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Conversion of organic films into fluorine-containing onion carbon as anti-adhesion solid lubricants

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ABSTRACT

Coating a thin-layer solid lubricant with low adhesion and friction is desired for silica-based micro/nano electromechanical systems (MEMS/NEMS). Onion carbon is a promising one, especially fluorine-containing onion carbon with low surface adhesion. Herein we report a new route to synthesize fluorine-containing onion carbon (FOC) through carbonizing electrophoresis-deposited organic films. A little fluorine (1.65–3.64 at.%) could manyfold decrease the surface adhesion. The optimized FOC integrates the merits of fluorine doping and onion carbon, presenting ultralow surface adhesion (2.72 nN) and friction coefficient (0.03). These results suggest that this strategy is a promising approach to fabricate the desired solid lubricants for MEMS/NEMS.

1. Introduction

Energy saving is a concerned topic, also a considerable challenge for sustainable economic growth [1]. Friction reduction benefits to save energy and prolong life for mechanical products from macro-scaled assemblies to micro/nano electromechanical systems (MEMS/NEMS) [2]. The traditional liquid lubricating oils/greases are proper lubricants for the former but not suitable for the latter because of their high viscosities [3]. Coating a thin layer of solid lubricant on the surface is an effective solution for MEMS/NEMS [4,5]. Onion carbon, a typical solid lubricant with low friction, high stability, and strong mechanical properties, has been regarded as a promising candidate [6–9]. Whereas onion carbon usually presents relative high surface energy [10,11], which is not in favor of the lubrication between the micro/nano-scaled moving parts in MEMS/NEMS.

Introducing fluorine into carbon lubricants is beneficial to reduce surface adhesion and friction [12–15]. For instance, the fluorine-containing fullerene-like carbon with a fluorine content of 4.34% effectively reduced surface adhesion and presented low friction performances [16]. In previous studies, we had developed an anodic electrophoresis method to prepare heteroatom-containing (e.g., H, Cl, F, N, and S) carboxylic-acid molecular films using carboxylic acids as precursors [17,18]. Based on these gains, in this study we report a new method to synthesize fluorine-containing onion carbon (FOC) through annealing electrophoresis-deposited trifluoroacetic acid (TFA) molecular films. With the thermal decomposition of carboxylic groups in TFA films, their structures transformed from the relatively disordered polymer texture into the fluorine-containing carbon structure. The optimized FOC integrates the merits of fluorine doping and onion carbon, presenting low surface adhesion, friction coefficient, and wear, indicating that this strategy is a promising approach to construct advanced anti-adhesion solid carbon lubricants for silicon-based MEMS/NEMS.

2. Experimental

Fig. 1 shows the preparation of FOC. The zeta potential of TFA decreases from −2.0 to −7.5 mV with increasing concentration (Fig. 1a), and the ionic conductivities increase from 0.07 to 0.52 mS/cm (Fig. 1b), indicating the good ionization of TFA in aqueous solution (i.e. CF_3COO^- and H^+). The negatively charged CF_3COO^- can be migrated and deposited on the anodes under electric fields. Accordingly, two silicon wafers with the distance of 0.5 cm are immersed in TFA solutions as anode and cathode, respectively (Fig. 1c). The TFA molecular films deposited at 20, 25, 30, 35, and 40 V can be obtained on the anodic silicon wafers,

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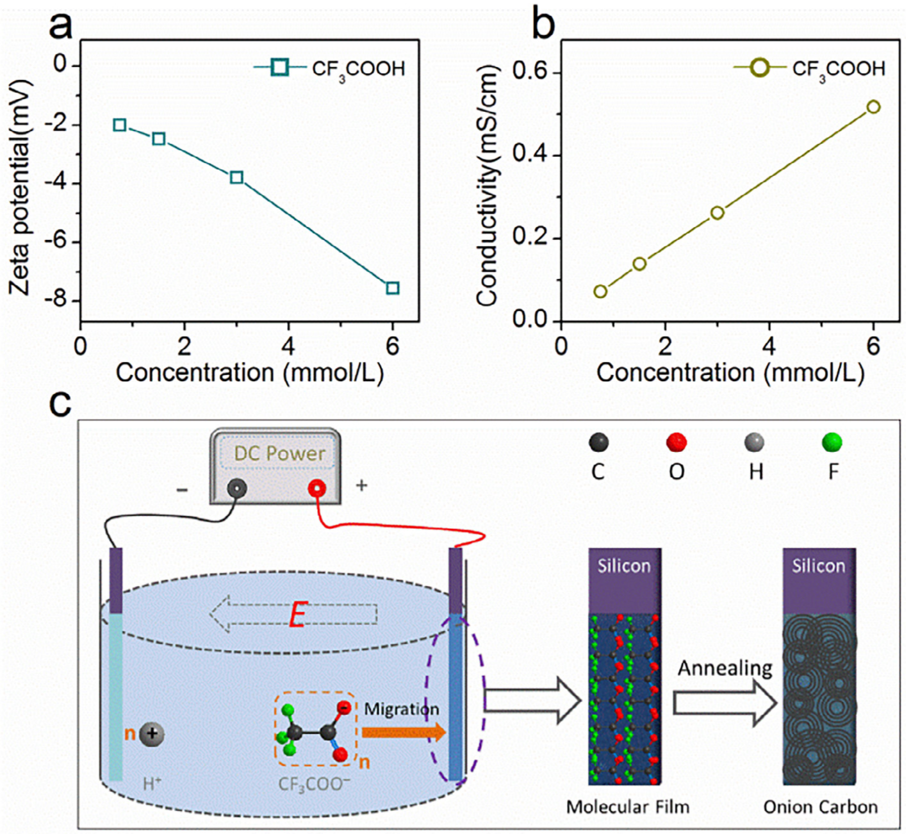

