Pure transfer

Spectral purity can now be transferred from one laser to another with a very different wavelength at an order of magnitude better than previously achievable. Yann Le Coq spoke to *Nature Photonics* about the new development.

Why is laser frequency stabilization important?

Laser frequency stabilization is important in the context of time and frequency metrology and also for high-precision measurements in which the laser frequency is the carrier of the high-precision measurement information. This is a basic tool in, for example, optical clocks, length measurement and gravitational-wave detectors.

What is spectral purity?

The spectral purity of a continuous-wave laser is about how well its electromagnetic-field oscillation resembles an ideal sinusoid. Although most lasers exhibit a very 'well-behaved' field over a few cycles, over longer time spans the phase of the field wanders, causing the electromagnetic field to diverge from a pure sine wave. The amplitude of the field oscillation is normally bounded by physical means (such as gain saturation); consequently, phase diffusion is the main source of trouble. Only very sophisticated lasers, frequency locked to an external reference (typically a high-finesse Fabry–Pérot cavity) can exhibit a good spectral purity over timescales of a second or longer, so that the rapidly oscillating electromagnetic field can be reasonably described by a constant-period sine wave over time periods as long as a few seconds.

What is spectral purity transfer?

The goal of spectral purity transfer is to servo lock a laser that has a moderately good spectral purity to one with a very good purity to force the former to behave better — ideally as well as the 'master' laser. This is relatively easy to do — it's regularly done in many laboratories — for two lasers operating at nearly identical wavelengths. In this case, the optical beat-note signal has a sufficiently low frequency that it can be detected electronically. However, performing the transfer between lasers operating at relatively different wavelengths requires the use of an optical-frequency comb. In our paper, we demonstrate transfer of spectral purity between lasers operating at frequencies hundreds of terahertz from each other (from a laser with a wavelength of 1,062 nm to one with a 1,542 nm wavelength). Our work is unique in that we characterize how well we can perform such transfer, and we establish an ensemble of techniques that enables the spectral purity of any currently developed laser to be transferred with negligible degradation.

How does the performance compare with that of previous studies?

We demonstrate spectral purity transfer with a limitation that is more than one order of magnitude below current laser technology. Previous optical-frequency comparisons with frequency combs were performed in the 10^{-17} range for a measurement time of 1 s. We have realized not only frequency comparison, but also full spectral purity transfer with a performance of 4×10^{-18} in the 1 s range — substantially lower than that of previous studies. At timescales of 1 s and below, our technique is presently limited by the signal-to-noise ratio of the beat-note detection, which depends on the optical power of the comb at the relevant wavelength. Although we have ideas about how we can further increase the optical power, current laser technology doesn't necessarily require improving the performance of our system.

What applications do you think this could be useful for?

We believe it will be extremely useful for optical clocks with neutral atoms. The performances of these systems are currently limited by the spectral purity of the laser used to probe the narrow atomic transition on which the clock is based. As a result, we are conducting several research projects to develop better lasers. In a nutshell, the goal of our work is to develop a better laser that we can use at any desired wavelength in the visible/near-infrared region.

What do you intend to do next?

We, as well as other laboratories in the world, have plans to develop continuous-wave lasers with a spectral purity below what has been demonstrated to date. We will transfer the spectral purity of such lasers to optical clock systems. This will be a big step towards reaching the quantum projection noise limit. We intend to develop 'lattice' optical clocks based on strontium atoms as well as on mercury atoms. We will work hard to apply our techniques to these systems. Another project is the generation of low-phase-noise microwave signals using optical-frequency combs phase locked to continuous-wave near-infrared lasers. This is, in a sense, transfer of spectral purity from a continuous-wave near-infrared laser, not to another laser in the optical region (as demonstrated in the current paper), but to the microwave domain. The present demonstration will also benefit this project, as the microwave signal spectral purity is currently limited by that of the continuous lasers onto which the frequency comb is phase locked (at least for low Fourier frequencies). The ability to transfer the spectral purity of an extremely good laser (which has yet to be developed) operating at any wavelength to that of the microwave generated field will certainly help to realize an unprecedented low phase noise in the microwave domain.


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Yann Le Coq and colleagues transfer the spectral purity of a very good laser to another that has a relatively poor spectral behaviour and lases at a very different wavelength.

INTERVIEW BY DAVID PILE

Yann Le Coq and co-workers have a Letter on spectral purity transfer on page 219 of this issue.