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Nanolubrication of sliding components in adaptive optics used in microprojectors

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ABSTRACT

Integrated microprojectors are being developed to project a large image on any surface chosen by the users. For a laser-based microprojector, a piezo-electric based adaptive optics unit is adopted in the green laser architecture. The operation of this unit depends on stick-slip motion between the sliding components. Nanolubrication of adaptive optics sliding components is needed to reduce wear and for smooth operation. In this study, a methodology to measure lubricant thickness distribution with a nanoscale resolution is developed. Friction, adhesion, and wear mechanisms of lubricant on the sliding components are studied. Effect of actual composite components, scan direction, scale effect, temperature, and humidity to correlate AFM data with the microscale device performance is studied.

1. Introduction

As portable electronic devices such as mobile phones, media players, and gaming devices get smaller, their flat-panel displays also decrease in size. To solve this limitation, microprojectors that allow the display of large images from these electronic devices are currently being developed [1–4]. In addition, the development of microprojectors represents the miniaturization of the commercial projector. The microprojectors being sold commercially to date come as lightweight devices (about 100–150 g) that can be attached to other hand-held devices (such as mobile phones) and can display images on any surface. In the near future, these microprojectors will be integrated within the mobile phone instead of being a stand-alone device [2,3]. This implies that the microprojector chipset has to be further reduced in dimensions in order to fit inside the mobile phone and at the same time, require minimal electrical power for operation [1].

There are three main microprojection engine technologies being developed [2]. One is based on liquid crystal on silicon (LCOS) projection (3 M, St. Paul, MN) and uses polarized light with two polarizations, “p” and “s.” The voltage applied to the liquid crystal switches the light polarization in order to form dark or light pixels on the screen [5]. Another one is based on the digital light processing (DLP) technology of Texas Instruments (Dallas, TX), which uses light emitting diodes (LED) as the light source. Since the light beam diverges, one mirror is used to create one pixel, requiring the number of mirrors to be equal to the number of pixels (typically up to more than 2 million micromirrors) [6,7]. The third technology, sold as the PicoP by Microvision (Redmond, WA), is based on two-dimensional pixel-by-pixel scanning and uses modulated laser beams as the light source [2,4]. The laser based projection provides a coherent beam and uses a single scan mirror to create a pixel array. As shown in Fig. 1a, a pixel is created by combining modulated red, green, and blue laser sources. Each laser has a lens near the laser output which collects the light and yields a very low numerical aperture (NA) beam at the output. This allows the beam expansion rate to match the rate of increase of the scanned image size. As a consequence, a projection lens or focal adjustment is not required since it remains in focus at any projection distance, which is an advantage over the other two microprojection engines. In addition to autofocus capability, the coherent laser beam also provides high resolution, high brightness, and less power consumption. A schematic of the current generation of the microoptoelectromechanical system (MOEMS) scanning mirror is shown in Fig. 1b. The scanning mirror is rotated along the two axes to provide deflection horizontally at about 18 kHz and vertically at 60 Hz refresh rate to form a rectangular image. The MOEMS scanner is made using a bulk silicon microelectromechanical system (MEMS) fabrication process and actuated by the moving coil in a magnetic field oriented at approximately 45° to scan axes. A singly composite drive is applied in the coil that contains the superposition of the 18 kHz horizontal drive and 60 Hz vertical drive waveform. The combina-

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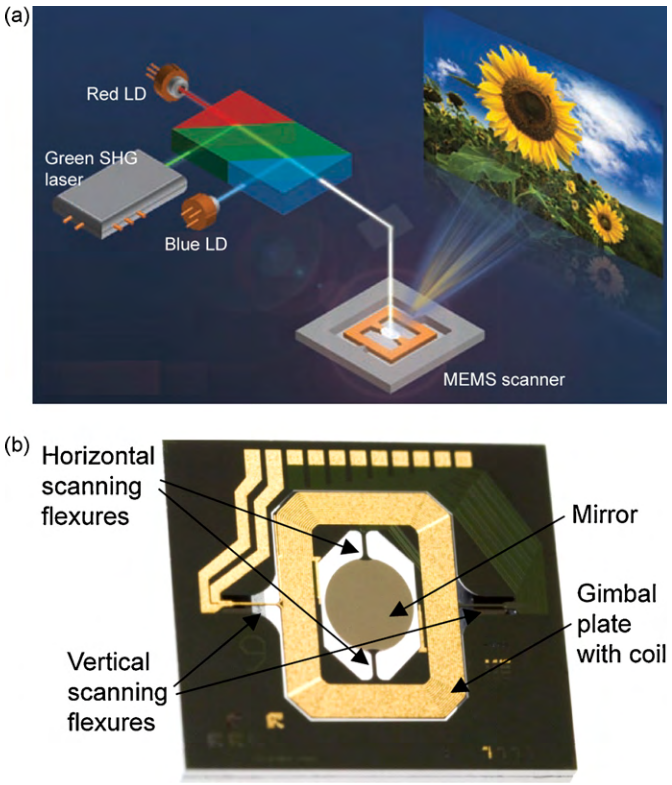

Fig. 1. (a) Schematic illustrating the operation of the microprojector (adapted from Ref. [2]) and (b) schematic showing the details of the MOEMS scanning mirror [43].

tion of the low NA beam and two-dimensional scanner results in a high contrast and always-focused image. An additional advantage is that this technology consumes low power and is compact. Table 1 provides a comparison of existing microprojector technologies.

