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RADIOFREQUENCY-SPUTTERED COATINGS FOR LUBRICATION SYSTEM COMPONENTS AND OTHER COMPLEX SURFACES

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16. Abstract

Irregularly shaped surfaces, such as lubrication system components (ball bearings, seals, gears, etc.), can be coated on all surfaces, including irregular shapes, when radiofrequency sputtering is used. When the specimen is properly located with respect to the sputtering target, the sputtered material covers the entire surface of the object irrespective of its geometrical configuration. An adherent, dense film is formed. The film thickness varies from 20 to 50 percent on, for example, a bearing cage or race depending on its geometry. When sputtered solid film lubricants such as molybdenum disulfide are used, a film thickness only of the order of 10^{-7} m (thousands of angstroms) is required at the contacting areas. It is only essential to determine the required film thickness at the critical areas in need of lubrication. The sections outside the areas to be lubricated fall within the thickness deviation range of 20 to 50 percent, which still constitutes a negligible change with respect to tolerance requirements.

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SUMMARY

Irregularly shaped surfaces, such as lubrication system components (ball bearings, seals, gears, etc.), can be coated on all surfaces, including irregular shapes, when radiofrequency sputtering is used. When the specimen is properly located with respect to the sputtering target, the sputtered material covers the entire surface of the object irrespective of its geometrical configuration. An adherent, dense film is formed. The film thickness varies from 20 to 50 percent on, for example, a bearing cage or race depending on its geometry. When sputtered solid film lubricants such as molybdenum disulfide are used, a film thickness only of the order of 10^{-7} meter (thousands of angstroms) is required at the contacting areas. It is only essential to determine the required film thickness at the critical areas in need of lubrication. The sections outside the areas to be lubricated fall within the thickness deviation range of 20 to 50 percent, which still constitutes a negligible change with respect to tolerance requirements.

INTRODUCTION

Direct-current (dc) and radiofrequency (rf) sputtering techniques are generally used to deposit adherent, thin films on planar surfaces, and it is commonly indicated that sputtering is a line-of-sight coating method (ref. 1). Most of the commercially available sputtering units are designed with a substrate platform which can accommodate planar-sheet type specimens like wafers for coating the surfaces directly facing the target. The dimensions of the substrate plate are usually slightly less than the diameter of the corresponding bell jar, and the plate is generally located a few centimeters from the target and has a very limited vertical movement. This configuration of the sputtering apparatus is strictly designed for coating surfaces of specimens which are in direct line of sight with the target. However, complex geometric specimens can be coated when radiofrequency sputtering is used by mounting the specimen in such a fashion that the specimen is essentially immersed in the glow discharge a relatively short distance from the target.

All sides of the specimen must be exposed to the plasma sheath. This is accomplished by using specimen holders which make minimum contact with the specimen and have no shielding effects. Under these conditions, all surfaces of complex geometrical objects can be entirely coated, including surfaces which are not in direct line of sight with the sputtering target.

RADIOFREQUENCY SPUTTERING

The present state of knowledge of rf sputtering has been described in detail (refs. 1 and 2). The purpose of this report is to describe and illustrate how geometrically complex surfaces can be completely coated while the specimen is kept stationary. Many aspects and characteristics of the glow discharge phenomena are still not reliably established, especially the form in which sputtered atoms or molecules are transported through the vapor phase. It is known that a large number of energetic particles (electrons, ions, and neutrals - sputtered particles) are liberated from the target and propelled toward the specimen. When sputter coating techniques are described, it is generally implied that the sputtered material travels in a line of sight. This concept is true only when dc sputtering techniques are used. Therefore, it is important to distinguish between the plasma characteristics created by dc and rf potentials. In dc sputtering, a voltage of 500 to 5000 volts may be applied between a cathode and an anode, and this is sufficient to generate plasma and induce sputtering. The sputtered material under these conditions has a tendency to travel in straight lines, with the exception of weak backscattering effects.

The mechanism of generating an rf plasma is different from that for a dc plasma. A high-frequency potential (in the low megahertz range) is applied to the electrode onto which the target is bonded. The plasma is produced by the radiofrequency fields, which accelerate the plasma electrons to ionizing energies, and the plasma is localized in the target region.

