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Preparation and frictional investigation of the two-components silanes deposited on alumina surface

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ABSTRACT

Functionalization and pattering technique that permits two-component pattern-specific modification of alumina surface with silanes molecules are reported. The method relies on a two-component molecular system that simultaneously decreases coefficient of friction of the alumina surface and provides uniform chemical functionality suitable for further elaboration. Pattern/two-component modification is achieved via gas-phase deposition of the silanes using polydimethylsiloxane stamp. The frictional behaviors of the two-component films of the silane molecules with different chain length covalently absorbed on alumina surfaces, were characterized by the ball-disk (microtribometer) tester. The surfaces of the substrate modified by two-component molecular films were examined by atomic force microscopy (AFM). The measured tribological results showed that the mixing of the fluoroalkylsilane and alkylsilane enhance the lubrication and decrease the friction compared to the one-component thin films.

1. Introduction

The miniaturization of almost all types of devices and systems is a common practice in an electronic, engineering, automotive industry as well as opportunity of a commercial profit and technological advances. The real effect of a miniaturization in industry is micromechanical systems' (MEMS). MEMS are defined as devices and systems on the scale of micrometers or nanometers and also technologies which can be used to produce some complex structures [1]. The use of MEMS technology allows many types of devices to be reduced in size by orders of magnitude (e.g. inertial sensors, optical switch arrays, biochemical analysis systems) [2–4]. Friction and adhesion are crucial aspects that control the efficiency and the durability of MEMS [5].

In the case of MEMS wear can cause some limitations in their production and potential usage. For the purpose of better mechanical and chemical properties, MEMS surfaces are modified and protected by lubricants. One group of the lubricants which is used in MEMS are organosilane compounds. Monomolecular films' formation based on organosilanes is one of the strategies that is used for minimizing stiction, adhesion and friction [6,7].

A growing appreciation for the potential impact of MEMS and limitations in exploitation of microelectronic devices are the reasons for investigations concerned with the tribological properties of organosilanes films on some surfaces, such as silicon, aluminum, titanium, which are used for MEMS production.

One of the methods that is used in solving problems which are caused by both the development of a modern technology and the appearance of a miniaturized microelectromechanical systems, is the use of a vapor phase deposition method and multiple patterned chemical functionalities (two-component films) [8–10]. With regard to above reasons, this paper undertakes the theme that aims at producing two-component organosilane films on the alumina surface which are very promising for micro- and nanofabrication technologies future.

Presented work will allow to define an influence of the received films' structure on the frictional properties of alkylsilane film/surface systems. Obtained results will enable indicate alkylsilanes that provide the best frictional properties of produced two-component films, which in the future may be used as lubricants for micro-/nanoelectromechanical systems.

The innovative nature of the presented problem manifests in the fact that the obtained film consist of two-components with different structure composition. An element of novelty is also applying the method of vapor phase deposition to produce the two-component films and perform friction tests in the milinewton load range. These test are bridge between the measurements obtained in the nano- and macro scales. So far, based on the vapor phase deposition method the one-component alkylsilane films were obtained and characterized.

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2. Experimental

2.1. Materials and sample preparation

The micropatterned silicon matrix with micro-scale features was created by photolithography [11,12]. Polydimethylosiloxane (PDMS) resin and curing agent (Sylgard 184) were purchased from CH Erbslöh and fabricated by mixing PDMS resin with a curing agent at a 10:1 ratio. The mixture was stirred thoroughly and poured over the micropatterned silicon matrix and were placed in a vacuum desiccator to remove bubbles. Next the PDMS was cured at a temperature of 50 °C for 48 h. After curing, the PDMS molds were removed from the matrix and cut into pieces of desired size and stored in desiccator (Fig. 1a).

Polycrystalline aluminum film with the thickness of 100 ± 2 nm was deposited on naturally oxidized p-type Si (1 0 0) wafers, using the process of thermal evaporation at an incidence angle of 0° (with respect to the surface normal) in a system maintained at a base pressure of about 10^{-3} Pa [13].

The 1H,1H,2H,2H-perfluorodecyltrichlorosilane (FDTS), (3,3,3-trifluoropropyl)-trichlorosilane (FPTS), and *n*-decyldimethylchlorosilane (DDMS) were purchased from ABCR, GmbH & Co. KG, Karlsruhe. These chemicals were chosen because of their ability to be deposited as a monolayer which is favorable for coating inside the microchannels and to compare the effect of the structure on frictional performance at the microscale.

