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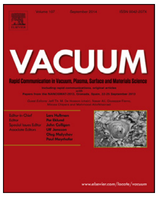

Improved in dry routing performance with optimized diamond-like carbon films

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ABSTRACT

The efficiency of cutting tools was increased by deposition diamond-like carbon (DLC) films on microrouter bits to improve the chip flow and reduce cutting force. DLC films deposited under a mixture of acetylene/argon plasma in a large area and three dimensional deposition electron cyclotron resonance (ECR) system. Router bit performance in dry routing of FR-4 type printed circuit board was evaluated by inspecting the surface roughness of trench sidewalls and the routing precision width tolerance. By optimizing deposition conditions, the DLC lubricant-coated microrouter bits achieve a better enhancement in performance. Surface analysis with scanning electron microscopy reveals that DLC coated microrouters exhibit lower friction and enhance the anti-adhering properties of the microrouter, resulting in significant improvements in routing quality. The microstructure and chemical configuration are investigated by Raman spectroscopy and X-ray photoelectron spectroscopy, respectively. The routing efficiency shows a high dependence on the microstructure of DLC coating, which varies with deposition conditions, in particular with substrate bias voltage.

1. Introduction

Several coatings such as titanium nitrides, oxides, carbides, Diamond-like carbon (DLC) and diamond coatings are commercially available to improve cutting efficiency and increase tool life [1–4]. They have been used for the microdrilled processing of printed circuit boards (PCB) to improve the chip flow by reducing the friction coefficient and reducing the cutting force [5]. However, due to limited research on the microrouting process reported previously [6], the microstructure properties of DLC films relevant to the routing performance remain ambiguous and still need to be revealed.

The mechanical property of a DLC coating depends mainly on the sp2/sp3 bonding ratio of the microstructure, which is varied by changing the process parameters [7,8]. For various DLC coating preparation methods reported [9–12], electron cyclotron resonance chemical vapour deposition (ECR-CVD) is a better approach for the steady-state growth of the DLC coating, and also has advantages of combining a high plasma density, a low substrate temperature and an independent control of ion energy during deposition [13,14]. Recently, DLC coated on tool bits using the ECR-CVD technique has shown a promising future for applications.

In this study, DLC films deposited on the microrouter bit (UNION tool RCM-series diamond-patterned, 1.0 mm) under a mixture of acetylene/argon plasma in a large area and three dimensional ECR system is investigated. A functionally-graded Ti/TiN/TiCN multilayer was pre-deposited on the microrouter bit to improve the adhesion of the DLC coating. In particular, the top layer of the lubricant DLC coating was deposited by varying the process conditions in the same coating cycle. The micro-structural characteristic of the DLC coating was investigated by Raman spectroscopy and will be discussed in detail. Routing quality was assessed from the surface roughness of the inner trench sidewall and the routing precision width tolerance. The routing performance was evaluated by examining an FR-4 type of printed circuit board (PCB). The dependence of routing efficiency on the quality of the DLC coating was investigated.

2. Experimental

2.1. DLC film deposition

A HBS900 system produced by Roth and Rau is used in a modified version for ECR plasma processes [5,15,16]. Fig. 1 shows

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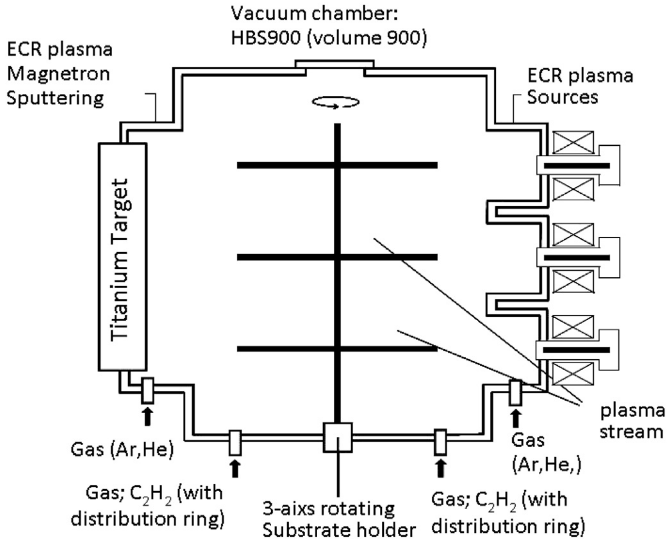

Fig. 1. Schematic diagram of the deposition apparatus.

Table 1
Typical growth conditions of DLC films.