APPARATUS AND PROCEDURE

The sputtering apparatus used for coating complex geometrical objects is shown schematically in figure 1. It consists of an evacuated chamber with the appropriate fixtures and two independently operated power systems: power for rf sputtering and dc sputtering. The dc sputtering process is used strictly for cleaning or sputter etching of the specimen before rf sputter coating. It can also be used for biasing the specimen during rf sputtering. The rf diode mode is for sputter deposition. The system is thus capable of sequential substrate cleaning or etching and sputter deposition or simultaneous etching and sputtering. Figure 2 shows photographically the rf diode mode with the glow discharge during sputtering. The sputtering chamber consists of a water-cooled copper electrode to which a sheet of circular target material is bonded. The rf power is applied to the electrode at an argon pressure of 20 torr (2×10^{-2} mm Hg) and an ion plasma is generated. The specimen to be coated is placed close to the target, generally about 3.2 centimeters from the target, with the argon pressure maintained in the 20-torr (2×10^{-2} mm Hg) range. It is essential that no section of the specimen is shielded and that all surfaces are exposed to the glow discharge sheath. The rf diode mode in figure 2 is necessary to coat the complex specimens of any shape with an adherent coating. To improve the adherence characteristics of the film, the specimen is normally cleaned by dc sputter etching before the film is applied. Figure 3 shows photographically the complete sputtering assembly during sputtering. Before sputter coating, a negative dc potential is applied to the specimen and the surface is sputter etched. Once the surface of the specimen is properly cleaned by sputter etching, the dc power is turned off and the rf power is immediately applied to the target.

RESULTS AND DISCUSSION

The technique of sputter coating complex geometrical surfaces was performed on a number of differently shaped specimens. It was of special interest to coat the components of ball bearings with solid lubricants, such as molybdenum disulfide (MoS_2), silver, polytetrafluoroethylene, and so forth. Figure 4 shows ball bearing components coated with MoS_2 film. The entire surface area of the cage, including the ball pockets, was coated. The operation was accomplished without rotating or moving the cage. These films exhibit strong adherence to the surface and maintain the original chemical composition, as previously reported (ref. 3). The film thickness and uniformity are functions of the distance between target and specimen and the particular geometric configuration of the specimen. The deposition rate drops off as the inverse square of the distance. The following sputtering conditions were used for coating bearing components with various bore and outer diameters: argon pressure, 20 torr (2×10^{-2} mm Hg); rf power input, 400 watts; dc input, 500 volts; target ac voltage, 1.3 kilovolts; target to specimen distance, about 3.1 centimeters. The result was a thickness variation of 20 to 50 percent depending on the geometry of the bearing.

It should be pointed out that a minimum film thickness of 3500×10^{-10} meter (3500 Å) is required at the contact areas of ball bearings for effective lubrication. It is only necessary to determine that these critical areas have the required thickness. The other areas, depending on the particular geometry of the components, will fall within the deviation range of 20 to 50 percent. When a 3500×10^{-10}-meter- (3500-Å-) thick film is required in the groove of a certain race, the upper section of the race (closest to the target) will have a maximum film thickness of 5250×10^{-10} meter (5250 Å). For useful bearing operation, the extra thickness which amounts to 1750×10^{-10} meter (1750 Å) has no effect on the possible tolerance requirements.

A number of bearings (bore diameter, 17 mm; outer diameter, 35 mm) were coated by this method with MoS_2 film 3500×10^{-10} meter (3500 Å) thick. Low-speed torque measurements at 44.13-newton thrust loads were made with each bearing running at 88 rpm for periods to 2 hours or until a steady-state torque condition was reached (ref. 4). These films gave the lowest torque when compared to bonded MoS_2 films (ref. 4). Stylus profilometry showed that the sputtered MoS_2 films were smoothest and as a result they gave the lowest torque performance and less degradation during the run-in condition (ref. 4).

Figure 5(a) illustrates a seal 3.1 centimeters in height and 4 centimeters in diameter to be coated with MoS_2. The inside and outside of the walls were coated. Possible flow of the sputtered material is shown in figure 5(b). The ion plasma which is generated by rf fields has apparent oscillatory or curving effects on the sputtered material and also backscattering effects which contribute to the coating of irregularly shaped surfaces, cavities, and surfaces around corners.

