STANDING-WAVE MICROSPectROMETER FOR MULTIPLE FLuORESCENCE DETECTION

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Abstract

We have developed a compact optical microspectrometer, based on a standing-wave architecture, for integration with a microfluidic chip. The device is designed for adaptive discrimination among fluorescence signals, with tunable spectral resolution and selective suppression of broadband background light.

Keywords: Optical, spectrometer, standing wave, tunable resolution

The ideal portable microfluidic chip-based fluorescence detection system would include an integrated optical microsensor capable of detecting and flexibly discriminating among a wide range of simultaneous fluorescence emission signals. We present a compact optical microspectrometer based on a standing-wave architecture [1], and we discuss results of spectral discrimination of optical test sources in the visible (488 nm – 665 nm) and near infrared (633 nm – 866 nm).

Fig. 1. Left: Near-IR microspectrometer schematic. Light enters from below the detector holder, traverses the detector, and reflects off the mirror pillar back toward the detector. Right: Photos of mirror and detector components.
This device (Fig. 1) is based on the standing-wave transform spectrometer architecture with a moving mirror and a partially transmitting photodetector. Incident light reflecting off the mirror creates an optical standing wave. While the mirror scans along the optical beam axis, the detector samples the moving standing wave; the Fourier Transform (FT) of the resulting time varying photocurrent yields the optical spectrum. This architecture offers the same advantages as other FT spectrometers, but in an optically 1-D system; this eliminates the need for a beamsplitter and reference mirror. Hybrid integration allows implementation of any photodetector material, and thus detection in any wavelength range. Our near infrared device contains a GaAs/AlGaAs photodiode [2], and our visible device contains an a-SiC:H/a-Si:H photodiode [3]. In both cases the mirror component is a parallel-plate electrostatically driven Si MEMS actuator. High-amplitude harmonic oscillation, up to 52 nm at 800 Hz, enables fast, continuous spectral analysis. With an actuator capacitance of only 4.2 pF, it should draw < 0.1% of the power drawn by a typical piezoelectric transducer.

![Graph of Wavelength vs Optical Spectrum](image)

**Fig. 2.** Superimposed spectra from near-IR micro-spectrometer for lasers at 866 nm and 633 nm, demonstrating a spectral resolution of 100 cm⁻¹ (4 nm at λ = 633 nm, or 7 nm at λ = 866 nm).

With a surface-normal, linear optical design, the 17 × 13 × 1 mm device is well-suited to integration with a microfluidic chip. Spectral resolution of 4 nm (λ = 633 nm), which is much less than the typical fluorescence bandwidth, was recently achieved with an integrated near infrared prototype (Fig. 2). Whereas most microspectrometers (commonly grating-based devices with a detector array) have poor spectral multiplexing...
characteristics, our standing-wave microspectrometer has the multiplexing advantage and simple single detector readout of a FT spectrometer. Microspectrometers usually have fixed spectral resolution, however our device can be easily configured for a particular sensing task by tuning its spectral resolution, allowing real-time optimization of sensitivity. With a visible device, continuous resolution tuning from 72 nm to 6 nm ($\lambda = 633$ nm) was demonstrated (Fig. 3).

![Interferograms and Optical Spectra](image)

Fig. 3. Top row: Interferograms (AC photocurrent) from visible microspectrometer for mirror scan lengths of a) 3.8 $\mu$m, b) 14 $\mu$m, and c) 31 $\mu$m. Bottom row: Optical spectra derived from interferograms, with low, medium, and high resolutions (peak full-width at half-maximum, at $\lambda = 633$ nm) of a) 1800 cm$^{-1}$ = 72 nm, b) 340 cm$^{-1}$ = 14 nm, and c) 140 cm$^{-1}$ = 5.6 nm, respectively.

Two unique physical properties of this device can be used to suppress scattered pump light in fluorescence experiments. The minimum mirror-detector distance can be set by adjusting the actuator drive amplitude; this reduces the sensitivity to sources with low spectral coherence, which allows for preferential suppression of any broadband light source such as a broadband lamp pump. Also, the photodetector thickness can be designed so that there is a minimum of generated AC current for one wavelength, and a relatively strong AC signal for nearby wavelengths; this enables suppression of laser pump light with preferential detection of fluorescence emission.
In conclusion, we have investigated a number of intriguing capabilities of the standing-wave microspectrometer, with particular attention to those that could make this device useful in microsystems dependent on analysis of fluorescence emission.

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References