The Effect of Nitrogen Gas Flow in the Production of Chromium Nitride Coatings Deposited by DC Magnetron Sputtering for Biomedical Implant Applications

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Statement of Purpose: In the United States, an estimated 11 million people have received at least one medical implant device. The number of total hip and knee replacements performed each year in the U.S.A is 198,000 and 245,000 respectively[1]. Revision surgeries account for 17 percent of all hip replacement and eight percent of all knee replacement surgeries, for a combined total of nearly 54,000 revision surgeries each year. Despite improvements in the surgical technique and in the designs of prostheses, revision rates do not seem to be declining over time. Wear of articulating surfaces has been cited as a dominant factor limiting the long-term success of the implants. We have evaluated the effect of nitrogen gas flow in the production of hard and smooth chromium nitride coatings that can reduce the friction and wear in mating total joint replacement components, thus contributing to their significantly improved function and can resolve the early failure of the artificial implant.

Methods: Chromium nitride thin films were deposited by DC magnetron sputtering (Denton Vacum, Discovery 24). The target was a high-purity (99.999%) chromium disk. Pure argon (99.999% purity) was used as inert gas in the chamber with nitrogen (99.999% purity) gas. All the films were deposited at 150 degree C substrate temperature. The process pressure was 0.4 Pa with DC power of 100 W. XRD patterns on the coatings were examined using glancing angle XRD (X'pert MPD, Philips, Eindhoven, The Netherlands). The mechanical properties mainly hardness and Young's modulus were measured by Nanoindenter XP (MTS Systems, Oak Ridge TN) system. Surface morphology and roughness of the deposited coatings were examined by Surface Probe Microscope TopoMetrix Explorer®. We evaluated the biocompatibility of diamond coatings *in vitro* using standardized tests including human mesenchymal stem cells (hMSCs). hMSCs were seeded onto the coatings and allowed to adhere for 1 hour, 24 hours and 7 days. Unattached cells were then removed by washing with phosphor buffered saline (PBS) on a mechanical shaker. The attached cells were then fixed and observed via SEM.

Results / Discussion: It was found that the change of nitrogen flow in argon and nitrogen mixture has an influence in the mechanical and structural properties of chromium nitride coatings. The relative intensities of CrN (111), CrN (200) and CrN (220) XRD diffraction peaks changed with the increase of nitrogen flow in the plasma. Hardness of the deposited coatings varies from 11 GPa to 20 GPa with the change of nitrogen contents and can be increased up to 20 GPa at the nitrogen flow of 87%. Roughness decreased from 8.4 nm to 4 nm (RMS, 2 micron square area) from N_2 gas flow of 12% to 100% (Figure 1). Adhesion and spreading of MSCs were found on the deposited coatings after culturing for 1 hours, 1 day and 7 days.

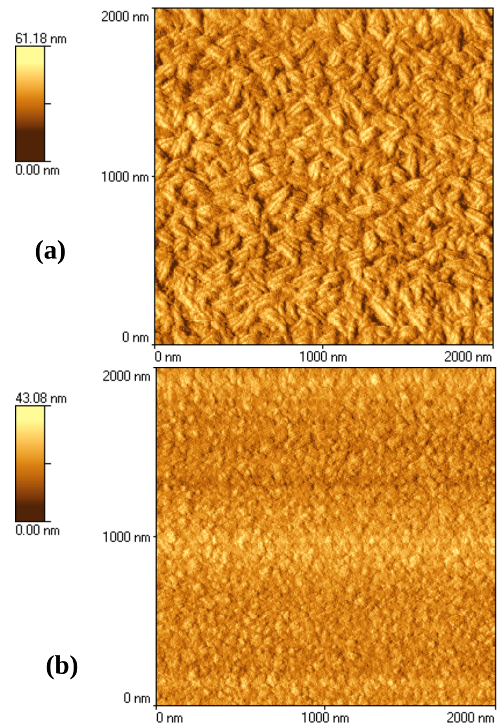

Figure 1: Surface morphology of chromium nitride coatings deposited in argon and nitrogen atmosphere with nitrogen partial pressure of (a) 12% and (b) 100%

Conclusions: Chromium nitride coatings were deposited by DC magnetron sputtering in argon and nitrogen atmosphere. We have investigated the effect of nitrogen partial pressure on the mechanical and structural properties of deposited chromium nitrite coatings. The hardness of the chromium nitride coatings increased up to 21 GPa with the increased of nitrogen pressure of 87% and then decreased afterwards. The relative intensities and surface areas of XRD diffraction peaks of CrN (111), CrN (200) and CrN (220) were changing with the increase of nitrogen partial pressure in the plasma. The smoothest coatings can be achieved by increasing the nitrogen partial pressure up to 100%. The coatings were biocompatible after finding the MSCs adhesion and spreading on the deposited coatings. The authors acknowledge support from the National Science Foundation (NSF) under a Nanoscale Interdisciplinary Research Team (NIRT) program Grant No. DMR-0402891.

References: 1. National Center for Health Statistics: Vital Health Statistics, 1994 Report (Hyattsville, MD, 1994).