Fig. 1. (a) Zeta potential versus TFA concentration; (b) conductivity; (c) schematic diagrams of preparation route.

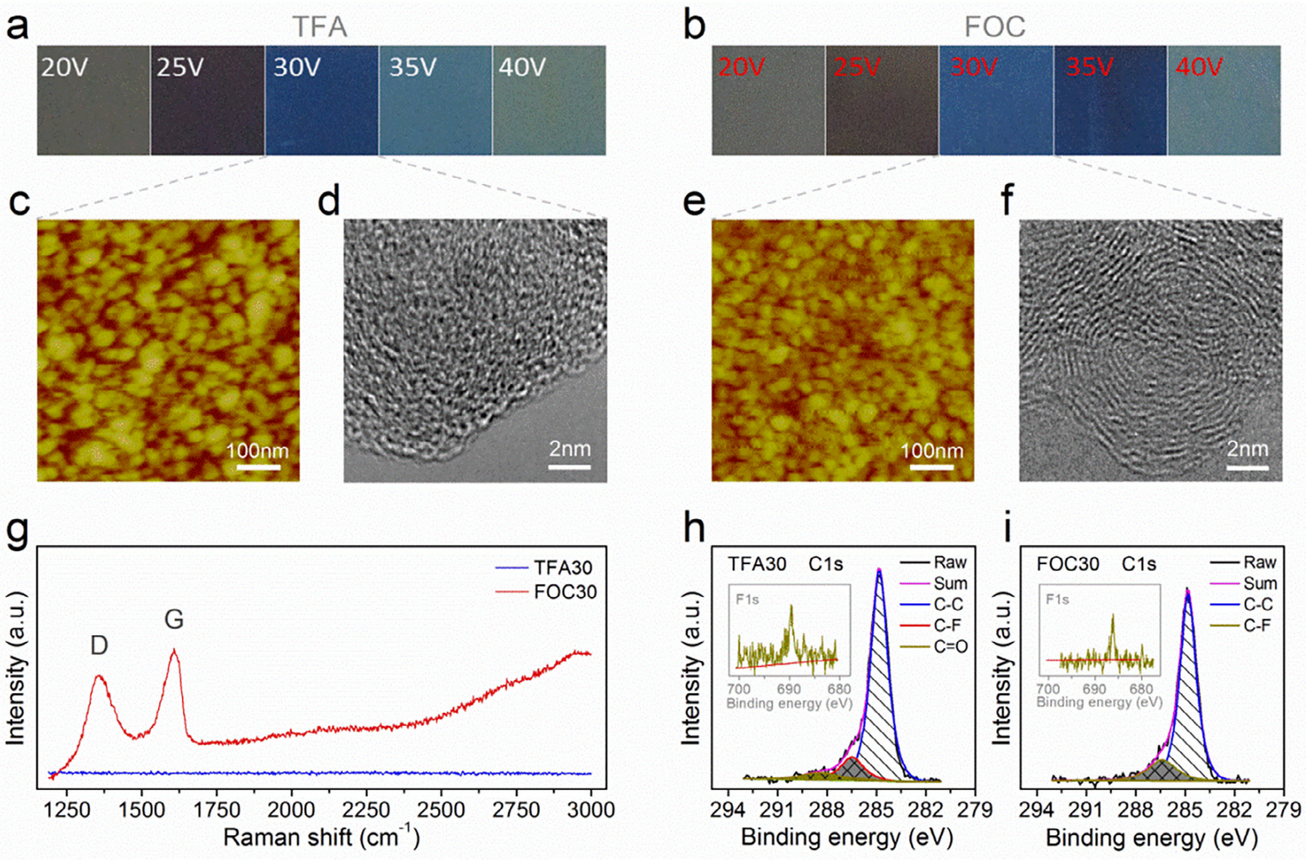

Fig. 2. Characterizations of TFA30 and FOC30. (a, b) Optical images; (c, e) AFM; (d, f) TEM; (g) Raman spectra; (h, i) XPS spectra.