All-Fiber Spectrometer

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Description:

Spectrometers, which measure the intensity of light at different wavelengths, are used for virtually all optical materials analysis techniques, from chemistry to astronomy. Because the resolution of a spectrometer (its ability to differentiate signals closely spaced in wavelength) scales with the distance the light travels, conventional systems consist of bulky and complex arrangements of mirrors, gratings and lenses. Yale researchers have now discovered a way to replace all the spectrometer components and housing with a multimode fiber, transforming the humble optical fiber into a distinct platform that offers a new generation of high resolution spectrometers with reduced size, weight, and cost. The fiber spectrometer technology also lends itself to the development of high resolution hyperspectral imaging systems–optical systems that collect spectrally resolved images of objects and scenes, with an equally wide range of applications spanning medical imaging to earth observation.

Technology: The key innovation is a ‘Transmission Matrix’ technology that uses calibration data to reconstruct an arbitrary input spectrum from the speckle pattern generated by interference between modes in a multimode fiber. A reconstruction algorithm was developed which uses the transmission matrix to recover the spectrum in the presence of experimental noise.
Advantages:

**Higher spectral resolution.** Commercially available optical fibers are designed for long optical path lengths enabling very high spectral resolution (the proof-of-principle demonstration exhibited resolution of 0.03 nm at \( \lambda = 1500 \text{ nm} \)). Higher resolution can be achieved simply by using a longer fiber, allowing a fiber spectrometer to exhibit resolution equivalent to or better than the state of the art.

**Smaller footprint.** In traditional spectrometers, the resolution scales with the optical path length. To achieve resolutions less than 0.1 nm at 1500 nm, path lengths on the order of 100 mm are required and the total spectrometer footprint is typically ~1 meter. An optical fiber can be coiled to achieve a similar pathlength with a much smaller footprint.

**Lower-cost, lightweight all-fiber instrument.** Traditional heavy, expensive spectrometer components and housing can be replaced with a single, low-cost multimode fiber.

**Minimal insertion loss.** The fiber spectrometer leverages the extremely low-loss of commercial optical fibers, enabling highly efficient spectrometer operation.

**No special camera requirements.** The simplest realization that can be introduced to the marketplace will be a multimode fiber and a camera operating in the wavelength region of interest. Yale’s proof-of-principle was demonstrated with InGaAs near-infrared cameras, but low cost visible cameras will work just as well in the visible range.

**Easily scaled to realize 2D imaging spectrometer for hyper spectral imaging.** Appropriate commercially available imaging fiber bundles can be integrated with commercially available cameras for hyperspectral imaging. By using each core as its own spectrometer, a spectrally resolved image can be generated.
Stage of Development: Proof of Principle

IP Status: Patent Application in progress

Publications:


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