

# MICROSTRUCTURE OF ELECTRODEPOSITED Ni-W-P-SiC COMPOSITE COATINGS<sup>①</sup>

Guo Zhongcheng, Yang Xianwan, Liu Hongkang

*Department of Metallurgy,*

*Kunming University of Science and Technology, Kunming 650093*

**ABSTRACT** X-ray diffraction data showed that the Ni-W-P-SiC composite coatings are amorphous in plating status when their P content surpasses eight percent. The existence of SiC particles has no effect on the structure of the composite and they do not take part in the transition of the structure. The temperature of heat treatment has a considerable effect on the structure of the composite: when it is raised to 300~400 °C, metastable Ni<sub>5</sub>P<sub>2</sub> and stable Ni<sub>3</sub>P particles would form and that would lead to precipitation hardening; when temperature increase to 400 °C, Ni<sub>5</sub>P<sub>2</sub> phases would change into Ni<sub>3</sub>P phases. Ni<sub>3</sub>P, Ni<sub>5</sub>P<sub>4</sub>, WC and a few  $\gamma$ -(FeNi) phases are produced when Ni-W-P-SiC composite deposits are treated through nitrocarburizing. Scanning electron microscopy showed that the distribution of SiC particles in the composite is uniform. The crystalline temperature of the composite is raised to 100 °C when the additive is added in the bath.

**Key words** electrodeposition Ni-W-P-SiC composite coatings microstructure

## 1 INTRODUCTION

Making use of composite materials is the developing trend in current materials science. It means obtaining a new composite material by combining the best properties of several different materials so as to meet application demands. Composite electroplating is one of the most useful way to obtain such composite materials.

At present, composite electroplating is mostly used for nickel or copper base, such as Ni-SiC<sup>[1]</sup>, Cu-SiC<sup>[2]</sup>. Such composite materials have better wear resistance, but their corrosion resistance is rather poor. Another kind of composite materials, such as Ni-P-SiC<sup>[3-4]</sup> and Ni-B-SiC<sup>[5]</sup>, can be obtained by electroless plating. After appropriate heat treatment, their hardness can reach 1100~1200HV, and they have better wear resistance. But such composite materials are generally only 50~70  $\mu$ m thick, and their corrosion resistance is poor. Hard chromium has better wear resistance. However, when the working temperature reaches 500 °C, the wear resistance of hard chromium decreases sharply.

Besides, the corrosion resistance of the hard chromium is rather poor because of its slight microcracks.

In order to overcome all these disadvantages, a new composite material plating has been investigated<sup>[6]</sup>. The microstructure of Ni-W-P-SiC composite coatings by electrodeposition was also studied in this paper.

## 2 EXPERIMENTAL

### 2.1 Electroplating solution and technological conditions

The composition of electroplating solution of Ni-W-P-SiC composite coatings used in this work is as follows:

NiSO <sub>4</sub> •6H <sub>2</sub> O	50~100 g/L
Na <sub>2</sub> WO <sub>4</sub> •2H <sub>2</sub> O	80~150 g/L
NaH <sub>2</sub> PO <sub>2</sub> •H <sub>2</sub> O	5~40 g/L
H <sub>3</sub> O <sub>6</sub> H <sub>5</sub> O <sub>7</sub> •H <sub>2</sub> O	80~250 g/L
RE-1	0~3 g/L
ER-2	0~30 g/L
SiC (3~3.5 $\mu$ m)	30~100 g/L

The following are technological conditions:

① Supported by the Natural Science Foundation of Yunnan Province, China

Received Feb. 15, 1996; accepted Jun. 13, 1996

Current density( $D_k$ )	5~ 30 A/dm <sup>2</sup>
pH	3~ 8
Temperature	40~ 70 °C
Plating time	30~ 180 min

## 2.2 Specimens and methods of measurement

The 45 steel, pure aluminium and LY<sub>12</sub> aluminium alloy (40 mm × 30 mm × 2 mm) were used in this work. The composite coatings in different basic matrixes were the same.

The components of Ni-W-P-SiC composite coatings were measured by means of EDAX 9100 electron spectrum. The surface morphology and cross section of the coatings were observed by ASM-SX scanning electron microscopy. The microstructure of the composite was analysed by GX-3B X-ray diffractometer.