SUMMARY OF RESULTS

Radiofrequency sputtering methods can be used to coat irregularly shaped surfaces such as the components of ball bearings. An adherent film is deposited on a stationary specimen into cavities and around corners. The film thickness varies from 20 to 50 percent over the cage or race depending on the geometry of the particular bearing. It is only essential to determine the required film thickness at the critical areas requiring lubrication. The outer sections fall within the deviation range of 20 to 50 percent. When sputtered solid film lubricants such as molybdenum disulfide are used, a film thickness only of the order of 10^{-7} meter (thousands of angstroms) is required. Therefore, an overall deviation in film thickness of 50 percent constitutes a negligible change for practical lubrication.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 19, 1971,
114-03.

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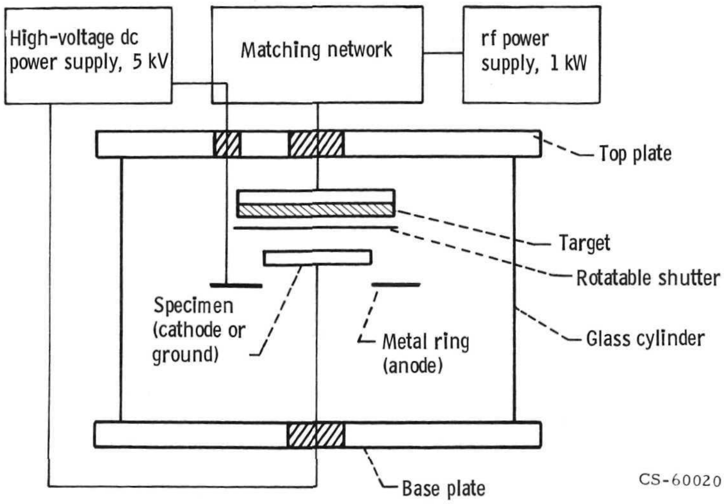


Figure 1. - Sputtering system using rf with dc bias.

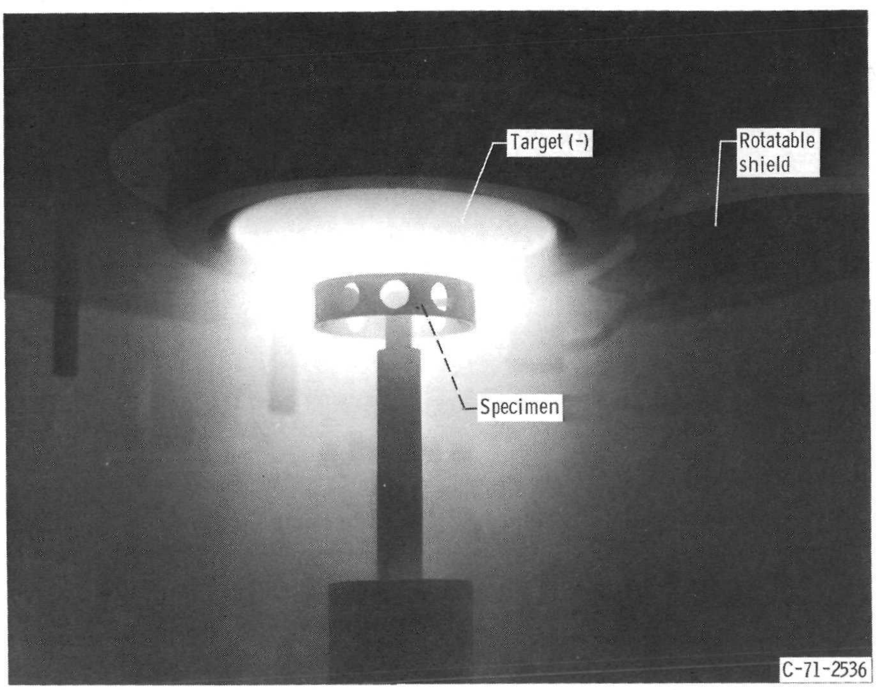


Figure 2. - Radiofrequency sputter coating of complex specimens.

