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Keynote: Electrical, mechanical, and medical applications of nanodiamond films prepared by physical vapor deposition

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KEYWORDS

nanodiamond, composite, amorphous carbon, coaxial arc plasma deposition, pulsed laser deposition, semiconductors, hard coating

SHORT SUMMARY

Nanodiamond films, which comprise a large number of nano-sized diamond grains and an amorphous carbon matrix, possess superior properties applicable to electronic devices, heat sink, hard coating for mechanical tools, and tribological and functional coatings for biomedical components. Our laboratory has realized the formation of nanodiamond films by employing pulsed laser deposition and coaxial arc plasma deposition. From the viewpoints of their film deposition processes, specifics to be emphasized are film growth at low temperatures, even at room temperature, which make possible the employment of a variety kinds of substrate materials. On the basis of the film preparation techniques, we have progressed research on the applications of nanodiamond films to photovoltaics and hard coating for mechanical tools. The nanodiamond research from the initial state to prospects from this is introduced.

EXTENDED ABSTRACT

Nanocrystalline diamond (NCD), which is one of carbon nanomaterials, possesses physical properties similar to crystalline diamond and specific properties owing to the existence of a large number of grain boundaries in film. As shown in Fig. 1, NCD films comprise a number of diamond nano-sized grains and an amorphous carbon matrix.

NCD films have ever been prepared mainly by chemical vapor deposition (CVD) using hydrocarbon source gases. On the other hand, we have succeeded in the formation by employing physical vapor deposition, concretely pulsed laser deposition (PLD) [1] and coaxial arc plasma deposition (CAPD) [2]. From our previous studies, it was found that highly energetic carbon species such as ions and excited atoms realize quasi-high pressure and high temperature situations for forming diamond. As schematically shown in Fig. 2, resultant film structures are different from those of CVD NCD films. Table 1 shows comparisons in the film deposition process and condition between CVD and PVD. Significant specifics to PVD are no requirement of pretreatment of substrates with diamond powder and growth at low substrate-temperatures. In particular, hydrogen atmospheres are not necessarily required for the growth of NCD films by CAPD.

Concerning applications as semiconductors, B and N were doped during the deposition process, and the production of p and n-type conductions were confirmed. Based on the results, B-doped p-type NCD films were deposited on n-type Si substrate, and the resultant pn junction showed a typical rectifying action and photodetection for DUV light, as shown in Fig. 3 [3].

For the purpose of application to hard coating on cemented carbide (WC-Co), the process developments have been made. It was found that the low-temperature growth can suppress the graphitization induced by the catalytic effects of Co on the WC-Co substrates and the internal compressive stress of NCD films is extremely small, for example 4.5 GPa for 5-GPa-hardness film, which is smaller than that of comparably hard a-C films [4]. This might be because the huge number of GBs structurally specific to NCD films might have a role in the release of the internal stress. To enhanced the film hardness, negative biases was applied in quasi-direct current during the film deposition. By optimizing the negative bias condition, an enhancement in the hardness to 85 GPa has been realized thus far. The Raman spectra of the films are apparently changed due to enhanced diamond content, as shown in Fig. 4.

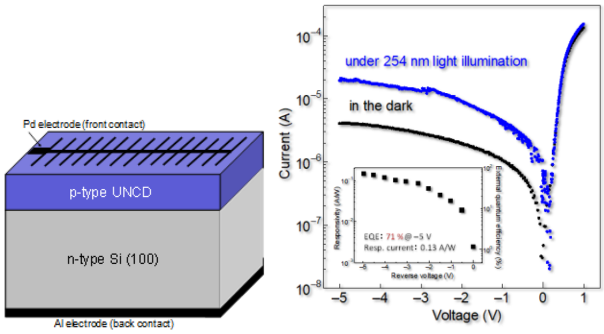
Table 1 Comparison in NCD preparation condition between CVD and PVD.

Chemical Vapor Deposition

This work
Physical Vapor Deposition

Pulsed Laser Deposition (PLD)
Coaxial Arc Plasma Deposition (CAPD)

	CVD	PVD	
		PLD	CAPD
energy of species	-	from tens to hundreds electron volts	
depo. process	continuous	pulsed	
seeding procedure	required	NOT required	
depo. rate	generally low	80 nm/min	400-6000 nm/min
substrate temp.	700 ~ 1000 °C	550 °C	RT ~ 550 °C
large area depo.	dependent on method	difficult	possible
others	generally high quality	amorphous carbon is cogenerated	



(a) (b)

Figure 3 (a) Schematic of heterojunction comprising p-type NCD film and n-type Si substrate, and (b) its photodetection for 254 nm light. Inset of (b) shows photoresponsivity and eternal quantum efficiency.

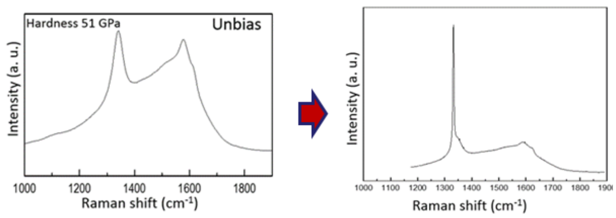


Figure 4 Change in Raman spectrum by applying negative bias.

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