Formation of Nanocarbon Ohmic Contacts on Phosphorous-Doped Single crystalline Diamond by Coaxial Arc Plasma Deposition

スリーナット マイロ ワラピル

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氏　　名　: Sreenath Mylo Valappil
Name

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（同軸型アークプラズマ成膜法によるリンドープ単結晶ダイヤモンド上へのナノカーボンオーミックコンタクトの形成）
Title

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Category

論 文 内 容 の 要 旨
Thesis Summary

The physical properties of diamond have received great attention in recent years to realize advanced devices. Their large breakdown field (~10 MV cm^{-1}), huge carrier mobilities, exceptional thermal conductivity (22 W cm^{-1} K^{-1}), and the wide band gap (5.4 eV) had already been intensively studied and applied in various devices in the areas of power electronics, quantum sensing, hard coating, and others. The recent technological advances in efficient p and n-type doping of the diamond have improved the device properties and their controllability. The attainment of advanced diamond-based devices is interrelated with the fabrication of practical ohmic contacts to semiconducting diamond.

This doctoral thesis focuses on fabricating efficient nanocarbon ohmic contacts to phosphorus-doped n-type and boron-doped p-type semiconducting diamonds through the coaxial arc plasma deposition method and their characterization as compared with conventional Ti-based ohmic contacts. The accurate extraction of the specific contact resistance is realized through the circular transmission line model theory. The nanocarbon ohmic contacts exhibited less specific contact resistance and interfacial potential drop when compared with the conventional Ti ohmic contacts.

In addition to the low contact resistance, the ideal ohmic electrode is preferable to have good mechanical adhesion and corrosion resistance for device applications. The contact behavior of n-type diamond/nanocarbon in an extremely corrosive environment exhibited excellent corrosion resistance and mechanical adhesion over conventional Ti-based contacts. Moreover, this study deeply explored the structural configuration of the alternative nanocarbon ohmic electrodes on the phosphorus-doped diamond. In addition, it is correlated to their corrosion resistance and mechanical stability.

The excellent corrosion resistance of nanocarbon ohmic contacts is then utilized to improve the process flow of p-type diamond Schottky barrier diode fabrication procedure by avoiding the post-annealing step that usually accompanies interface carbide forming ohmic contacts. The diode parameters obtained through the proposed fabrication procedure exhibited good uniformity with a very small standard deviation. Herein, this study suggests the possible application of nanocarbon ohmic contacts over conventional Ti-based ohmic contacts for diamond electronics. This thesis comprises six chapters elaborating the research findings as follows

Chapter 1: This chapter provides the material characteristics of the diamond as a wide bandgap semiconductor including its structural, mechanical, optical, and electronic properties. Through mentioning the essential material properties, current methods of diamond fabrication are discussed subsequently. Then, the recent advances in diamond doping and their applications in realizing state of art practical devices are comprehended. As this study focuses on efficient nanocarbon ohmic electrodes for semiconducting diamonds, recent ohmic contact strategies reported for both phosphorus and boron-doped diamonds are emphasized in detail in this chapter.
Chapter 2: The chapter focuses on the fabrication of nanocarbon films on diamond substrates and their structural characterization. Moreover, their structural properties are compared with nanocarbon films fabricated on silicon substrates. The chapter provides a detailed explanation of the basic nanocarbon fabrication method used for the complete study, that is coaxial arc plasma deposition (CAPD). Furthermore, the calibration of the oxygen plasma condition is demonstrated for the first time through visible Raman spectroscopy and scanning electron microscopy (SEM) for the enhancement of spectral response from composite nanodiamond grains in the nanocarbon film fabricated by CAPD.
Chapter 3: In this chapter, nanocarbon ohmic electrodes with enhanced carrier collection efficiency were deposited by coaxial arc plasma deposition. The fabricated nanocarbon ohmic electrodes were extensively studied in terms of specific contact resistance and corrosion resistance. Circular transmission line model (cTLM) theory was used to estimate the charge collection efficiency of the nanocarbon ohmic electrodes in terms of specific contact resistance at a specific voltage range (5-10 V), they exhibited a specific contact resistance of 1×10^{-3} Ωcm^2. The result revealed one order reduction in the specific contact resistance and hence potential drop at the diamond/electrode interface compared to the conventional Ti electrode.
Chapter 4: This chapter analyzes the contact behavior of n-type diamond/nanocarbon against an extremely corrosive environment realized by boiling acid solution and they exhibited excellent corrosion resistance and mechanical adhesion over conventional Ti-based contacts. Even though more characterization focus is given to nanocarbon ohmic contacts on a phosphorus-doped diamond, a similar trend is observed for nanocarbon contacts on boron-doped diamonds also. The performance of nanocarbon ohmic contacts is strongly correlated with the fabrication temperature, and the effect is discussed. The modest effect on the transfer length of the nanocarbon contacts with respect to acid treatment sessions indicates a tightly bonded diamond/nanocarbon interface and actively suggests their application in highly corrosive environments.
Chapter 5: In this chapter, the effect on the uniformity of Schottky barrier diodes fabricated on a wet chemically oxygen-terminated p-type diamond surface by avoiding the post-annealing step through corrosion-resistant nanocarbon ohmic contacts is discussed. Due to the strong interface because of partial sp^3 interfacial bonds, the nanocarbon ohmic contacts are found withstandable to wet chemical O-termination, unlike Ti contacts. The SBDs show good uniformity in their ideality factor (mean value = 1.25) and Schottky barrier height (mean value = 1.45) with a standard deviation of 0.04 and 0.03 respectively for 42 Schottky barrier diodes.
Chapter 6: Thesis summary and future perspectives of the Ph.D. research.