Surface & Coatings Technology 258 (2014) 797–803

Contents lists available at ScienceDirect

Surface & Coatings Technology

journal homepage: www.elsevier.com/locate/surfcoat

Effects of copper interlayer on deposition and flexibility improvement of diamond microelectrode

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ARTICLE INFO

Article history:
Received 6 May 2014
Accepted in revised form 24 July 2014
Available online 4 August 2014

Keywords:
CVD diamond film
Diamond microelectrode
Flexibility
Sputtered copper layer
Tungsten substrate
Carbide

ABSTRACT

Tungsten with sputtered copper layer (W/Cu) and bare tungsten (W) substrates were investigated for boron doped diamond microelectrode (BDDME). Traditional tungsten substrate becomes brittle after diamond film deposition and is prone to fracture when BDDME confronts slight bending force in practice because of formation of carbide on the surface of tungsten. To improve the flexibility of the microelectrode, a 100 nm sputtered copper layer has been chosen as a barrier interlayer to hinder diffusion of carbon into tungsten, as copper does not form compounds with carbon and tungsten. We have found that the copper layer greatly curbs the formation of tungsten carbide, making the W/Cu substrates more flexible than W substrates after deposition and the bending angle was up to 40°, which was 4 times higher than that of bare tungsten substrates. Besides, the sputtered copper layer made it easier for diamond nanoparticles to adsorb on the surface, which has improved nucleation and growth of diamond film. High-quality and well-adhesive diamond film without crack and holes has been deposited on the W/Cu substrate.

1. Introduction

Recent years, the small or thin conductive boron doped diamond microelectrode (BDDME) has attracted much attention due to its superior properties [1,2] such as wide electrochemical potential window, a low, stable and pH-independent background current, stable sp^3 microstructure and chemical inertness in physiological media and excellent biocompatibility. Compared with macro-electrode, the small size BDDME empowers with lower detection limit, increased rate of mass transport and a fast response analysis in low conducting media and a very small sample volume, and limits tissue damage and minimizes surgical challenges. These properties make the diamond a promising material in biosensors or other implants used in vitro and in vivo with a long-term service lifetime.

However, there still remain some technical challenges needed to be overcome for the widespread use of BDDME. One is the chronically implantable electrode requires excellent flexibility for maintaining its performance and mechanical integrity in intact behaving animals for weeks or months [3]. The main reason of this trouble is that diamond films are often deposited on heterogeneous substrates and these conventional heterogeneous substrates [3–8] inevitably react with carbon under CVD condition. It is very easy to form a brittle carbide layer between the substrate and diamond film. The formed carbide can reduce stress in the deposited diamond film and increase adhesion due to the compensation of lattice mismatch between the substrate and diamond film [9,10]. But carbide makes the substrate more brittle; therefore, it is less capable of withstanding the bending force. The embrittlement effect of carbide is much more obvious on the extremely small BDDME which generates some practical trouble. For example experimental animals have to be held still during testing [2,11] and complex techniques need to be utilized to transfer diamond film from a rigid substrate to a flexible biocompatible substrate [8]. Consequently, the widespread application of diamond microelectrode is restricted. Previous works to solve this problem include employing metals that do not react with carbon as substrates. Diamond film grown on copper [12,13] or rhenium [3,14] does not generate carbide, but the diamond film readily delaminated. Mo/Re alloy seems to be an appropriate substrate [3], which remains ductile after diamond film growth, while the cost increases to a much high level. The other approach is to sputter an interlayer as a diffusion barrier on the surface of substrate before diamond film deposition. One advantage of sputtered layer is that it can significantly improve nucleation [15,16], which is primarily to obtain continuous and dense CVD diamond films. Forming void-free and continuous film is critical for BDD microelectrode for acquiring excellent electrochemical performance. The alternative sputtered interl

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http://dx.doi.org/10.1016/j.surfcoat.2014.07.078
0257-8972/