorodetsky, R. Holzwarth, and T. J. Kippenberg, "Frequency comb assisted diode laser spectroscopy for measurement of microcavity dispersion," Nat. Photonics **3**(9), 529–533 (2009).

[3] Y. E. Zhichao, K. Twayana, P. A. Andrekson, and V. Torres-Company, "High-Q Si3N4 microresonators based on a subtractive processing for Kerr nonlinear optics," Opt. Express **27**(24), 35719–35727 (2019).

[4] W. Bogaerts, P. de Heyn, T. van Vaerenbergh, K. de Vos, S. Kumar Selvaraja, T. Claes, P. Dumon, P. Bienstman, D. van Thourhout, and R. Baets, "Silicon microring resonators," Laser Photonics Rev. **6**(1), 47–73 (2012).