Procedure steps	Process data	Time/min
Heating of substrates	T ~ 300 °C	90
High vacuum up to	P ~ 8 × 10^{-6}mbar	
Gas inlet	Ar	10
Bias (ECR + Sputtering)	$V_{sub} = -800$ V	
Plasma treatment	Sputtering + ARC	5
Reactive gas inlet	N_2	15
Bias	$V_{sub} = -100$ V	
Coating process	Alternate, with/without	90
Hard coating : TiCN/TiN	C_2H_2	
Cooling with He	T ~ 150 °C	30
Sputtering + ECR-plasma	Ar/He/N_2	10
	$V_{sub} = -800$ V	
DLC layer	Ar/He/C_2H_2	60
Bias	$V_{sub} = 0$ to -100 V	
Venting	N_2	10

the principle of the HBS900 hybrid coating system. The microwave power at 2.45 GHz is guided through a rectangular wave-guide and introduced into the ECR magnetron excitation chamber through a quartz window. The gas inlet for noble gases (Ar, He, N_2 excess of 99.995%) is directed into the plasma sources. The acetylene (C_2H_2, 99.99%) distributed by a gas shower in the vacuum chamber is located near the substrate holder. Prior to the deposition, the substrates, PCB-used microrouters (WC-6%Co) (UNION tool RCM-series diamond-patterned, 1.0 mm) and the polished WC-6%Co disks (Ra = 2.0 μm) were cleaned in an industrial cleaning machine CR266 following alkaline washing and rinsing in city-water and de-ionized water. The substrates were dried in hot air under a temperature about 115 °C, and then were loaded inside the deposition chamber.

The deposition chamber was pumped down to a base pressure below 5 × 10^{-4} Pa. Once the desired vacuum was reached, a dynamic flow of Ar gas was injected into the chamber to raise the pressure to 1–3 × 10^{-1} Pa. The Ar plasma is used to clean the substrates to remove undesirable oxide layers on the substrate surfaces. The sputtering period was by high energy ion bombardment at a bias of 800 V for about 10 min. For the preparation of DLC film, the ratio of Ar/C_2H_2 depends on the deposition conditions. Table 1 lists the typical growth conditions. Direct deposition of TiN onto the microrouter followed the same procedure. For optimization of coating, two deposition parameters; negative bias voltage and Ar/C_2H_2 ratio, were varied in the range of 0–400 V, and C_2H_2 flow rate from 5 to 30 sccm, respectively. The layer structure of the TiN/TiCN/DLC multilayer is described in detail elsewhere [5,6]. The thickness of the graded multilayer Ti/TiN/TiCN and the outermost DLC layer were approximately 1.5 μm and 0.5 μm, respectively.

2.2. Properties of DLC coatings

Properties of DLC coatings deposited on the polished WC-Co disks and microdrill bit were evaluated by various methods. The scratch tests were performed for adhesion at temperatures between 20 and 23 °C and 40–50% relative humidity (RH). A Rockwell C diamond (125 mm radius tip) apparatus was used for the scratch tests, and it slid across the testing surface at a constant linear velocity of 2.5 mm/s while increasing the load at a constant rate of 75 N/s. The critical load is defined as that for which the film first shows adhesive failure. The Universal Adhesion Tester is used to record the friction and load, and then mathematical fitting is made to the friction-versus-load curve and a first derivative is calculated. Pin-on-disc tests were performed using a 3 mm diameter uncoated steel ball (100 Cr6) sliding on a coated steel ring (φ35 mm, 100 Cr6) using a CSEM tribometer with a circular track of 20 mm. The rotation speed was 95 rpm, and sliding speed was 0.1 m/s with a load of 4.9 N.

The structure property of DLC films was characterized by Raman spectroscopic measurements (Dilor-Jobin Yvon-Spex 64000). The Ar^+-ion laser with an output power of 200 mW at a wavelength of 514.5 nm° is used to characterize the film structure. Micro-Raman backscattered spectra in parallel polarization were recorded by means of an Olympus microscope (objective × 100), coupled with a Dilor XY monochromator and a cooled photodiode array detector. Films were analyzed using X-ray photoelectron spectroscopy (JEOL; JMAP-9500F) for bonding characteristics and Energy dispersive X-ray spectroscopy (SEM-EDX; JOEL; JSM 8700F) for chemical composition.

2.3. Inspection of microtooled quality

Table 2 summarizes the dry routing parameters. The microrouting operations were performed using a high-speed Hitachi Via machine. The routing quality was evaluated by examining the inner contour sidewall. The end-point of the routing lifetime depends mainly on the surface roughness (maximum peak-to-valley) of the inner trench sidewall. This exceeds 25.4 μm (1 mil), and the common microrouting precision width tolerance exceeds ±50 μm, was determined by using a surface profilometer. Before and after microrouting, the optical microscopy and scanning electron microscopy (SEM) were used to inspect and examine the routed-quality. All samples were under dry machining conditions and underwent a high-speed process (at 40K rpm.). In this case of machine microrouting, the performance was evaluated in terms of FR-4 type PCBs production. The typical constituents of an FR-4

Table 2
Typical constituents of FR-4 laminates.

Constituent	Example material(s)
Reinforcement	Woven glass (E-grade) fiber
Coupling agent	Organosilanes
Resin	Epoxy (DGEBA)
Curing agent	Dicyandiamide (DICY), Phenol novolac (phenolic)
Flame retardant	Halogenated (TBBPA) or Halogen-free (Phosphorous compounds)
Fillers	Silica
Accelerators	Imidazole, Organophosphine