Semiconductor laser diode produces stabilized optical-frequency combs

Peter Delfyett, Ibrahim Ozdur, Mehmetcan Akbulut, Nazanin Hoghooghi, Dimitrios Mandridis, Sarper Ozharar, and Franklyn Quinlan

Phase-locked, coherent periodic optical channels provide a cost-effective, competitive alternative to conventional solid-state and fiber-based sources.

Over the past decades, the use of lasers in communications, signal processing, test and measurement systems, and spectroscopy has enabled many key advances owing to the wide range of useful characteristics inherent in coherent laser radiation. Further advances are expected from simultaneous deployment of multiple lasers spanning a range of wavelengths. This will allow generation of parallel optical channels, thus increasing the system's measurement and processing capability. Additional functionality is achieved if each optical-frequency channel is phase-locked to the other channels, i.e., if the relative phase relations among all channels are well established, fixed, and not drifting over long times. To construct such a set of frequency combs, one can use a single continuous-wave laser, combined with modulation techniques such as amplitude or phase modulation to create sidebands. Alternatively, mode-locked lasers can generate a frequency comb with phase-coherent relationships between all wavelength components. The main drawback of a conventional mode-locked laser is that the frequency comb can drift because of both environmental and background quantum effects.

We have developed an optical source that is capable of producing a set of widely spaced optical frequencies and suitable for a broad range of communication and signal-processing applications. Our approach is also self-referencing because the optical-frequency comb is referenced to a secondary optical standard, such as a high-quality etalon. To achieve wide optical-channel spacing and high spectral purity, we engineer the optical cavity so that the optical-frequency comb has simultaneous wide channel spacing and a very narrow linewidth for each frequency-comb ‘tooth.’ This approach leads to very low noise and excellent spectral purity for each comb component.

We generate a stabilized comb of coherent, phase-locked optical frequencies by employing a nested-cavity configuration, where the main cavity has a free spectral range of ∼7MHz, while a secondary internal cavity has a finesse of 1000 and a free spectral range of 10.287GHz. This configuration generates a frequency comb with a spacing determined by the internal...
cavity, and individual narrow comb linewidths defined by the main cavity. The secondary cavity’s free spectral range also defines the laser’s pulse-repetition frequency. A schematic of the laser system is shown in Figure 1. The setup consists of two parts, i.e., the laser cavity and the Pound-Drever-Hall (PDH) optical-stabilization loop.

The purpose of the internal-cavity Fabry-Perot etalon (FPE) is twofold. First, inclusion of the etalon allows only a single-phase locked-mode group, or ‘supermode,’ to lase. Without the etalon, ~1500 interleaved supermodes would compete, and the resulting random fluctuations in amplitude and phase would disturb the output pulse train. This noise manifests itself in the timing and amplitude noise spectra as a series of noise spurs, or ‘supermode noise.’

The simultaneous lasing of different optical supermodes also precludes using a single phase-locked frequency comb with multigigahertz spacing. Without stabilization of the laser cavity, however, environmental effects will cause the optical frequencies to drift relative to the FPE’s transmission peaks. These frequency fluctuations will destabilize the mode locking. A solution is provided by PDH laser-frequency stabilization, which uses the FPE to detect small changes in the optical laser frequencies to create an error signal that—after conditioning by a proportional gain-integration-differentiation controller—is fed back into a piezoelectric optical-phase shifter for compensation. Thus, supermode suppression and optical-frequency stabilization are achieved simultaneously with a single intracavity FPE.

The resulting performance produces a spectrally flat, stabilized optical-frequency comb of ~150 components on a 10.287GHz grid. The individual comb linewidth is <1kHz with a stability of ~150kHz, and has >45dB contrast. The resulting periodic pulse train has an overall timing jitter (1Hz to 100MHz) of ~8.3fs, with an intensity noise of 0.038%. This makes this source well suited for a broad range of applications in areas of optical communications, signal processing, metrology, and test and measurement.

To realize the potential processing speeds and accuracy that photonics promises, using stabilized phase-coherent optical-frequency combs is a step toward that vision. Our work shows that generation of stabilized optical-frequency combs can be obtained with excellent stability and with the cost effectiveness, electrical efficiency, and compactness of semiconductor diode lasers. Future work will focus on addressing the stability limitations imposed by the present cavity configuration.

Author Information

Peter Delfyett, Ibrahim Ozdur, Mehmetcan Akbulut, Nazanin Hoghooghi, and Dimitrios Mandridis
College of Optics and Photonics
University of Central Florida
Orlando, FL

Sarper Ozharar
Northwestern University
Chicago, IL

Franklyn Quinlan
National Institute of Standards and Technology
Boulder, CO

References