Wear 274–275 (2012) 43–49

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

The pairing-dependent effects of laser surface texturing on micro tribological behavior of amorphous carbon film

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ARTICLE INFO

Article history:
Received 14 February 2011
Received in revised form 23 July 2011
Accepted 4 August 2011
Available online 11 August 2011

Keywords:
Amorphous carbon
Laser surface texturing
Micro-tribology
Graphitization

ABSTRACT

In this paper, a kind of textured amorphous carbon film with the pattern of micro dots matrix was developed by irradiating amorphous carbon film with Nd–yttrium aluminum garnet laser system. Confirmed by the characterizations is that the produced micro dots are protuberant and in nanocrystalline graphite phase with a porous structure and reduced hardness. The micro tribological behavior of textured film was studied experimentally using steel balls and Si_3N_4 balls as the counter body. It turns out that the influences of laser treatment on the tribological performance of amorphous carbon film are strongly dependent on the friction pairs. By specially probing into the effects of localized micro graphite bulges, possible friction reduction mechanisms are discussed.

1. Introduction

Micro-tribology which investigates tribology at micro scale has been intensively studied over past years due to broad application of Microelectromechanical systems (MEMS) such as sensor technology, medical appliances, mechatronics, etc. Due to low force applied to such systems and high surface to volume ratio, surface forces such as adhesion and friction could dominant the performance inducing undesirable effects which reduce the operational reliability [1–4]. Recently, there has been a great deal of interest in various types of surface coatings to improve the micro tribological performances of substrate materials. In micro-systems, the tribological requirements of low friction, low wear, and low stiction must be simultaneously met [2]. The organic layers like self-assembled monolayers to reduce in-use adhesion can alleviate the friction of MEMS to a certain degree. However, practical application of this method is quite limited owing to the degradation of organic layers and their poor durability in operating conditions [5–7].

Hard coatings have been explored to reduce friction and wear of MEMS devices. The main idea is to coat the device surfaces with high modulus/hardness and wear resistant materials. The intrinsic hardness of these materials typically gives lower friction (because of reduced contact area) and wear, as well as much higher durability than organic films [6]. One of the most actively investigated hard coatings is amorphous carbon (*a*-C), which is already successfully used in magnetic hard disk data storage systems [3,5,8–12]. In MEMS electrostatic motor tests, the *a*-C coated devices outperform the uncoated devices by two or three orders of magnitude in operation time [9].

Besides the selection of the coating material, further optimization could be attained by texturing the devices surfaces to enhance micro tribological properties. A decrease in real contact area caused by surface texturing could decrease adhesion and friction of the material [6,13,14]. For instance, surface roughness of rigid disk surfaces is optimized in the landing zone to minimize stiction and friction. Studies to identify an optimum pattern shape and the relationship between the optimum distributions of textured units as a function of various unit shapes have been conducted by Bhushan [15].

To combine the advantages of protective tribological coatings and the beneficial effects of surface texturing, coatings with well-defined surface structure have been prepared. Improved tribological performance of conventional coatings caused by surface texturing in both micro and macro scale have been reported by several authors. In macro scale, it is suggested that the produced patterns could act as reservoirs for lubricants and trap wear debris to reduce wear due to third bodies trapped at the sliding interfaces [16–18]. In micro scale, Bandorf et al. investigated the micro tribological behavior of *a*-C film with well-defined surface structure. It turned out that an optimized structure size existed resulting in minimum friction coefficient. Also, the counterpart must be considered for optimization [14,19].

Recently, it is reported by us that nanosecond laser pulse could produce specific patterns on *a*-C film [20]. The topography of

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doi:10.1016/j.wear.2011.08.008

