Completing the vacuum scale with photonic measurements: Ideas und needs

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The realization of a continuous, traceable vacuum pressure scale based on first principles is a central objective in modern vacuum metrology. Primary photonic approaches such as Cold Atom Vacuum Standards (CAVS) and Fabry–Perot Refractometry (FPR) provide a fundamental route to pressure determination via gas density. In particular, FPR offers a non-invasive alternative to conventional ionization-based methods, which are affected by outgassing, aging, and the need for calibration against dynamic expansion systems.

FPR-based pressure standards typically achieve relative uncertainties on the order of a few parts per million, limited by both system performance and the accuracy of gas parameters. In contrast, CAVS uncertainties remain at the percent level, largely due to limitations in the underlying collision cross sections. Consequently, a direct comparison primarily serves to validate the physical models used in CAVS, rather than the reverse. Demonstrating the capability of high-end FPR systems to also operate in the ultra-high vacuum (UHV) regime is therefore a crucial step toward such validation and, ultimately, toward a continuously covered photonic vacuum scale.

This talk presents the framework required to link CAVS and FPR across the vacuum range, with particular emphasis on the transition between high vacuum (HV) and UHV, around 1 µPa, where an overlap between both techniques can be established. While CAVS performance is limited at higher pressures by rapidly increasing atom loss rates, FPR systems are constrained by cavity stability and the precision of beat frequency measurements. Nevertheless, recent experimental results obtained at PTB demonstrate that state-of-the-art FPR systems are capable of primary pressure realization in the UHV regime, thereby enabling a substantial overlap with CAVS.