Improvement of Wear Resistance of Electrcial Contact Surface by utilizing Nano-structured Coating

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1. Introduction

Today, several machines and electronic devices rely on electrical contacts to transmit signals and power for their operation. These contacts may undergo periodic contact and relative motion, depending on their types. The electrical contacts experiencing relative motion such as terminals of memory cards, brushes in DC motors, and pantographs in railway vehicles can be referred to as sliding electrical contacts. One of the issues regarding the sliding electrical contacts is the degradation of their performance as electrical contacts due to surface wear, formation of metal bridge, and oxidation caused by continuous contact and friction [1]. In the automotive industry, it is known that a single vehicle can contain around 400 types of sliding electrical contacts. Connectors that may experience fretting due to vehicle vibrations, even without intentional relative motion, can also be considered a type of sliding contact. Among the failure cases related to electrical contacts in actual vehicle operations, about 30% are reported to be caused by poor contact due to wear of the contacts [2]. In the telecommunications industry, there has been a growing focus on the research and application of RF MEMS switches, driven by the increasing demand for high-bandwidth communication. Compared to active components like transistors and diodes, RF MEMS switches offer superior characteristics in terms of insertion loss, linearity, bandwidth, and power consumption. These advantages are expected to drive rising demand in high-value industries such as 5G communication, defense radar systems, and the Internet of Things (IoT). However, as the switching frequency increases at high frequencies, material transfer phenomena such as softening, adhesion, cold-welding, and metal bridge formation can occur at the contact areas on the substrate. This results in a reduction of the actual contact area between the two surfaces. When current flows through these limited contact points, it can become highly concentrated, leading to excessive heat generation on the substrate surface and potentially causing the contact to melt. Therefore, ensuring the reliability and lifespan of these electrical contacts is essential [3,4].

In order to resolve the problems, several researchers have focused on applying materials or coatings with high hardness and melting point. However, a potential drawback of this approach is the reduction in actual contact area due to the high hardness and elastic modulus, which in turn leads to an increase in contact resistance. Additionally, the surface roughness of such hard materials can lead to abrasive wear caused by asperities, making it challenging to control wear. Previous studies aimed at improving the durability and performance of electrical contacts have explored various methods. These include creating composites using metals and graphite, increasing the number of electrical contacts to reduce contact resistance , and utilizing noble metals like gold, rhodium, and platinum, which exhibit excellent electrical conductivity, low shear strength, and solid lubrication characteristics . However, these approaches have limitations and may not provide a fundamental solution to the durability issues encountered in electrical contacts. Therefore, there is a need for new approaches that can ensure electrical conductivity, wear resistance, and stable contact behavior [5-7]. In this work, carbon nanotubes and metal thin film and nanoparticles were utilized to improve wear resistance and ensure adequate characteristics as an electrical contact.

2. Experimental setup

To fabricate a durable electrical contact, carbon nanotubes were coated onto a Si wafer by spin coating method. The dip-coating process, utilizing a suspension of carbon nanotubes mixed with metal nanoparticles, resulted in a coating characterized by a randomly entangled network of carbon nanotubes with embedded nanoparticles. To protect the surface, a relatively mechanically strong chromium thin film was deposited, followed by the deposition of a soft silver thin film to enhance lubrication properties. The metal deposition processes were carried out using sputtering method. To investigate the tribological properties of the specimens, friction tests were conducted using a tribometer. The friction tests over tens of thousands cycles were performed at least five times for each specimen to quantitatively compare and evaluate the differences in friction and wear characteristics with respect to the fabrication conditions. To assess the electrical properties of the specimens, sheet resistance was measured using a 4-point probe method.

3. Results and discussion

The sheet resistance measurements revealed that there was little difference in sheet resistance between the nanostructured surface fabricated with CNTs and a conventional metal thin film. The measured sheet resistance of those specimens was approximately 0.1 ohms per square, indicating a sufficiently low resistance for use as an electrical contact. The friction test results showed that the specimens coated with CNTs exhibited a slightly higher coefficient of friction compared to those with only a metal thin film. The higher coefficient of friction in the nanostructured coating consisting of CNTs is likely attributed to the lower mechanical stiffness caused by the porous structure of the CNT coating. On the other hand, the nanostructured surface containing CNTs demonstrated significantly superior wear resistance compared to the metal thin film. While the metal thin film gradually wore out during the friction tests, the nanostructured surface showed little to no wear under certain conditions. Moreover, when measuring electrical resistance before and after the tests, the metal thin film showed a significant increase in resistance after the experiment, whereas the nanostructured surface exhibited almost no change in resistance. This indicates that the nanostructured surface has superior durability and reliability as an electrical contact.

4. Conclusions

In conclusion, we proposed a nanostructured surface, which resulted in a coating with excellent wear resistance and electrical properties. The nanostructured surface consists of CNTs and metal nanoparticles, combined with a functional coating that provides durability and lubrication properties. The excellent mechanical properties of this nanostructured surface are attributed to the elastic recovery characteristics of the coating. Given the minimal wear observed, it is anticipated that this technology could be applied to electrical contacts subject to repeated connections and disconnections, as well as to dynamic components in precision mechanical systems.

References

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