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High-reflectivity electromagnetic two-axis microscanner using dielectric multi-layer reflective surface

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ABSTRACT

A high-reflectivity electromagnetic two-axis microscanner is presented, which uses dielectric multi-layer coating on the aluminum film at the reflective surface. The microscanner is driven biaxially with the torque generated between the radially directed magnetic field and the current path through a single-turn copper coil patterned on the scanner. To enhance reflectivity, dielectric multi-layers of Al_2O_3 and TiO_2 films are coated on the aluminum reflective surface of the mirror. A reflectance of 96.31% was obtained by using two pairs of dielectric films at a wavelength of 850 nm. Laser irradiation tests were performed to measure the operational reliability of the microscanner. The temporal drift of the optical scan angle for the mirror with two pairs of dielectric layers was measured to be 0.16° during a 6-h operation using a femtosecond pulsed laser irradiation with an average power of 2.3 W and a high repetition rate of 80 MHz. However, for the mirror where the reflection surface was coated with an aluminum layer only, a 1.74° degradation of the tilting angle was observed.

1. Introduction

Up until now, various types of micromirror-based micro-electro-mechanical systems (MEMS) scanners have been studied and developed for applications, such as small form-factor projection display systems, biomedical imaging, optical switching, and microsensors [1–10]. Recently, the focus of research in MEMS scanners has been extended to new fields of application, which include light detection and ranging (LIDAR) systems. LIDAR is a remote sensing technology capable of measuring a wide variety of environmental characteristics, such as the distance and shape of an object, aerosol and cloud distribution, and terrain data using a coherent light source. Macroscale LIDAR systems have been utilized to obtain high-resolution digital elevation or terrain models, relative concentration and spatial distribution of aerosol and cloud particles, and information on the relative distance and shape for spacecraft navigation [11,12]. With the advances and progress of autonomous vehicle and robot technology, the need for a lightweight LIDAR system with a smaller form-factor, satisfying the requirement of a high-performance requirement, is ever increasing. As the conventional LIDAR systems, based on scanned laser sources and time of flight (TOF) sensors, typically rely on macro-scale motorized scanners, the reduction of size and weight has been challenging. Recently, MEMS scanners have been applied to the LIDAR systems to overcome these issues [9,10,13]. MEMS scanners can be excellent alternative to conventional motor-based scanning systems as they provide a cost-effective high-performance solution, with high performances such as 2 degrees of freedom (DOF) scan capability, high scan speed, and large scan angle. The long-term reliability of MEMS scanners have also been verified for projection display system applications. Although, results from feasibility testing for integrating MEMS scanners in a LIDAR systems have been reported, more research on the application-specific designs of the MEMS scanners is required. For instance, micromirrors used in LIDAR systems have relatively large diameter compared to those used in other applications, such as in projection display systems and biomedical imaging, to cover the larger diameter of the higher power laser beam [9,10]. However, a high-reflectivity mirror, which can withstand a high-power laser beam, is required for the MEMS scanner to be compatible with a LIDAR system with a long-range measurement capability. Even for typical LIDAR systems, which do not require significantly long measurement range could can benefit from the high- reflectivity of the mirror surface.

In a previous study [14], we realized an electromagnetically actuated biaxial scanning micromirror and analyzed its performance. A 2-DOF motion of the micromirror is achieved by using

