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Compact Fourier transform spectrometers using FR4 platform

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ABSTRACT

A novel magnetic actuated polymer optical platform is integrated into lamellar grating and Michelson type Fourier transform spectrometers. The proposed advantages of the novel platform over existing approaches, such as MEMS spectrometers, or bulky FTIR systems, include millimeter range dimensions providing a large clear aperture and enabling conventional machining for device fabrication, a controllable AC and/or DC motion both in rotational and translational modes, and real-time measurement. The platform is capable of achieving ±250 μm DC deflection (i.e., 20 cm^{-1} frequency resolution) in ambient pressure in the translational mode. A spectral resolution of 0.89 nm at 638 nm is demonstrated using this platform in a Michelson interferometer configuration. In addition, an overview of system integration methods including an optical position feedback mechanism is also discussed.

1. Introduction

Infrared (IR) absorption spectroscopy is an established method for the detection and analysis of chemical and biological samples extensively used in a wide range of industrial and research oriented applications. Fourier transform infrared (FTIR) spectroscopy is one of the numerous IR spectroscopy techniques, distinguished by its unprecedented spectral discrimination paired with the inherent sensitivity. Due to its throughput and multiplex advantages, FTIR spectroscopy provides higher SNR and speed compared to conventional methods, such as grating or Fabry-Perot spectrometers [1]. Despite the major decrease in their size and increase in integrated software complexity in the last 30 years, most FTIR spectrometers are still large instruments consisting of individual opto-mechanical components, optics, sensors and processing electronics manually assembled in the traditional manner. Furthermore, the output of these spectrometers consists of spectra, which are interpreted either by individuals or by specifically developed algorithms, significantly reducing the throughput. Hence, Fourier transform infrared spectrometers are limited to be used when size and cost of the equipment are of secondary importance compared to performance.

IR spectrometers could potentially be used as compact and portable sensors or analyzers, but current instrumentation, particularly the scanning mirror mechanisms, do not fulfill the requirements of a small and easy to use sensor. Such a compact and real-time operating analyzer could be used for monitoring the quality of gasoline at gas stations, the quality and consistency of products (e.g. food and drug industry), the safety in fermentation environment (CO_2), and countless other out-of-the lab applications. Hence, a number of compact IR spectroscopy systems, mostly using MEMS technology, have been developed. Our group has demonstrated a vertical comb actuator based lamellar grating interferometer with a wide travel range in ambient, good optical efficiency, and compact structure [2]. The MEMS component utilizes vertical resonant comb drives for actuation, light dispersion, and optical path difference monitoring. Schenk has developed a moving grating spectrometer using a torsional microscanner [3]. A Michelson interferometer based FTIR spectrometer with a vertically moving resonant micromirror operating in vacuum was introduced by Kenda [4]. Manzardo has developed a novel MEMS lamellar grating based FTIR with 6 nm resolution in the visible region [5]. The structure uses side walls of thick SOI wafers; however, surface roughness and side-wall thickness limitations imposes tight opto-mechanical tolerances and light collection efficiency limitations and requires the use of anamorphic optics for illuminating the thin and long mirror area. Correira et al. developed a 16 channel CMOS integrated Fabry-Perot spectrometer which is highly miniaturized but has lower spectral resolution compared the other methods listed [6].

In this work, we present two compact FTIR systems in Michelson interferometer and lamellar grating configurations, employing a novel electromagnetically actuated FR4 scanning platform. FR4 is a polymeric epoxy-glass resin commonly used as a substrate material for printed circuit boards (PCB) found in almost all electronics equipment. Therefore, the material has well engineered electrical, thermal and mechanical properties and the fabrication technology

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is widely available at low-cost. There have been numerous attempts at integrating new functionality into PCB technology through novel usage of the FR4 substrate [7,8]. To our knowledge, our group was the first to utilize FR4 as an electro-mechanical platform with integrated optical and optoelectronic functionalities [9,10]. In this paper, we extend the use of this novel platform into FTIR spectroscopy. Measurements with narrow and broad band sources and with integrated position feedback are demonstrated.

In Section 2, the fundamentals of FR4 mechanics – material properties, fabrication, and actuation – are presented. A lamellar grating interferometer employing a FR4 platform and a new method of optical position feedback are discussed in Section 3. Section 4 presents a high performance Michelson type FTIR spectrometer with a FR4 platform bearing a retro-reflector. A discussion on the improvement of motion linearity and implementation of other spectroscopy methods with the presented platform are given in Section 5.