## 3 RESULTS AND DISCUSSION

### 3.1 Spectrum analysis of Ni-W-P-SiC composite coatings

Fig. 1 shows the qualitative spectrum analysis of Ni-W-P-SiC composite coatings. It is clear that the composite coatings contain nickel, tungsten, phosphorus and silicon carbide species. The results of the quantitative analysis are Ni 70% ~ 75%, W 5% ~ 7%, P 9% ~ 12% and Si 9% ~ 15% (i. e. SiC 13% ~ 21%).

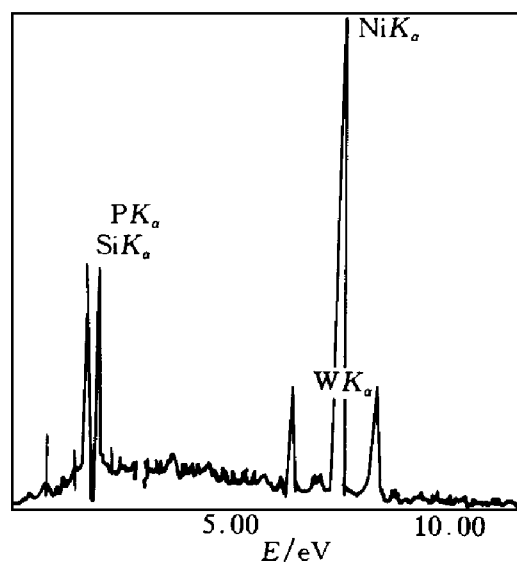


Fig. 1 Qualitative spectrum analysis pattern of the composite coatings

### 3.2 Structure of the coatings in plating status

Fig. 2 indicates the X-ray diffraction patterns of Ni-W-P alloy and Ni-W-P-SiC composite coatings with the same contents of high phosphorus (9% ~ 12%). The structures of Ni-W-P alloy and its composite coating are basically the same. Their X-ray diffraction patterns at  $2\theta = 45^\circ$  appear to be "broad" diffraction peaks, and the diffraction strength decreases gradually within wide extent of diffraction angle. This is the mark of amorphous structure. In addition, a few sharp diffraction peaks turn up in the pattern of the Ni-W-P-SiC composite coating because it contains SiC particles.

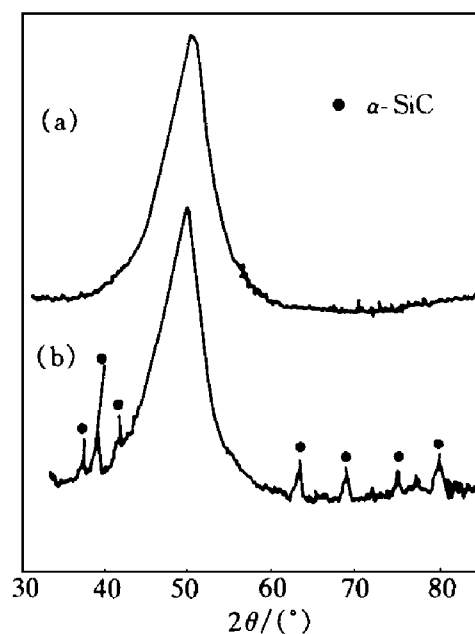
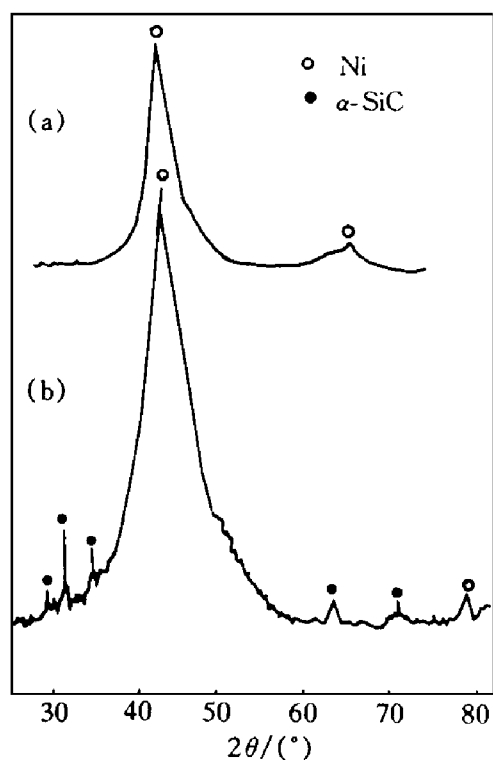