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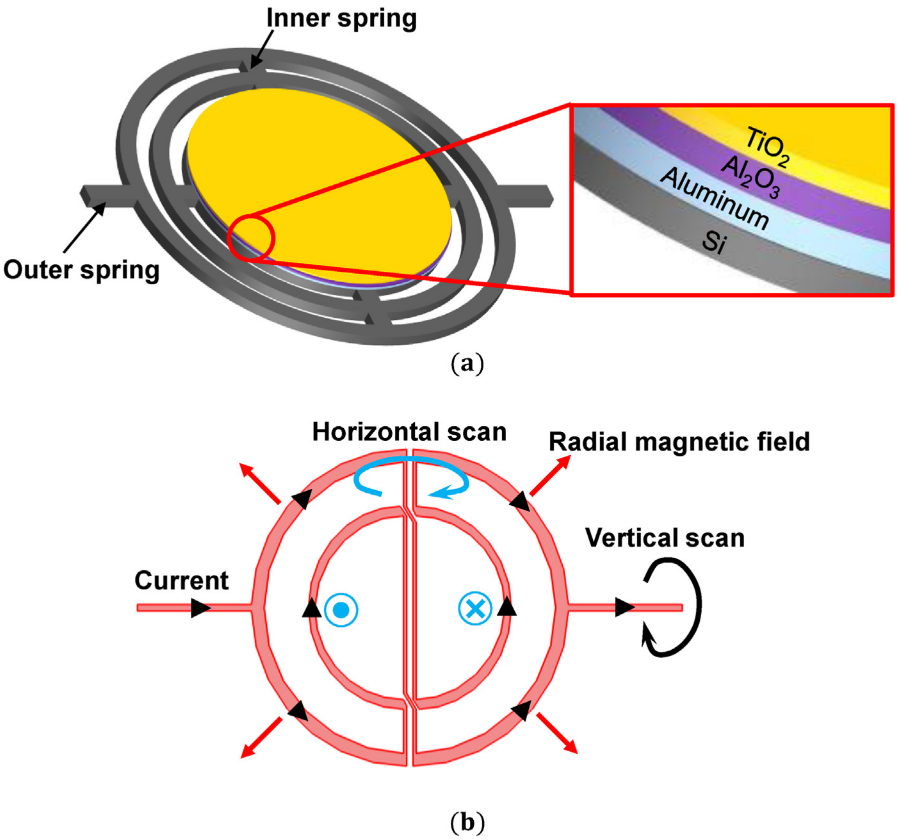

Fig. 1. (a) Schematic view of the two-axis microscanner and reflective mirror surface and (b) coil pattern on the backside of the mirror surface and two-axis operation scheme using radial magnetic field.

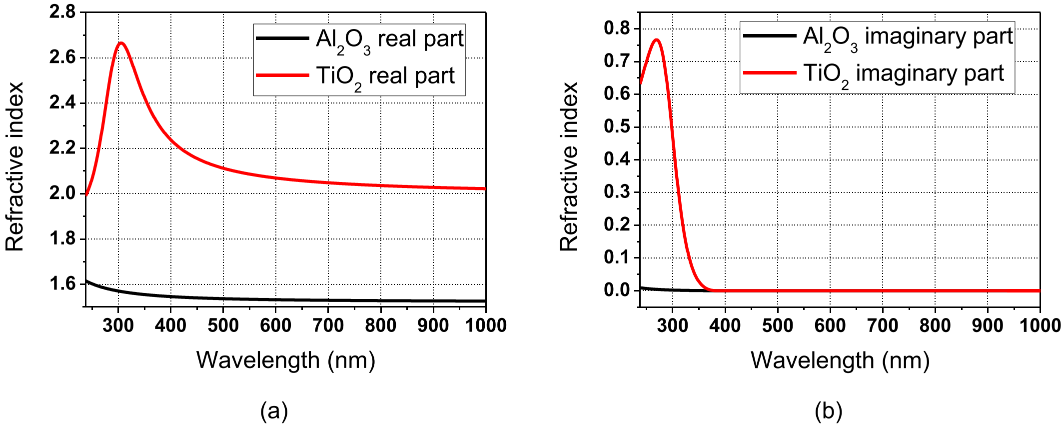

Fig. 2. Measured refractive index of Al_2O_3 and TiO_2: (a) real part and (b) imaginary part.

the Lorentz force between the current in the coil, integrated onto the mirror and the radial magnetic field generated by the external magnet assembly. We also realized an indirect TOF-type LIDAR system, with a successful test of the fabricated micromirror and distance measurement [15]. If a high-power laser can be applied to this LIDAR system using MEMS scanner, improvement in the distance measurement and better accuracy can be achieved. However, damage to the mirror surface due to the high energy density of the laser results in a scattered reflection, which can be a critical problem for the LIDAR system. Therefore, the improvement of the reflectivity of the micromirror is required, without compromising the fundamental performance.

Using a multilayer dielectric film is one of the well-known solutions to improve the reflectivity and has been applied to various high-power laser applications [16–19]. Furthermore, the addition of a metal layer between the dielectric films and the substrate is an efficient method to decrease the deposited number of dielectric films [20]. Previously, a laser surgery machine using scanning micromirror and a high-power 532-nm picosecond laser with a maximum average laser power of 20 W was presented, employing a multilayer dielectric film on an Ag metal film [21]. An electrostatically driven micromirror was used, which required high driving voltage, and vacuum packaging as well, to substantially increase the scan angle.