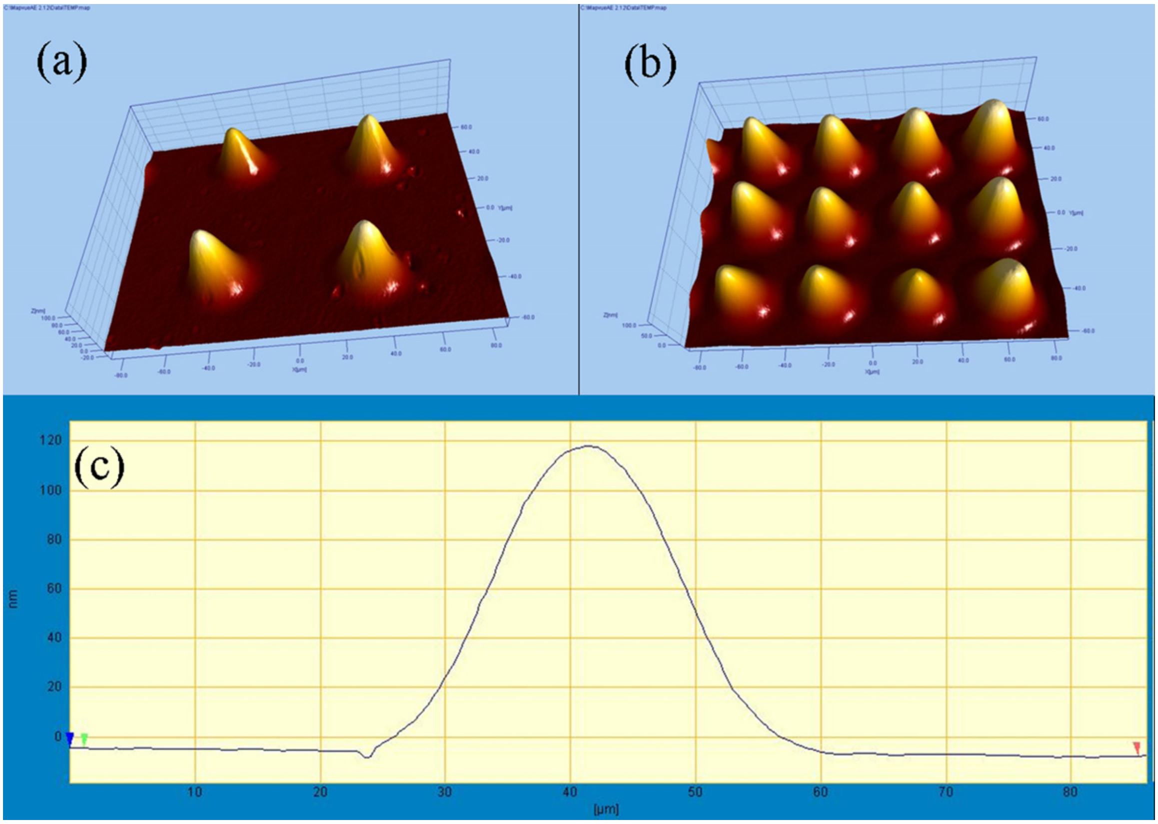

Fig. 1. 3D images and profile data of irradiated dots on *a*-C film.

produced pattern could be micro bulge or micro pit depending on different pulse power density. Additionally, besides the change in morphology, localized nanocrystalline graphite (*nc*-G) was produced in the irradiated spot which exhibiting different phase structure and mechanical properties from the original *a*-C film. However, to our knowledge, there is less work to specially investigate the influences of such localized nanocrystalline graphite dots on the micro tribological properties of *a*-C film.

In this paper, the textured *a*-C film with the pattern of micro dots matrix was prepared by a Nd–yttrium aluminum garnet laser system. The aim of this research is to investigate the influences of laser treatment on micro tribological behavior of *a*-C films. By specially probing into the effects of localized nanocrystalline graphite bulges induced by laser, possible friction reduction mechanisms are discussed.

2. Experimental details

2.1. Deposition of a-C films

The *a*-C films were prepared on a single-crystal *p*-Si (1 0 0) wafer by a magnetron sputter deposition system. Before deposition, the substrates and targets were cleaned by the Ar plasma in sequence. For the deposition process, a Ti transition layer was needed to enhance the adherence. A potential of −500 V was applied to the substrates when the Ti transition layer was deposited. The used *a*-C film was deposited using graphite target as the carbon source with a bias voltage of −300 V. The pressure during the deposition was about 0.5 Pa, and the deposition time was 120 min.

2.2. Laser irradiation of a-C films

The prepared *a*-C coating was ablated a with a Nd–yttrium aluminum garnet laser system delivering pulses 4 ns with a wavelength of 1064 nm at a frequency of 10 kHz. The laser beam was focused with a glass lens ($F = 10$ cm) into a spot with a diameter of 67 μm and each spot was irradiated by incident pulse for one time. The fluence was tuned to 21 mJ/cm^2 at which the micro bulges pattern could be produced on the *a*-C film. The morphology of ablated film surface was examined by field emission scanning electron microscopy (FESEM) and optical profiler (MicroXAM 3D). Laser-induced structural modifications were studied by means of Micro-Raman spectroscopy (Ar$^+$ laser, $k = 532$ nm) and Nanoindentation (Nano Indenter II, MTS Ltd., US).

2.3. Tribological evaluation

The micro tribological behavior was tested on a UMT-2MT tribometer (CETR, USA) at room temperature with a relative humidity of 25–30%, using a reciprocating ball-on-disk mode. Two kinds of upper ball were used: AISI-52100 stainless steel balls and Si_3N_4 balls (diameter 6 mm). Although micromotors usually deliver forces well below 1 mN, a reasonable level of contact load involved in MEMS is reported in the range of 1–1000 mN, the necessary one for force or torque measurements [21]. Therefore, the tests were performed under the loads of 100, 300, 500 and 1000 mN at constant sliding velocity of 10 mm/s for 30 min. After test, scan electron microscopy (SEM) and optical profiler (MicroXAM 3D) were used for morphology characterization. In order to investigate structural variation of the *a*-C films during friction, the Micro-Raman spectroscope was performed on as-deposited film and wear tracks.

3. Results and discussion

3.1. Characterization of patterned a-C film

Fig. 1 shows the 3 dimension (3D) images of irradiated dots on *a*-C film in different distribution. As illustrated in Fig. 1(a and b), the