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Acta Materialia 53 (2005) 4079–4086
Acta MATERIALIA
www.actamat-journals.com

Titanium nitride pacing electrodes with high surface-to-area ratios

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Received 6 April 2005; received in revised form 5 May 2005; accepted 7 May 2005
Available online 20 June 2005

Abstract

High surface-to-area ratio TiN coatings for cardiac pacing electrodes were obtained by arc ion plating. The substrate bias potential and the processing time were critical for obtaining coatings with the appropriate topography. Dark high surface-to-area ratio TiN deposits were found to be near stoichiometric TiN, with a columnar growth of strongly oriented crystals in the (1 1 1) direction with an open structure. The difference in color observed with the traditional golden TiN films have been attributed to the topography of the coatings. Pacing impedance values were found to decrease markedly with the most favorable dark TiN coatings achieving full electrical depolarization of the electrode–fluid interface. Ion nitriding of Ti substrates did not result in favorable results for the conditions tested.

Keywords: Titanium nitride; Arc ion plating; Ion nitriding; Topography; Pacing impedance

1. Introduction

Titanium nitride is used in biomedical devices because of its biocompatibility, excellent mechanical properties, as well as fairly low corrosion rates. In those applications in which an electrical conductor is needed, such as stimulus electrodes in cardiac pacemakers, this material can be used in films and electrode coatings due to its high electrical conductivity as well as its low contact potential with the base metal of the electrode.

Considering that an adequate stimulus is produced on an excitable tissue by conveying a given current density above a certain threshold value [1–3], a reduction in the modulus of the stimulus (pacing) impedance is of marked importance in order to increase energy efficiency and extend battery life [4]. If a pacing electrode with a high surface-to-geometric-area ratio can be manufactured, it is possible to lower the interface impedance between the electrode and the body fluids, thus effectively lowering the total pacing impedance [4–6]. Considering that the scale of the electrode surface roughness required to produce a significant effect on the electrical characteristics of the electrode is rather small, TiN coatings applied by plasma assisted deposition techniques may deliver suitable results.

TiN coatings have been used traditionally in mechanical applications, such as surface hardening, low friction coefficient surfaces, with excellent success, and a variety of techniques and equipments are available for these purposes. However, a rather smooth surface deposit is sought in these that in principle will not produce coatings with the desired topography for the electrical application at hand. In spite of this, the correct manipulation of the variables involved in the coating process could lead to the generation of films onto metallic substrates with the appropriate topography.

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1359-6454/$30.00
doi:10.1016/j.actamat.2005.05.008

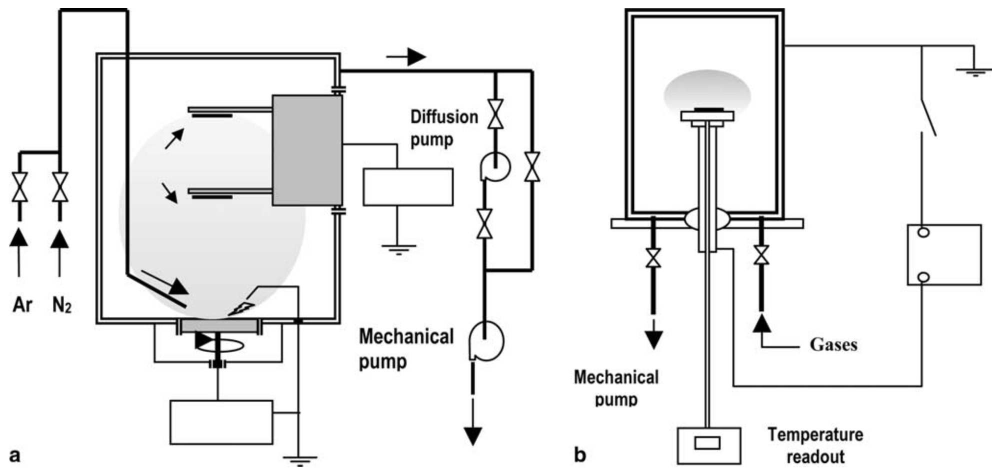

Fig. 1. Schematic representation of plasma assisted reactors: (a) arc ion plating; (b) ion nitriding.

Arc ion plating (AIP) is a surface overlay coating technique that has found wide acceptance in the production of TiN coatings for mechanical applications, due to its reliability, high deposition rate, and excellent overall results [7]. AIP basically evaporates metallic titanium from a cathode, by means of a direct current (d.c.) electric arc, followed by its reaction with nitrogen introduced into the plasma chamber to form films of TiN on a substrate (see Fig. 1(a)). AIP is a robust technique, with a high production throughput, that offers the possibility of manipulating the coating microstructure by varying the substrate bias potential and temperature [8–13], as well as by regulating the contribution to the growing film of projected droplets from the cathode generated by the arc [14].

In contrast to AIP, ion nitriding (IN) is a surface modification technique, traditionally employed for hardening surfaces, that incorporates nitrogen into a metallic substrate to form nitrides (see Fig. 1(b)). Although IN involves a more intense thermal treatment of the substrate, it has been reported that a significant increase in the roughness of the surface has been observed, particularly for long processing times [14–16]. This effect probably derives from the differential sputtering of the TiN layer formed due to the bombardment of nitrogen ionic species, resulting in extreme cases in the generation of surfaces with a cone-like topography [17].

The object of this work was to test the aforementioned plasma assisted processing techniques in order to obtain TiN coatings and surface layers with high surface-to-geometric area ratios to be used in cardiac pacing electrodes.

2. Experimental procedure

2.1. Arc ion plating

The substrates employed were grade A titanium plates of 20 mm × 10 mm × 0.5 mm, as well as platinum −10% iridium cylinders of 2 mm in diameter and 5 mm high. Samples were prepared by polishing with 600 grit paper, followed by ultrasonic cleaning in acetone and isopropylic alcohol.

A reactive ion plating equipment fitted with an evaporator based in a rotating cathodic arc was used. After establishing a vacuum of 5×10^{-3} Pa, the coating process was started in flowing argon, 10 cm^3/min and 1.3 Pa – with a cathode rotating speed of 100 rpm, and a d.c. arc current of 80 A. A nitrogen flow of 35 cm^3/min was set, and a total pressure of 3.3 Pa was established with Ar in the reactor chamber to produce the TiN coatings.

Thirty-two different experimental conditions were tested, employing both aforementioned substrates, with bias substrate potentials of 0, −20 and −300 V, depositions times of 10, 30, and 60 min, distances to the arc of 14 and 24 cm, and orientations facing and not facing (opposite) the arc.

2.2. Ion nitriding

The substrates employed were titanium grade A plates of 20 mm × 10 mm × 0.5 mm with two different starting surface topographies: as-received and sand blasted surfaces R_t[1] = 7.4 and 10.4 μm, R_a = 0.99 and 1.48 μm, respectively, followed by ultrasonic cleaning in acetone and isopropylic alcohol.

A nitriding chamber fitted with d.c. potential source to bias the substrate was used. Prior to the deposition of the film, the surface substrate was cleaned by sputtering for a period of 30 min in an Ar/H_2 2:1 (volume) flow at 90 Pa, employing a d.c. bias potential of 400 V to light the plasma and a resulting substrate tempera-

[1] Surftest Mitutoyo SV-400, detector diameter 5 μm, testing length 8 mm. R_t: profile total height and R_a: profile arithmetic mean deviation.