Modification procedure in case of one-component film was as follows: the alumina surface activated by oxygen plasma was placed into a vapor phase deposition system and kept under low pressure (0.1 Pa) for 30 min. Then the sample was kept in the modifier vapor from 30 min to 1 h (depending on the used compound) at room temperature and finally outgassed at low pressure for 1 h at 40 °C to remove any of physisorbed and unreacted molecules [13]. For two-component films modification procedure proceeded as follows: the alumina surface activated by oxygen plasma to remove organic contaminants and generate hydroxyl groups. The alumina surface activated by oxygen plasma was covered with PDMS stamp and placed into a vapor phase deposition system and kept under low pressure (0.1 Pa) for 30 min. Next the sample was kept in the modifier vapor 1 h at room temperature and finally outgassed at low pressure for 1 h at 40 °C to remove any of physisorbed and unreacted molecules. In this first procedure step organosilane compound was selectively transferred onto the parts of the alumina substrate in a place where the stamp does not makes a direct contact with it. A second molecules transfer onto the surface were also be leaded from a gas phase when the stamp was removed from the substrate. Modification was carried out in the same parameters as previously.

In this way, molecules were transferred in a pattern that is defined by the topography of the stamp with a width about micrometer (Fig. 1b). All the samples after modification procedure were removed from the vacuum chamber and transferred into a vacuum desiccator until characterization.

2.2. Surface characterization

The two-component alkylsilane thin films were characterized using atomic force microscopy (Solver P47 apparatus (NT-MDT) operating in air under ambient conditions) for surface morphology and root mean square (rms) roughness values. Images were typically obtained in the tapping mode using silicon nitride cantilever

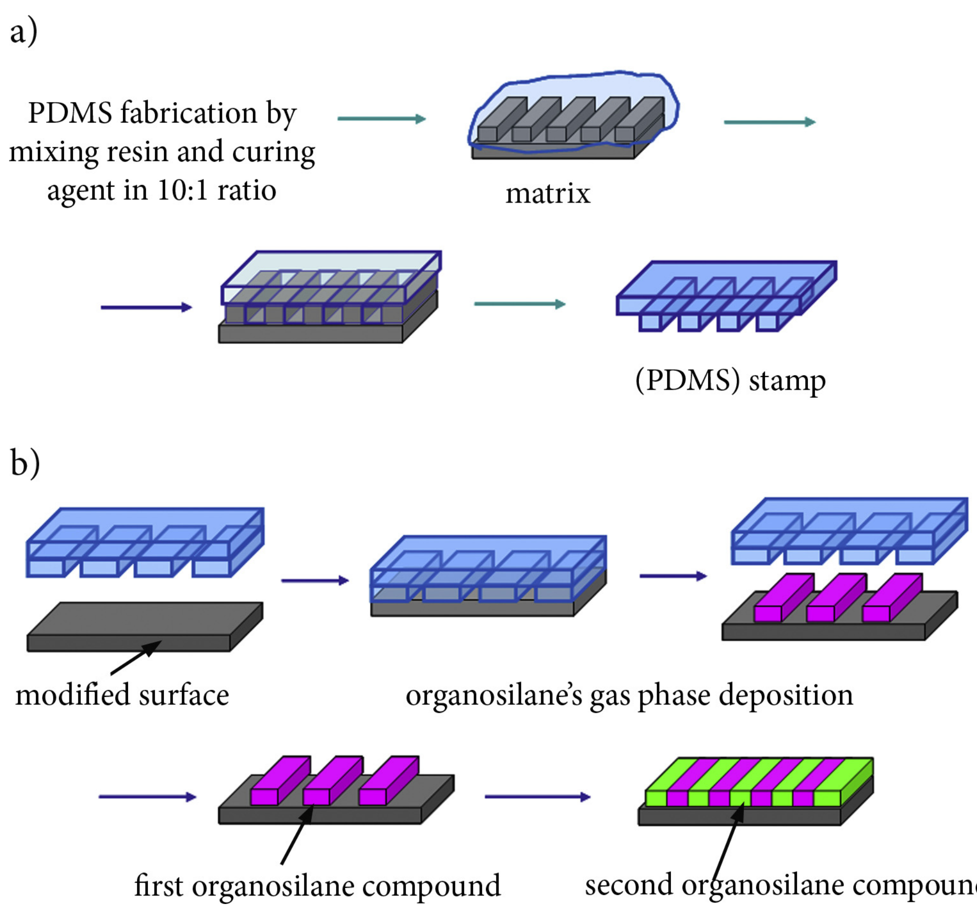

Fig. 1. Scheme of the polydimethylsiloxane stamp preparation procedure (a) and the modification procedure of the surface by two-component films (b).