2. FR4 as a mechanical platform

2.1. Material properties and fabrication

Crystalline silicon is proven to be an excellent structural material for high performance microsystems due to its exceptional mechanical properties. However, crystalline silicon is very stiff and brittle; thus, low frequency (in the order a few hundred Hz) MEMS structures become very delicate and may not be able to survive the environmental shocks and vibrations. FR4, having a low Young modulus of about 20 MPA, is inherently a soft material and a good candidate for low frequency scanning applications, which usually are very challenging for silicon MEMS devices. Moreover, the electrical circuitry required to drive the FR4 mechanical elements can easily be integrated on the same circuit board with additional optic-optoelectronic components, using conventional PCB manufacturing equipment. A drawback of FR4 based mechanics, as a result of conventional machining, is their relatively low structural precision compared to microfabricated components. The FR4 platforms presented in this paper have a minimum linewidth and spacing of 125 μm for the coil and a minimum mechanical feature size of 500 μm with a precision in the order of 100 μm. Using laser cutting techniques, precision of FR4 machining can be improved to about 20 μm, but this value is still far from sub-micron precision attainable with microfabrication techniques. The effect of low precision

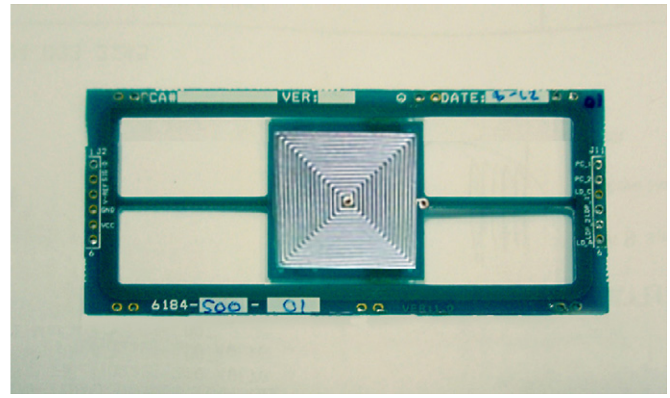

Fig. 1. Photograph of the conventionally machined FR4 scanner with a double-sided coil for electro-magnetic moving coil type actuation.

in the context of Fourier transform spectroscopy is discussed in the following sections.

Fig. 1 is a photograph of the FR4 movable platform carved from a PCB with 130 μm thick polymer and 35 μm thick top and bottom copper layers. On either side of the central 8 mm by 8 mm square plate, the copper layer is scraped to form a single electromagnetic coil. This plate is linked to the outer frame through two flexure beams in a simple torsional scanner form, which also carry the electrical feed-throughs for the coil (Fig. 2a). For optical functionality, two aluminum coated silicon mirrors are mounted on either side of the central plate.

2.2. Electromagnetic actuation of FR4 scanners

FR4 platforms are actuated with electromagnetic forces, allowing both DC and AC operation. In the moving coil actuation configuration, a rectangular or circular permanent magnet is symmetrically placed underneath the platform, creating a magnetic field B. A current $\boldsymbol{i}$ passing through the device coil under this magnetic field induces a mechanical Lorentz force that vertically translates the platform ($\boldsymbol{F}=\boldsymbol{B}\times\boldsymbol{i}\times\boldsymbol{l}$). Fig. 2b is a schematic drawing illustrating this actuation principle. On either side of the platform, lateral component of the magnetic field and the direction of the coil current are in opposite directions, creating a net force on the

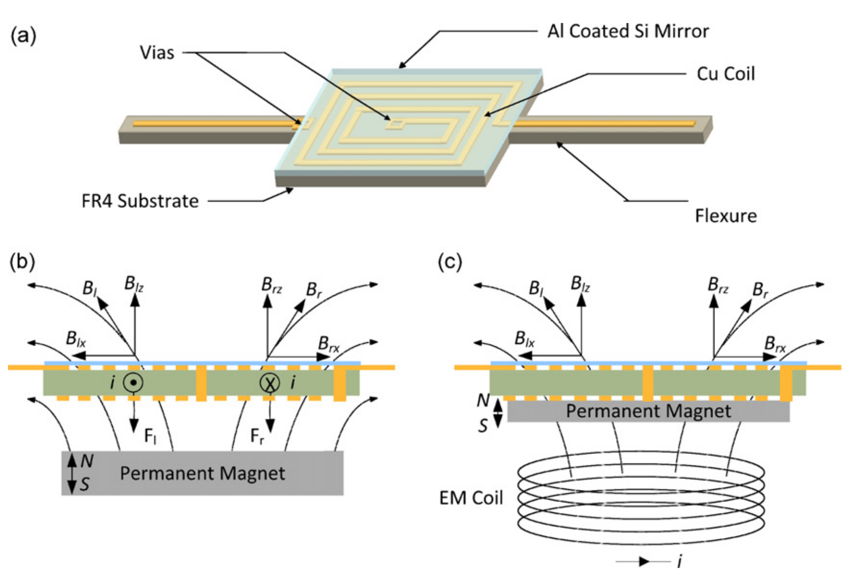

Fig. 2. (a) Schematic drawing of the platform with attached reflective mirror. Copper coils are machined on either side of the platform. (b) Electromagnetic moving coil actuation of the FR4 platform with an external permanent magnet. (c) Moving magnet actuation with a permanent magnet attached to the platform and an external EM coil. In this actuation type, the coil on the platform has no function.