Fig. 2 X-ray diffraction patterns of high phosphorus coatings

(a) —Ni-W-P alloy coating;  
(b) —Ni-W-P-SiC composite coating

It is proved that these sharp peaks are the diffraction peaks of SiC particles. Fig. 3 shows the X-ray diffraction patterns of Ni-W-P alloy and its composite coatings with the same contents of medium phosphorus (5% ~ 7%). The sharp and narrow diffraction peaks of nickel solid solution appear at  $2\theta = 45^\circ$ . This is the mark of crystal structure.

### 3.3 Effect of heat treatment temperature on the coating structure



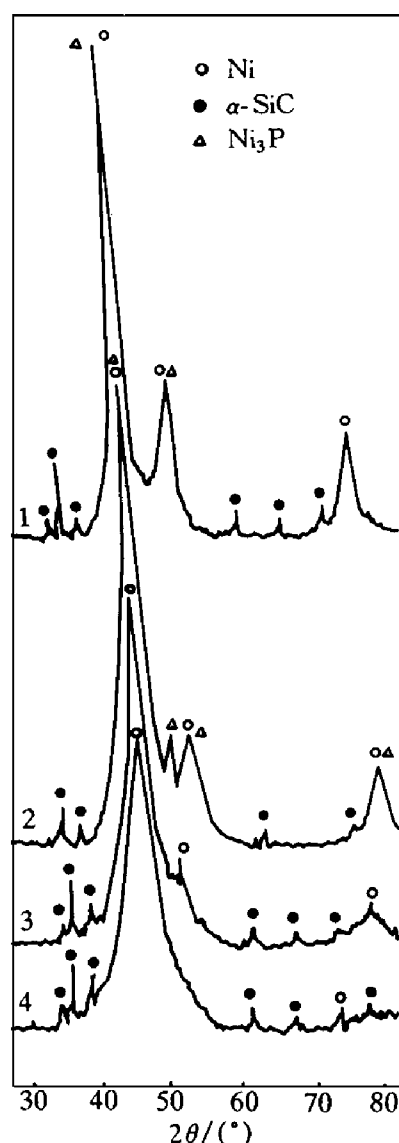
**Fig. 3 X-ray diffraction patterns of medium phosphorus coatings**

(a) —Ni-W-P alloy coating;  
(b) —Ni-W-P-SiC composite coating

Fig. 4 shows the effect of heat treatment temperature on the structure of medium phosphorus (5% ~ 7%) coatings. X-ray diffraction data indicate that medium phosphorus composite coatings are mixture in plating status and change into crystalline when heat treatment temperature is over 300 °C.  $\text{Ni}_3\text{P}$  precipitates when the temperature reaches 400 °C, and then the  $\text{Ni}_3\text{P}$  particles grow up, agglomerate and coarsen with increasing temperature. Therefore the composite coatings soften and the hardness decreases.

Fig. 5 shows the effect of heat treatment temperature on the structure of high phosphorus (9% ~ 12%) composite coatings. X-ray diffraction data display that the composite coatings are amorphous when heat treatment temperature is no more than 200 °C. But they become crystalline when heat treatment temperature reaches 300 °C, and  $\text{Ni}_5\text{P}_2$  particles precipitate and then change into  $\text{Ni}_3\text{P}$  particles at 400 °C.