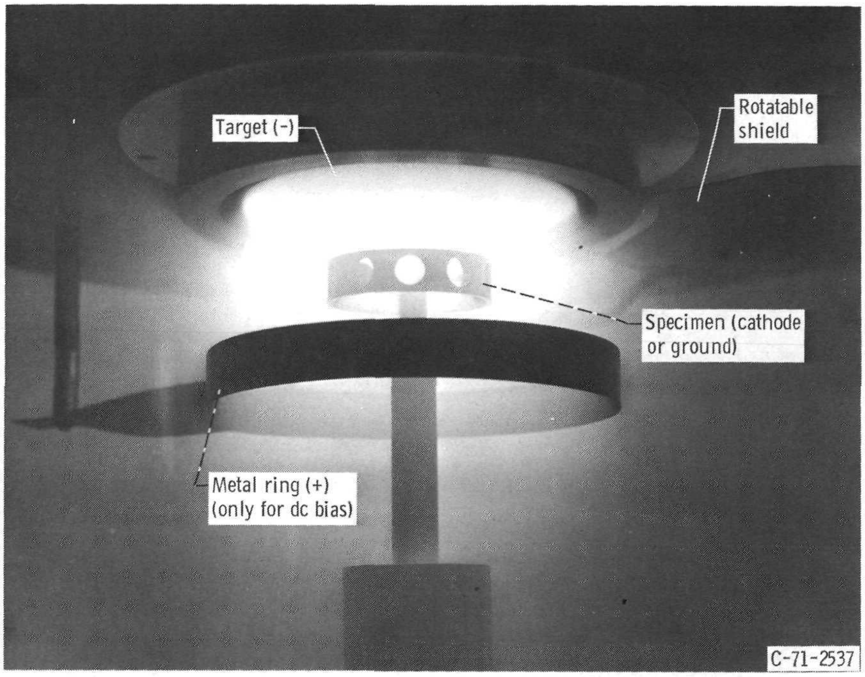


Figure 3. - Radiofrequency with dc bias during sputter coating of complex specimens.

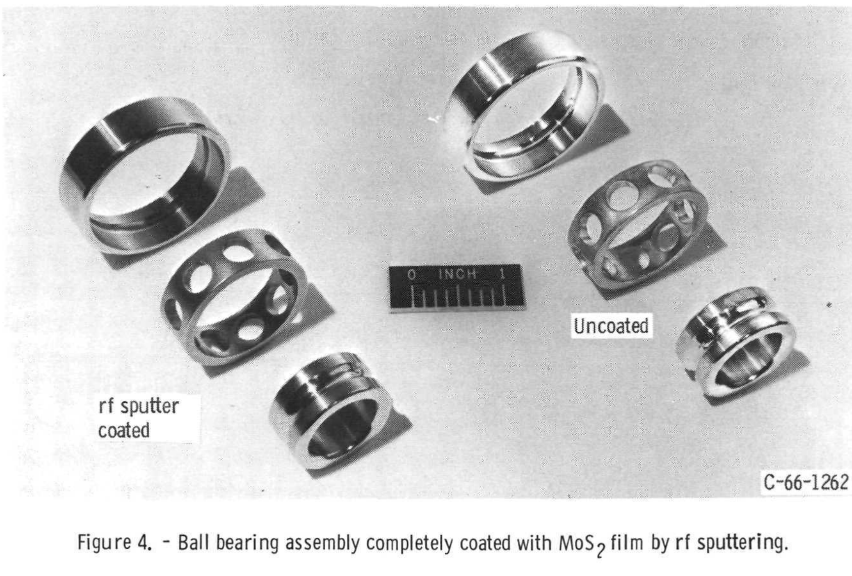
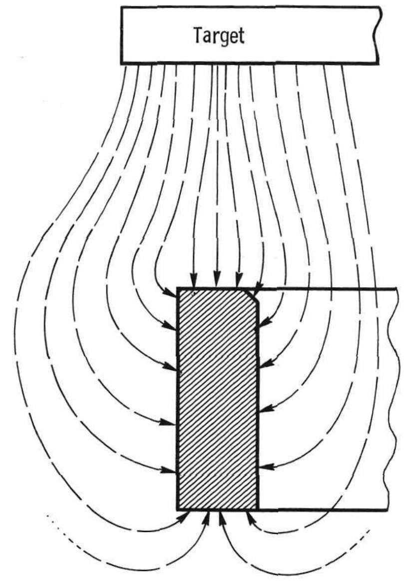


Figure 4. - Ball bearing assembly completely coated with MoS_2 film by rf sputtering.

(a) Completely sputter coated seal specimen.



(b) Flow of sputtered material.

Figure 5. - Flow of rf-sputtered material to seal specimen.

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