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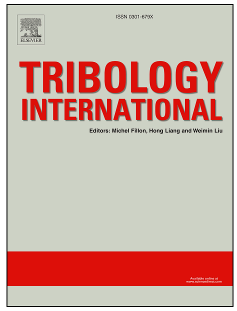

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Damage of Functionalized Self-Assembly Monomolecular Layers Applied to Silicon Microgear MEMS

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Abstract

Tooth surfaces of silicon-based MEMS microgears are described as smooth surfaces covered by adhesive asperities (nanoblocks). To reduce adhesive effects, the tooth surfaces are functionalized by OTS-SAM (Octadecyltrichlorosilane self-assembly monomolecular) carbon-based functionalized coatings. The wear of the coating is modelled using the modified Goryacheva-Torskaya model of damage accumulation. The amount of energy dissipated by different physical and chemical mechanisms along with energy dissipated by mechanical deformation of the counterparts is used to evaluate the frictional force. The main scenarios of wear process within the coating are described and discussed. The damage evolution is described for several levels of external load

Keywords: fatigue wear; adhesion; friction; sliding.

1. Introduction

Micro-Electro-Mechanical Systems (MEMS) can be of various kinds depending on the specific industrial or space applications [1-4]. MEMS consist of a significant number of micro/nano components and the majority of them work in contact with each other to transfer the load and torque between MEMS parts. Adhesion is the key issue for the MEMS devices that highly restricts the movements of the micro/nano elements [5, 6]. Here we defined stiction as the unintentional adhesive connection between the teeth that does not allow MEMS to work at all. Stiction may lead to structure failure or significantly reduces the MEMS reliability [7, 8]. Adhesive interactions between surfaces may be greatly affected by environmental conditions. Here we focus on clean MEMS surfaces working in the vacuum environment when one of the leading mechanisms of stiction is cold welding (cohesion) between micromachined surfaces, while the capillary adhesion and effects of gaseous environment are out the scope of this study. If the teeth of a microgear MEMS are simulated as working in the vacuum environment then, the mechanisms of the energy dissipation may be reduced to the following: (i) dissociation of chemical and van der Waals bonds, and (ii) the elastic interlocking between counterpart's proturberances. One of the successful solutions that allows the researchers to reduce cohesion and, therefore, to eliminate stiction is surface functionalization [1]. Carbon-based functionalized coatings have commonly been used in friction and sliding conjunctions to improve the lifetime expectations of the surfaces. Many researchers have tried to investigate and model this problem to reduce the effect of friction and wear on the contacting surfaces [8, 9]. Tribology of self-assembled monolayers has been intensively studied in many papers (see, e.g. [10-15]). Indeed, the adsorbed organic molecules that are organized into oriented layers may drastically change the surface properties of contacting solids. It was observed experimentally that friction of surfaces covered by molecular self-assembled monolayers has anisotropic properties [10]. It was also shown that thin diamond-like carbon films covered by octadecyltrichlorosilane self-assembled monolayers exhibit considerable reduction of friction due to its ultra-low surface energy and special film structure [14]. If such a layer is used to cover titanium films then they exhibit hydrophobic and improved tribological properties [15]. The properties of monomolecular layers can be studied both theoretically [16-18] and experimentally [10-13]. It was shown that for a single-crystal strip, the Young modulus increases with decreasing thickness of the strip; in particular, the elastic modulus of a very thin crystal film consisting of two atomic layers can differ from its macroscopic value by a factor of two [17]. It is clear that the functionalized coatings may be worn away; therefore, studies of wear of the functionalized layers are of great importance for modern nano/micro technology.

Self-assembled monomolecular (SAM) layers are often used to functionalize the silicon surfaces of the microdevices. Generally, the SAM layers are formed by exposing silicon substrate to the vapour phase of the desired molecule and incubation for some time. Here we will study OTS-SAM (Octadecyltrichlorosilane SAM)