Compact transform spectrometer based on sampling a standing wave

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We demonstrate a Fourier-transform spectrometer based on a large-displacement MEMS mirror and sampling an optical standing wave with a thin photoconductor. The 1-D design should permit integration of many spectrometers into an imaging array.

MEMS technology has enabled the miniaturization of several types of spectrometers, including Fabry-Perot interferometers,[1] grating based spectrometers[2] and Michelson Fourier-transform spectrometers.[3] Here we present a compact, transform spectrometer based on a new approach of sampling an optical standing wave. Like all transform spectrometers, it has throughput and multiplexing advantages compared to Fabry-Perot and grating designs. The use of a standing wave to generate the interferogram eliminates the need for a beam splitter, simplifying fabrication, and allowing the possibility of 2-D arrays for collecting spectral images without raster scanning.

The optical set-up is shown in Figure 1. A photoconductor that is thinner than a wavelength partially transmits an incoming beam. The transmitted light then hits a movable MEMS mirror and the reflected and forward waves are superposed, generating a standing wave. The inteferogram is detected by the thin film photoconductor. As the mirror moves, the amplitude of the standing wave at the photoconductor varies. The Fourier transform of the resulting time domain signal determines the optical spectrum.

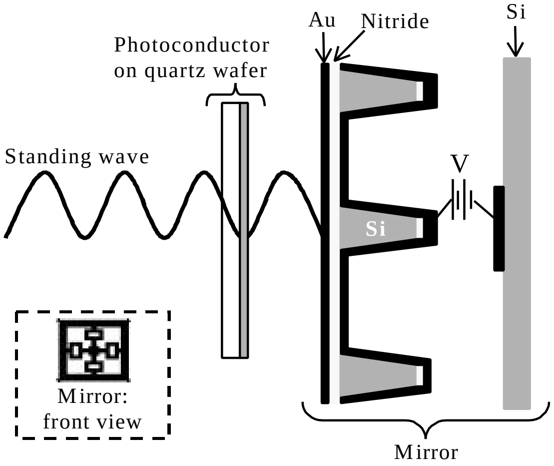

Figure 1- Optical set-up. Incoming light passes through a partially transmitting photoconductor and reflects off the MEMS mirror. The photoconductor samples the standing wave. The front surface of the mirror is shown in the insert on the left.

The photoconductor was fabricated by depositing 1000 Å of intrinsic amorphous silicon (a-Si) by low pressure chemical vapor deposition (LPCVD) onto a quartz wafer. 200 Å of *p*-doped a-Si was grown on top of the *i* a-Si for ohmic contacts. 1000 Å of gold was then evaporated onto the material in a metal-semiconductor-metal pattern with finger and spacing width of 40 μm. The photoconductor has a dark resistivity of 4.2 MΩ; when illuminated with 1 mW of 633 nm light (HeNe) it has a resistivity of 3.4 MΩ. At this wavelength ~50% of the incoming light is reflected by the gold fingers of the detector, and total power transmission is ~30%. The maximum operating speed of the detector is less than 7 kHz; this is a consequence of the finger spacing and material properties of the LPCVD a-Si.

The mirror was fabricated by depositing ~1 μm of LPCVD low-stress silicon nitride onto both sides of a double-side-polished <100> 4-inch silicon wafer. The wafer was then patterned and the nitride was removed from the exposed areas by a plasma dry-etch. The wafer was placed in a bath of potassium hydroxide to etch the exposed silicon down to a thickness of ~20 μm. The mirror was then coated on both sides with 2000 Å gold. The back plane was fabricated by depositing gold onto a silicon wafer.

A diagram of the front plane mask is shown in Figure 1. The central inner square and outer square are 2 mm and 13 mm on a side, respectively. The connecting arms are designed such that they bend rather than stretch, allowing the central square reflective surface to move large distances when an electrostatic force is applied.

To drive the mirror, we apply an amplified voltage across the front and back planes of the mirror structure, and the parallel surfaces are attracted. The outer border is fixed, so only the center square moves toward the back plane. This attraction is countered by a restoring force due to the deformation of the thin segments that connect the outer border to the center. The mirror has a mechanical resonance at approximately 700 Hz. When the mirror is driven on resonance with a drive voltage of 215 V_{pp} the maximum mirror displacement is 65 μm.

