Standing-wave Microspectrometer for Multiple Fluorescence Detection

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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 will discuss results of spectral discrimination of optical test sources in the visible (488 nm – 665 nm) and near infrared (633 nm – 866 nm). Spectral resolution of 4 nm ($\lambda = 633$ nm) was recently achieved with an integrated near infrared prototype (Figs. 1a-1b). With a surface-normal, linear optical design, the $17 \times 13 \times 1$ mm device is well-suited to integration with a microfluidic chip. 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 Fourier transform (FT) spectrometer. Microspectrometers also 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. 2).

This device 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 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 μm 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.

We will introduce two unique physical properties of this device that 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 and will discuss 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.

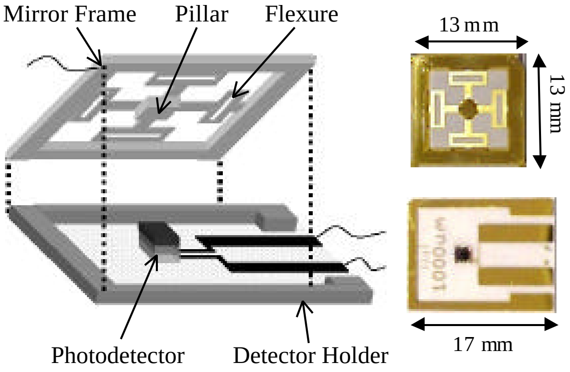

Fig. 1a. Left: Near-IR microspectrometer schematic. Light enters from below the detector holder, traverses the detector, and reflects off the mirror pillar back toward the detector. Right: photos of mirror and detector components.

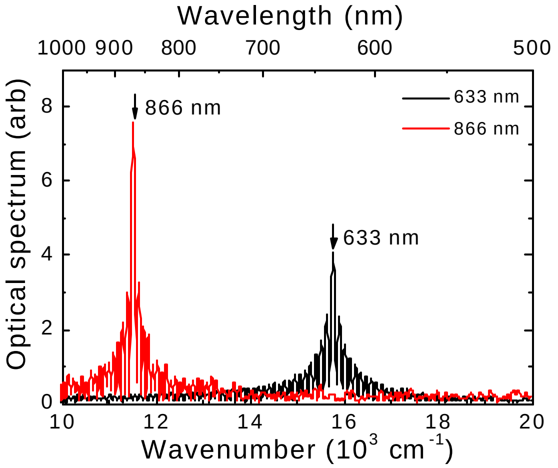

Fig. 1b. Superimposed spectra from near-IR microspectrometer for lasers at 866 nm and 633 nm, demonstrating a spectral resolution of 100 cm^{-1} (4 nm at λ = 633 nm, or 7 nm at λ = 866 nm).

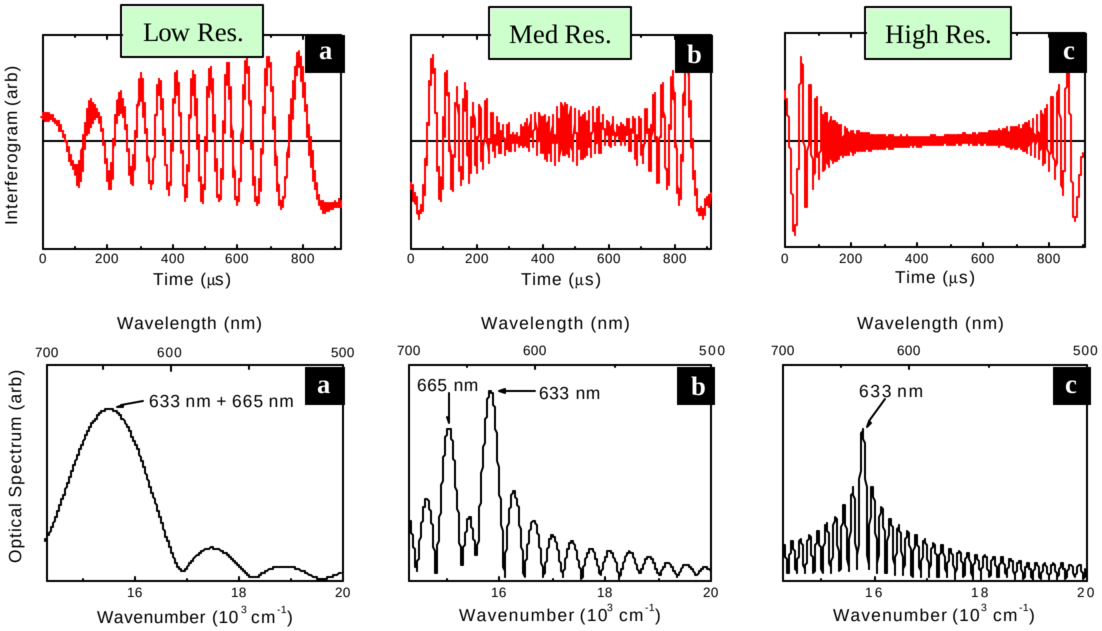

Fig. 2: Top row: Interferograms (AC photocurrent) from visible microspectrometer for mirror scan lengths of a) 3.8 µm, b) 14 µm, and c) 31 µm. Bottom row: Optical spectra derived from interferograms, with low, medium, and high resolutions (peak full-width at half-maximum, at λ = 633 nm) of a) 1800 cm^{-1} = 72 nm, b) 340 cm-^{1} = 14 nm, and c) 140 cm^{-1} = 5.6 nm, respectively.

References

[1] H. L. Kung, S. R. Bhalotra, J. D. Mansell, D. A. B. Miller, and J. S. Harris Jr., “Standing-wave transform spectrometer based on integrated MEMS mirror and thin-film photodetector,” J. Selected Topics in Quantum Electronics, vol. 8 (2002).

[2] S. R. Bhalotra, H. L. Kung, J. Fu, N. C. Helman, O. Levi, D. A. B. Miller, and J. S. Harris, Jr., “Integrated standing-wave transform spectrometer for near infrared optical analysis,” in Proc. of IEEE Lasers and Electro-optics Society 15th annual meeting, ML5 (2002).

[3] D. Knipp, H. Stiebig, S. R. Bhalotra, H. L. Kung, and D. A. B. Miller, “Thin film technology based micro-Fourier spectrometer,” in Proc. of SPIE Photonics West Conference, 4983-15 (2003).