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Rabi Prize Talk: The Art of Light-based Precision Measurement[1]

JUN YE, JILA and Physics Department, National Institute of Standards and Technology and University of Colorado

Improvements in spectroscopic resolution have been the driving force behind many scientific and technological breakthroughs over the past century, including the invention of the laser and the realization of ultracold atoms. Maintaining optical phase coherence is one of the two major ingredients (the other being the control of matter) for this scientific adventure. Lasers with state-of-the-art control can now maintain phase coherence over one second, that is, 10^{15} optical waves pass by without losing track of a particular cycle. Translating into distance, such a coherent light wave can traverse the circumference of the Earth 10 times and still interfere with the original light. The recent development of optical frequency combs has allowed this unprecedented optical phase coherence to be established across the entire visible and infrared parts of the electromagnetic spectrum, leading to direct visualization and measurement of light ripples. Working with ultracold atoms prepared in single quantum states, optical spectroscopy and frequency metrology at the highest level of precision and resolution are being accomplished. A new generation of atomic clocks using light has been developed, with anticipated measurement precision reaching 1 part in 1018. The parallel developments in the time domain have resulted in precise control of the pulse waveform in the sub-femtosecond regime, leading to demonstrations of coherent synthesis of optical pulses and generation of coherent frequency combs in the VUV spectral region. This unified time- and frequency-domain spectroscopic approach allows high-resolution coherent control of quantum dynamics and high-precision measurement of matter structure across a broad spectral width. These developments will have impact to a wide range of scientific problems such as the possible time-variation of fundamental constants and gravitational wave detection, as well as to a variety of technological applications.

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