Compact Optical Delay Line Based on Scanning Surface Micromachined Polysilicon Mirrors

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Adjustable optical delay lines are important functional elements in ultrafast optical science and interferometry. Ultrafast optical time resolved measurements are performed using pairs of interfering laser pulses; a probe pulse propagating along a variable-length path, and a reference pulse propagating along a fixed-length path. A commonly used method for creating variable optical time delays involves mechanically moving a retro-reflecting mirror along the pulse propagation direction using a lateral translation stage. This method offers excellent accuracy when precision lead screws are employed. However, scans are inherently slow owing to substantial mechanical inertia. Some important applications, such as Optical Coherence Tomography, require scan rates exceeding 1 kHz [1].

The rapid scanning optical delay (RSOD) [2], which is based on femtosecond pulse shaping technology [3], was developed to overcome the speed limitations of traditional approaches. In an RSOD the traditional translating mirror is replaced by a scanning mirror with a rotation angle of a few degrees. In this paper we present the integration of a scanning silicon micromirror into a compact RSOD geometry only about 5 cm in length. We demonstrate a 40 psec rapid scanning optical delay of 100 fsec time scale optical pulses.

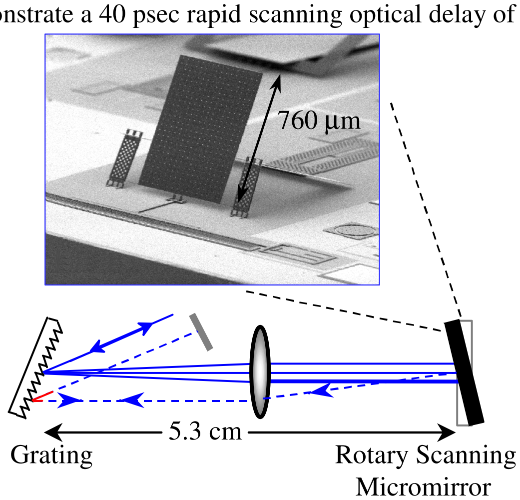

Fig. 1. Schematic of double pass rapid scanning optical delay line with a silicon micromachined rotary scanning mirror.

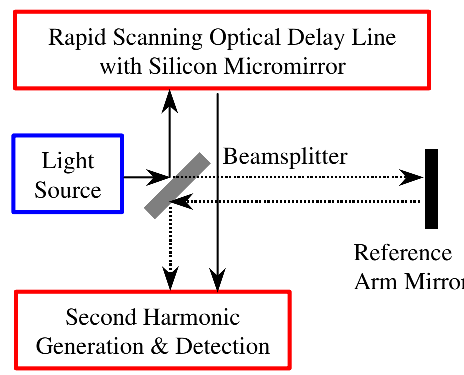

Fig. 2. Schematic of optical delay line in a µMichelson interferometer configuration.

Our RSOD is based on a surface micromachined tilt-up mirror [4] as shown in Fig. 1. The polysilicon mirror is connected to a supporting frame with torsional polysilicon beams and is dynamically driven by an electrostatic comb-drive actuator. The rectangular mirror face is 760 µm by 500 µm, with a resonant frequency of 1060 Hz and a measured range of deflection of 16 degrees optical. The residual stress gradients give the micromirror a measured convex radius of curvature of 34 cm [5]. The RSOD is characterized using a Michelson interferometer as shown in Fig. 2. Figures 3 and 4 shows the frequency and deflection characteristics of the micromirror.

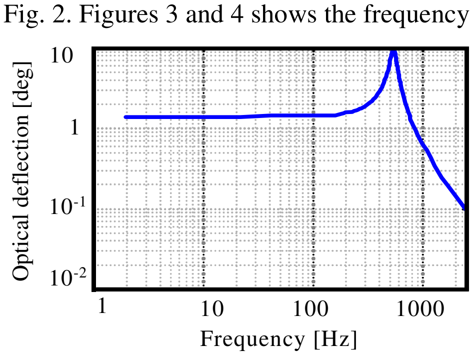

Fig. 3. Micromirror frequency response.

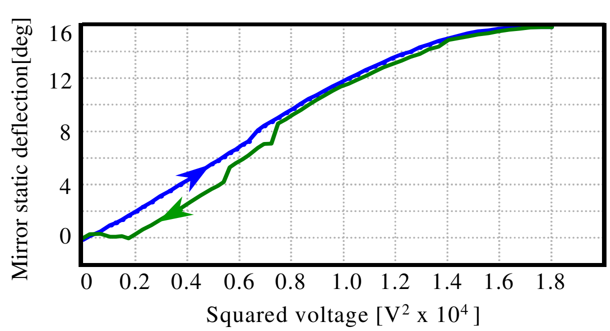

Fig. 4. Static micromirror deflection.