The spectrometer mirror was run on resonance for large displacement and more stable motion. The photoconductor was biased at 15 V. The signal from the photoconductor was passed through a 3.39 kHz high-pass filter to remove the DC components (dark current, first pass absorption, ambient light), and amplified with a total gain of 10^7 V/A. We tested the system with two sources: a small HeNe laser at 633 nm and a diode-pumped solid-state laser (Spectra-Physics Millenium) at 532 nm, each attenuated to ~2 mW. Given the photoconductor's speed limitations, we chose a mirror displacement of 2.7 µm, which corresponded to 37 V_{pp} applied across the mirror. For each source we obtained graphs of the AC photocurrent signal versus displacement of the mirror, as shown in Fig. 2. It is apparent that there is a new interference fringe for every $\lambda/2$ mirror displacement, as expected.

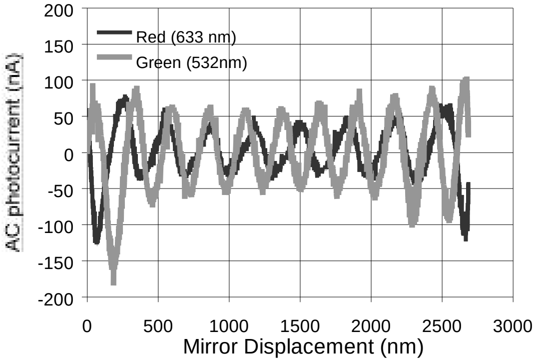

Figure 2- AC photocurrent vs. mirror displacement for red and green laser sources coupled separately into the spectrometer.

When both the red and green sources are incident on the spectrometer simultaneously there is a beat frequency in the photocurrent curve, as shown in Figure 3(a). The Fourier transform of Figure 3(a) is shown in Figure 3(b); peaks at 633 nm and 531 nm correspond to the frequencies of the two lasers. The two peaks are broadened compared to the true frequencies of the lasers, due to the fact that the total mirror displacement was only 2.7 µm. For this displacement the fundamental resolution using unapodized even-intensity delta functions to represent the lasers is 1852 cm^{-1}.[4] The two wavelengths were separated by 3000 cm^{-1} but they were not of even intensity. Since we operated beyond the minimum resolution requirement, the two frequency components could be resolved.

In conclusion, we have demonstrated a transform spectrometer based on sampling a standing wave pattern at a moving mirror. The spectrometer's resolution is limited by the speed of the present photoconductor. If the photoconductor were capable of running at speeds greater than 170 kHz, then the maximum resolution, determined by the maximum displacement of this long-throw MEMS mirror, would be 77 cm^{-1}. Future improvements include making a faster and more transparent photoconductor, and integrating both parts of the MEMS mirror and thin-film photoconductor into a single pacaged device.

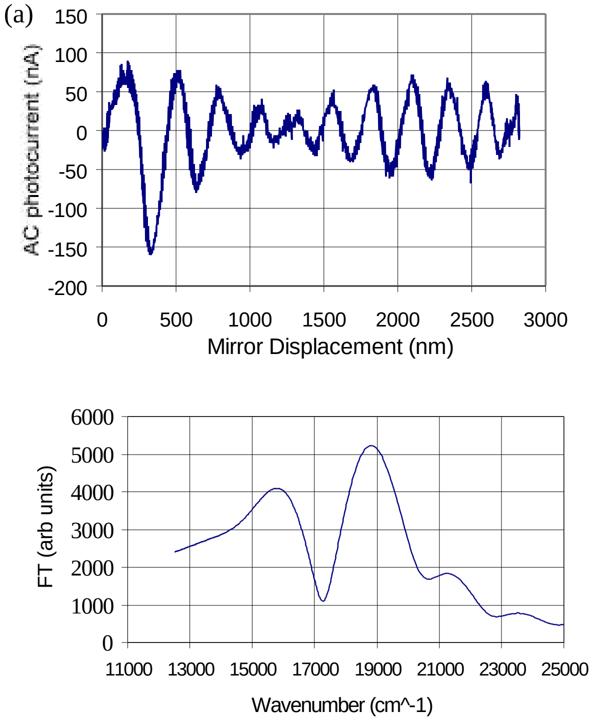

Figure 3– (a) AC photocurrent vs. mirror displacement for red and green laser sources simultaneously coupled into the spectrometer. (b) The corresponding FT: the two peak frequencies are at 633 nm (15798 cm^{-1}) and 531 nm (18832 cm^{-1}).

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