Table 1
Comparison of existing microprojector technologies.

Vendor	Projection engine	Features
3M	Liquid crystal on silicon (LCOS)[a]	Each liquid crystal creates a pixel; projection lens required[a]
Texas Instruments	Digital light processing (DLP)[b]	Each mirror creates a pixel; projection lens required[b]
Microvision	MEMS scanning mirror[c]	Only one mirror is used; no projection lens or focal adjustment required because image is always in focus; low power consumption[c]

[a] Eckhardt et al. [5].
[b] Hornbeck and Nelson [6].
[c] Freeman et al. [2].

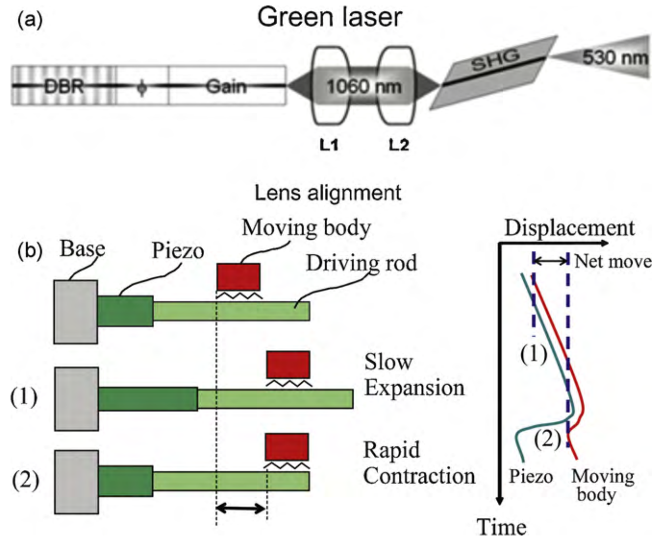

Fig. 2. Schematic of (a) the green laser architecture and (b) the operation of the drive mechanism used in the green laser [9,11].

As described above, Microvision microprojectors require red, green, and blue lasers to provide high contrast, high brightness, high resolution, and a focus-free image and low power consumption. While red and blue semiconductor lasers are easily obtainable, a compact green laser with high power is not commercially available. A green laser module has been introduced by Corning Incorporated for microprojector applications. In order to produce a compact green laser, a frequency doubling technique is used with a distributed Bragg reflector (DBR) laser diode, where a 1060 nm wavelength light is passed through a second harmonic generating crystal to produce a 530 nm green laser, as shown in Fig. 2a [8,9]. The operating temperature of the microprojector (case temperature) ranges from 10 to 60 °C (typically 40 °C) and up to 90% RH. The storage environment of the microprojector can have temperatures as high as 85 °C and relative humidity as high as 93%. Extreme operating environment and mechanical shock and vibration can cause lens misalignment and degrade optical output. To correct for this, the green laser module uses an adaptive optics component with a drive mechanism to align the optics and maintain constant power output with time and temperature. This drive mechanism is also commonly referred to as the smooth impact drive mechanism or SIDM [10]. Lens alignment along the *x*- and *y*-axes is obtained by using adaptive optics, represented by L1 and L2 in Fig. 2a. A feedback signal based on the green laser output power is used to drive the actuators.

Schematics of the operation and construction of the drive mechanism are shown in Fig. 2b [9,11]. The main components of the drive mechanism are the piezo element, driving rod, moving body, and the friction plate. The moving body is a U-shaped frame upon which the lens is attached. The driving rod sits in the U-shaped frame with friction plates on two sides and is clamped with a leaf spring. During operation, a rectangular waveform with a given voltage, frequency, and number of cycles is applied to the piezo element. The rectangular waveform is then converted to a sawtooth motion by the mechanical transfer function of the piezo. On the gentle upward slope, the rod carries the moving body due to friction ("stick" operation), while on the rapid falling slope, the rod "slips" due to inertia. The net displacement is the minimum movement of the drive mechanism. This is repeated until the desired amount of displacement is achieved [8,9,11]. The full displacement range is approximately 350 μm, and the minimum displacement per pulse is 30–50 nm. Aside from stick-slip motion, the drive mechanism also operates in dither mode, where the moving body oscillates around the average position [10].

Carbon fiber reinforced polymer (CFRP) is the material used as the driving rod in the drive mechanism. It is used as a component for a wide variety of engineering applications, such as for aircraft structures, automobile, and solar cells, among many others [12–16]. For the friction plate, stainless steel is used. For the moving body, Zn alloy, which is commonly used in automotive applications, is used as the die-cast part [17]. A chromium conversion coating could be deposited on the Zn alloy to enhance the corrosion resistance of the surface [18]. During assembly of the drive mechanism, the CRFP gets exposed to 120–150 °C several times over 3–4 h.