Investigation of Backscattered Wave Effects on Cavity Ring-Down Spectrometers with Ring Cavities

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Imperfections on the surfaces of intra-cavity elements in optical ring resonators can cause scattering of light from one mode to a nearly degenerate counter-propagating mode. This can cause well-known problems such as mode locking in laser gyroscopes. We present theoretical and experimental results showing how backscattering affects CRDS measurements made with high-finesse ring cavities. Coupling between counter-propagating modes gives rise to a non-exponential ring-down waveform which biases the loss measurement. A stochastic simulation of the build-up of the mode amplitudes shows that it also increases the shot-to-shot variability, limiting the overall sensitivity. The frequency-dependence of the backscattering process can also be analyzed and is found to produce a ripple in the empty cavity spectrum whose form is determined by the cavity geometry. Under appropriate assumptions about the nature of the scattering process, it is found that improved results may be obtained by measuring the intensities of both counter-propagating waves and adding these together electronically. The sum of intensities decays exponentially, and the stochastic fluctuations in the individual mode intensities are anti-correlated, reducing the shot-to-shot noise. Figure 1 shows an empty cavity spectral scan from a ring cavity when using conventional processing (forwards wave only, in blue) and when the forwards and backwards intensities are added together (in green). This technique has been used in the manufacture of cavity ring-down spectrometers for measuring the isotopic composition of carbon dioxide and methane at near atmospheric concentrations. It has led to a significant improvement in the measurement precision and product yield.