With the use of a micromirror, the RSOD has an optical length of 5.3 cm, ~ 4 to 5 times smaller than pulse shapers used today in common practice. The resolution of our system on the micromirror is defined by the ratio of the spectral spread to the spot size of one spectral frequency. Therefore, we designed for the largest reasonable spot size of our input beam at the grating, subject to the constraint that the beam radius must be small enough to allow adequate translation motion across the lens. This is accomplished by defining our input Rayleigh range to be 10 times the focal length of our achromatic lens. By this conservative rule of thumb, we still attain a tight 23 μm spot size at the focal plane of the lens. Once this is established we decide upon the grating groove spacing, d. The grating spectral dispersion then dictates the minimum dimension of the scanning mirror face, Δx. Our system inputs a 835 nm central wavelength with 25 nm total bandwidth from a modelocked Ti:Sapphire laser. The 600 lines/mm grating and 2.54 cm focal length (f/2 achromatic) contribute to the compact size. Experimentally, the spectral spread slightly overfills the mirror face. Spectral narrowing contributes a broadening of about 25%, in addition to the residual uncompensated phase of the pulse.

The grating dispersion is defined by $\Delta\theta/\Delta\lambda = m/(d \cos\theta_d)$, where $\Delta\theta$ is the dispersion spread, $\Delta\lambda$ is the full spectral bandwidth, m is the diffraction order (or spectral order), and θ_d is the diffraction angle. The spatial extent of the spectral spread is then $\Delta x = f \tan\Delta\theta$, where f is the focal length of the lens. We define a usable lateral motion across the lens as $D_l = a + \Delta x$, where $a = f \tan(2\delta)$ is the motion of the beam center, D_l is 70% of the diameter of the lens, and δ is the mechanical angle of the mirror. With all the scaling guidelines met, the time delay is given by:

$$t_{delay} = \Delta L_{path}/c = 2(2f\lambda_0\delta)/(c\, d \cos\theta_d)$$

where λ_0 is the central wavelength. We collected a time window of 40 psec, while maintaining the pulsewidth on the same order as the 100 fsec pulsed laser source shown in Figures 5 and 6.

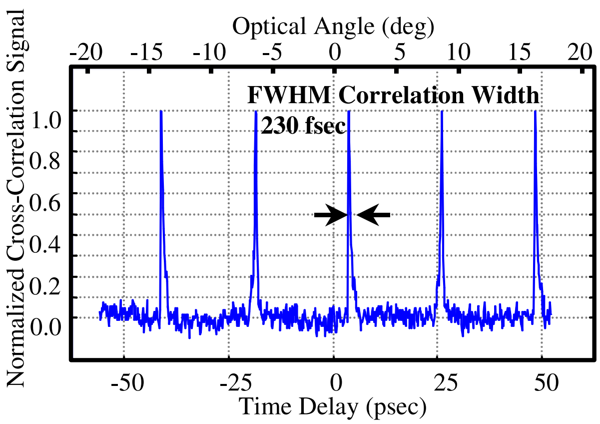

Fig. 5. Dynamic cross-correlation measurement, refresh rate 1060 Hz.

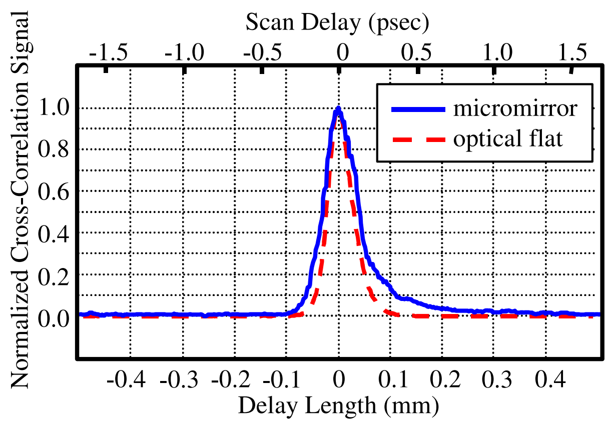

Fig. 6. Precision cross-correlation measurement

Our previously reported results yielded a good time window of approximately 10 psec but the pulsewidth was unacceptably broadened to 3.35 psec [6]. The dramatically improved results presented here are attributed to the improved flatness of the mirror face due to recent improvements in the MUMPS fabrication process. Residual broadening and asymmetry are a result of modest spectral clipping, noted above, as well as mild mirror imperfections including apparent third order ("S" shape) curvature of the mirror.

Successful integration of scanning micromirrors into the μMichelson interferometer configuration demonstrates the potential of MEMS technology for the creation of handheld portable optical devices. With the added benefits of microdevices, including speed and reduced vibration of mechanical components, the potential is also evident for use of this configuration in systems such as Optical Coherence Tomography (OCT) and Fourier transform infrared spectroscopy (FTIR).

References.

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