Dynamic Self-Locking of an OEO Containing a VCSEL

This is an alternative scheme for developing small, low-power atomic clocks.

A method of dynamic self-locking has been demonstrated to be effective as a means of stabilizing the wavelength of light emitted by a vertical-cavity surface-emitting laser (VCSEL) that is an active element in the frequency-control loop of an optoelectronic oscillator (OEO) designed to implement an atomic clock based on an electromagnetically-induced-transparency (EIT) resonance. This scheme can be considered an alternative to the one described in “Optical Injection Locking of a VCSEL in an OEO” (NPO-43454), NASA Tech Briefs, Vol. 33, No. 7 (July 2009), page 33. Both schemes are expected to enable the development of small, low-power, high-stability atomic clocks that would be suitable for use in applications involving precise navigation and/or communication.

To recapitulate from the cited prior article: In one essential aspect of operation of an OEO of the type described above, a microwave modulation signal is coupled into the VCSEL. Heretofore, it has been well known that the wavelength of light emitted by a VCSEL depends on its temperature and drive current, necessitating thorough stabilization of these operational parameters. Recently, it was discovered that the wavelength also depends on the microwave power coupled into the VCSEL. This concludes the background information.

From the perspective that led to the conception of the optical injection-locking scheme described in the cited prior article, the variation of the VCSEL wavelength with the microwave power circulating in the frequency-control loop is regarded as a disadvantage and optical injection locking is a solution of the problem of stabilizing the wavelength in the presence of uncontrollable fluctuations in the microwave power. The present scheme for dynamic self-locking emerges from a different perspective, in which the dependence of VCSEL wavelength on microwave power is regarded as an advantageous phenomenon that can be exploited as a means of controlling the wavelength.

The figure schematically depicts an atomic-clock OEO of the type in question, wherein (1) the light from the VCSEL is used to excite an EIT resonance in selected atoms in a gas cell (e.g., $^{87}$Rb atoms in a low-pressure mixture of Ar and Ne) and (2) the power supplied to the VCSEL is modulated by a microwave signal that includes components at beat frequencies among the VCSEL wavelength and modulation sidebands. As the VCSEL wavelength changes, it moves closer to or farther from a nearby absorption spectral line, and the optical power transmitted through the cell (and thus the loop gain) changes accordingly. A change in the loop gain causes a change in the
The apparatus (see figure) includes a commercial mid-infrared camera that contains a liquid-nitrogen-cooled focal-plane indium antimonide photodetector array, and imaging is restricted by a narrow bandpass centered at wavelength of 4 μm. This narrow wavelength range centered at 4 μm was chosen because (1) it enables avoidance of interfering absorptions by atmospheric OH and CO₂ at 3 and 4.25 μm, respectively; and (2) the coating material exhibits maximum transparency in this wavelength range. Delamination contrast is produced in the mid-infrared reflectance images because the introduction of cracks into the TBC creates an internal TBC/air-gap interface with a high diffuse reflectivity of 0.81, resulting in substantially higher reflectance of mid-infrared radiation in regions that contain buried delamination cracks.

The camera is positioned a short distance (=12 cm) from the specimen. The mid-infrared illumination is generated by a 50-watt silicon carbide source positioned to the side of the mid-infrared camera, and the illumination is collimated and reflected onto the specimen by a 6.35-cm-diameter off-axis paraboloidal mirror. Because the collected images are of a steady-state reflected intensity (in contrast to the transient thermal response observed in infrared thermography), collection times can be lengthened to whatever extent needed to achieve desired signal-to-noise ratios.

Each image is digitized, and the resulting data are processed in several steps to obtain a true mid-infrared reflectance image. The raw image includes thermal radiation emitted by the specimen in addition to the desired reflected radiation. The thermal-radiation contribution is eliminated by subtracting the image obtained with the illumination off from the image obtained with the illumination on. A flat-field correction is then made to remove the effects of non-uniformities in the illumination level and pixel-to-pixel variations in sensitivity. This correction is performed by normalizing to an image of a standard object that has a known reflectance at a wavelength of 4 μm. After correction, each pixel value is proportional to the reflectance (at a wavelength of 4 μm) at the corresponding location on the specimen.