Photo Induced Electron Emission from Nitrogen Doped Diamond Films on Silicon

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Abstract—Results are presented on the photo-induced electron emission from nitrogen doped diamond films prepared on doped silicon substrates. In contrast to results for films on metal substrates, a significant increase of emission intensity was observed at elevated temperatures. The results suggest a contribution from photon enhanced thermionic emission.

Keywords—nitrogen-doped diamond; photo-induced electron emission; thermionic electron emission

I. INTRODUCTION

Diamond films are known for their property of obtaining a negative electron affinity (NEA) after hydrogen passivation [1]. The electron affinity is defined as the energy required to remove an electron from the conduction band minimum (CBM) of a semiconductor to vacuum. For nanocrystalline diamond n-type doping has been achieved by incorporation of nitrogen, with a donor level of nitrogen at 1.7 eV below the CBM [2]. NEA and n-type doping lead to lowering of the electron emission barrier, i.e. the effective work function. This enables low temperature thermionic emission from doped diamond films. For films on absorbing substrates, photo-induced electron emission has been observed with visible light excitation [3]. The configuration of a diamond film on a semiconductor substrate provides both thermionic and photo-generated electrons which are emitted into vacuum through the low work function surface. It has been proposed that with a proper film-substrate configuration, the photon enhanced thermionic emission (PETE) mechanism can substantially enhance the emission current at elevated temperatures [4]. At moderate temperatures both direct photoemission and PETE contribute to the emission. This research presents an investigation of photo-induced electron emission from nitrogen-doped diamond film on Si substrates.

II. EXPERIMENT

Diamond films are prepared on Si substrates by microwave plasma enhanced chemical vapor deposition (MPCVD). The films are deposited first with a layer of nitrogen incorporated ultra-nanocrystalline diamond (N)UNCD) and then a top-layer of nitrogen doped diamond. A grain size of less than 10 nm is shown in the (N)UNCD layer (Fig. 1).

Aberration corrected microscopy is employed to examine the C/Si interface and to reveal its role in emitter characteristics.

III. RESULTS AND DISCUSSION

In photo-induced emission experiments, a Xe arc lamp with associated band pass filters provides illumination with light from 320 nm to 600 nm. The combined photo-induced and thermionic electron emission spectra are recorded as a function of temperature, using a hemispherical electron analyzer.

Computer based modeling is used to compare and understand the significance of the three different emission mechanisms: thermionic, direct photoemission, and PETE.

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Electron microscopy images (Fig. 1) indicate a continuous interface between Si and the (N)UNCD. A grain size of less than 10 nm is shown in the (N)UNCD layer. From UV photoemission spectra (21.2 eV excitation), a low effective work function \( \Phi_W \) (~ 1.5 to 2 eV) is observed for the diamond surface, which remains approximately constant with varying temperature. In contrast, the visible light photo-induced emission spectra exhibit a higher threshold energy which decreases at elevated temperatures, possibly due to the band offset at the diamond-Si interface. The intensity of the visible light photo-induced emission significantly increases with temperature, which is not observed for diamond films deposited on metal substrates [3] (as shown in Fig. 2).

![High resolution electron microscopy image of the C/Si interface.](image)

**Fig. 1.** High resolution electron microscopy image of the C/Si interface.
The visible light induced electron emission mechanism involves photons passing through the diamond film due to its wide band gap, and generating photo-electrons in the Si substrate, or in the nucleation layer which has a higher density of sp² bonds in the grain boundaries [7]. These results suggest that photo-generation at or near the diamond/Si interface contributes significantly to the observed electron emission characteristics.

IV. CONCLUSIONS

Significant increase of photo-induced electron emission with elevated temperature has been observed from nitrogen doped diamond films on silicon substrates. The results differ from previously reported features of diamond emitters on metal substrates. Possible photon enhanced thermionic emission is suggested, while electron microscopy images and computer-based modeling indicate a complex generation process. The results indicate potential applications of such diamond emitters in concentrated solar cell systems for combined energy conversion. Engineering the interface remains as a challenge to enhance the electron generation and emission. Further studies will also include examination of different substrate candidates for optimized PETE configuration.

ACKNOWLEDGMENT

We gratefully acknowledge the LeRoy Eyring Center for Solid State Science at Arizona State University for the use of the aberration corrected microscope and related equipments.

REFERENCES