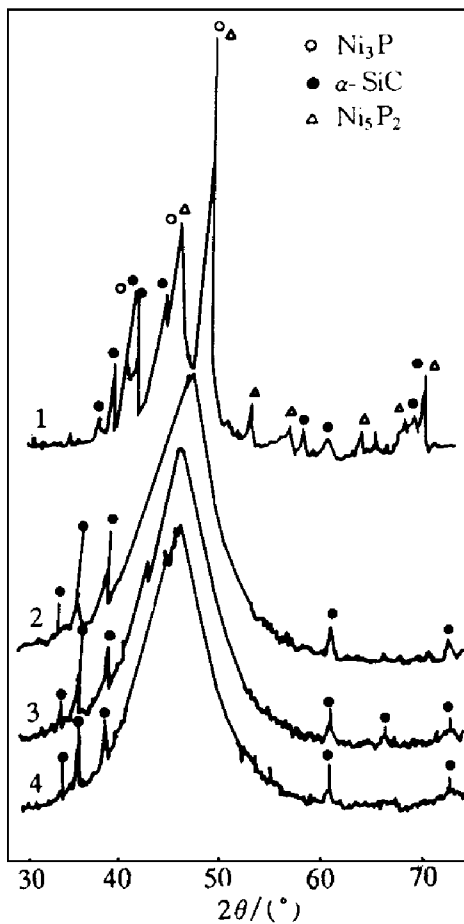
Fig. 6 shows the effect of heat treatment temperature on the structure of high phosphorus



**Fig. 4 Effect of temperature on the structure of medium phosphorus coatings**

1—500 °C; 2—400 °C;  
3—200 °C; 4—25 °C

(9% ~ 12%) composite coatings obtained from the bath containing RE. X-ray diffraction data indicate that the composite coatings are amorphous when heat treatment temperature is no more than 300 °C. However, the coatings become crystalline when the temperature reaches 400 °C, and a few  $\text{Ni}_3\text{P}$  particles precipitate. It is known from the diffraction patterns that the peaks of SiC keep constant in the process of the crystallization, and the crystallizing temperature of Ni-W-P-SiC composite coatings is increased by 100 °C when certain amount of RE is added in



**Fig. 5 Effect of temperature on high phosphorus coatings**

1—300 °C; 2—200 °C; 3—100 °C; 4—25 °C

the bath.

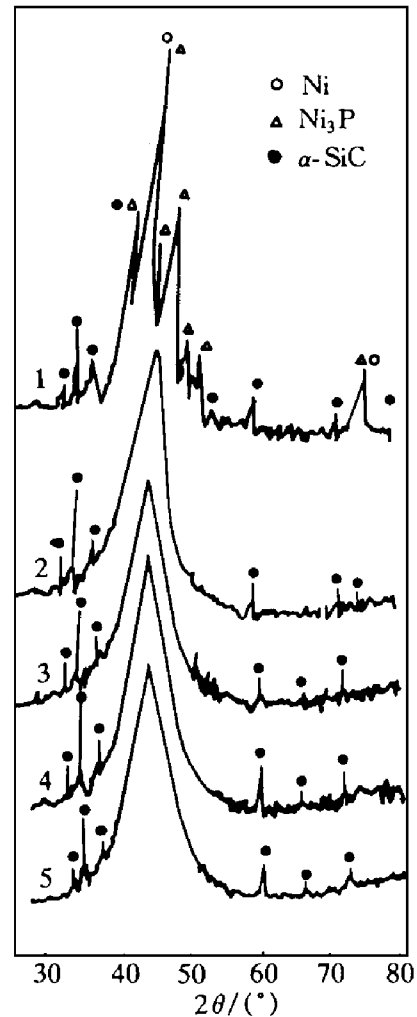
### 3. 4 Effect of nitrocarburizing on the structure of the composite deposits

The effect of low temperature nitrocarburizing on the microstructure of Ni-W-P-SiC composite deposits is shown in Fig. 7. A lot of diffraction peaks show up in the pattern, and it is proved that these phases are nickel solid solution,  $\text{Ni}_3\text{P}$ ,  $\text{Ni}_5\text{P}_4$ ,  $\gamma\text{-(FeNi)}$ ,  $\alpha\text{-SiC}$  and WC. Compared with Fig. 6, the phase components of the composite deposits are much more complicated; some new phases, such as  $\text{Ni}_5\text{P}_4$ , WC and  $\gamma\text{-(FeNi)}$  are produced after nitrocarburized. The existence of these phases enable the hardness and wear resistance of the composite to be increased.

