

Wavelength references for precision dimensional metrology in air

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Abstract: Laser wavelength references based on stable interferometers operating in air are considered. Optical frequency combs using femtosecond lasers are used to calibrate the stable cavities. Long-term monitoring of cavity stability is described.

OCIS codes: (120.3180) Interferometry, (120.3930) Metrological instrumentation

1. Introduction

Optical interferometers measure length in terms of a known wavelength. Most length measurements rely on a calculated value of the wavelength, derived from a known stable-frequency laser source, along with an estimate of the medium's refractive index. Inaccuracies arise during measurement of the parameters that are necessary to determine the air's refractive index, which depends on temperature, pressure, and humidity. Consequently, interferometric measurements in air are typically less accurate than what would be possible from a similar instrument operating in vacuum.

Another approach that has been suggested is to use a laser that is frequency-locked to a mode of a stable reference cavity open to the ambient air [1-3]. As the ambient air density changes, the laser frequency is changed to keep the laser in resonance with the cavity mode. The physical length of the cavity does not change, so the wavelength (in the air of the cavity) remains nominally fixed, precisely what is required for dimensional metrology under changing environmental conditions. It is possible to calibrate the resonance wavelength, thus allowing precision interferometry with tunable lasers. Furthermore, by the use of multiple known resonance wavelengths, multiple-wavelength interferometry is enabled, allowing absolute length measurements without the need for moving retro-reflectors. We have chosen to perform a series of experiments to using telecom-band DFB lasers as sources. The relatively inexpensive DFB lasers near $\lambda \sim 1.5 \mu\text{m}$ exhibit moderate power (20 mW), have spectral line-widths of a few megahertz, and are available in robust fiber pig-tailed packages.

2. Reference cavity design

The cavity designs we are testing are made from thermally stable materials such as ULE-glass or Zerodur [4] (see Fig. 1),

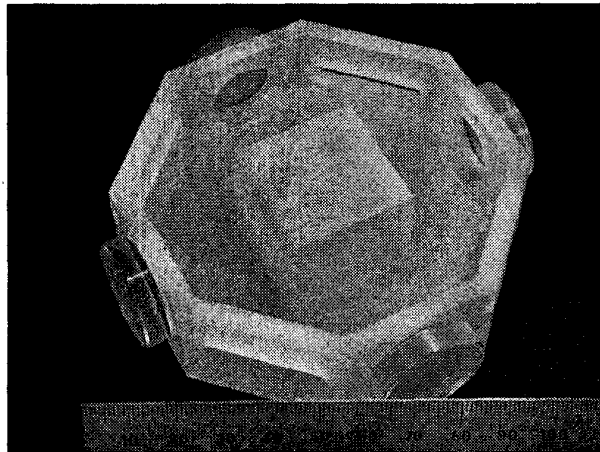


Fig. 1. A stable wavelength reference for precision dimensional metrology in air. Tunable lasers are frequency locked to TEM₀₀ modes of the cavity, providing a relatively constant wavelength in air. The resonances are calibrated in vacuum by a femto-second comb measurement. Long-term tests are underway to monitor the ability of these cavities to deliver accurate air wavelengths.

with optically contacted mirrors. Considerations during the cavity design included minimizing the effect of contamination on the mirror surfaces, reducing optical feedback to the diode laser, and methods of tuning a laser to a previously calibrated mode.

3. Wavelength Calibration

We are determining the wavelengths of lasers locked to cavity modes by performing optical frequency measurements while the cavities are under vacuum. The heterodyne measurements are accomplished by counting beat-notes with known modes of a femto-second comb. The wavelength of the resonance light in the vacuum may then be calculated by $\lambda = c/\nu$. This wavelength stays nominally constant when the cavity is back-filled with air, however a small correction (5×10^{-7}) must be applied to account for the cavity's contraction upon exposure to atmospheric pressure. A limitation appears to be the accuracy to which the cavity's material parameters (Poisson's ratio and the elastic modulus) are known. The approach of using calibrated wavelength references should enable higher precision metrology in air by supplying more accurately known wavelengths.

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3. J. A. Stone, "Wavelength tracking capabilities of a Fabry-Perot cavity," in *Recent Developments in Traceable Dimensional Measurements II*, J. E. Decker and N. Brown, eds., *Proc. SPIE Vol. 5190* (2003).
4. Trademark names are included for reference and do not constitute endorsement.