### 3. 5 Surface morphology and microstructure of cross section of the composite coatings

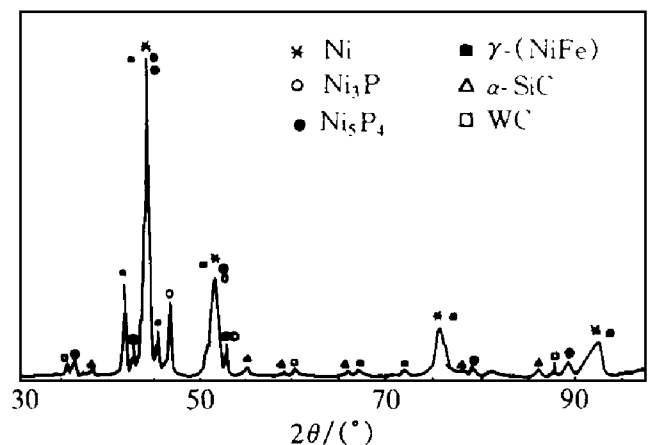
The cross section of Ni-W-P-SiC composite coatings is shown in Fig. 8(a). It is clear that

the dispersion of SiC particles (black points) in



**Fig.6 Effect of temperature on high phosphorus coatings with additive**

1—400 °C; 2—300 °C; 3—200 °C; 4—100 °C; 5—25 °C



**Fig. 7 Effect of nitrocarburizing on the structure of the coatings**

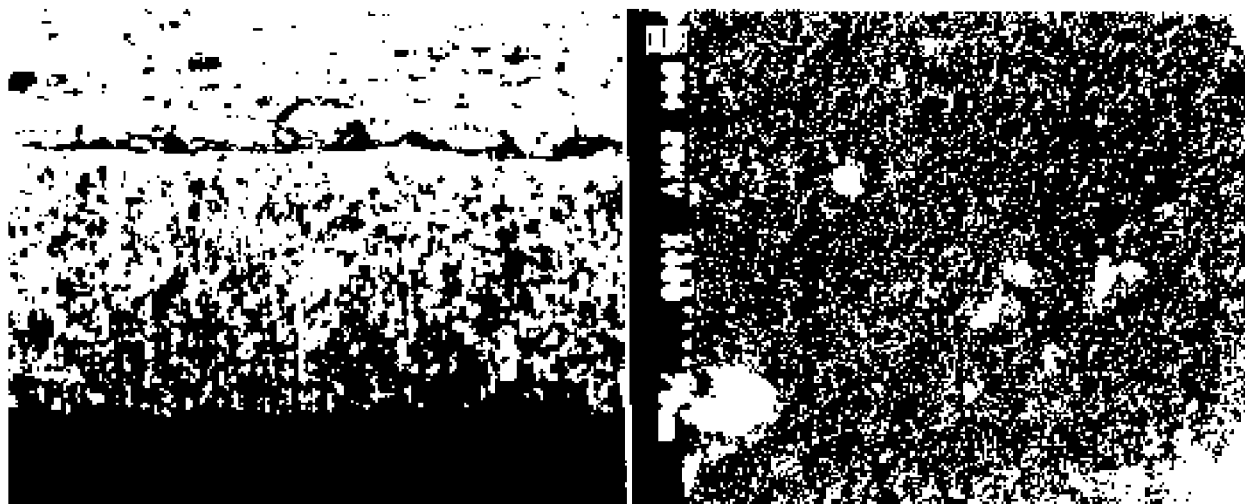


Fig. 8 Microstructure of cross section(a)  
and surface morphology(b) of the coatings,  $\times 400$

the coatings is very uniform. The surface appearance of the coatings is shown in Fig. 8(b).

#### 4 CONCLUSIONS

(1) Ni-W-P-SiC composite coatings are amorphous when phosphorus content surpasses 8% or crystal when phosphorus content is below 8%.

(2) Microstructures of Ni-W-P alloy films and its composite coatings are the same in plating status; the difference between them is that the diffraction patterns of the coatings contain the peaks of SiC particles.

(3) Heat treatment temperature has a considerable effect on the structure of Ni-W-P-SiC composite coatings, separating out  $\text{Ni}_3\text{P}$  particles and playing a precipitation hardening role when the temperature is raised to  $300 \sim 400^\circ\text{C}$ . Therefore the hardness of the coatings reaches peak value. However,  $\text{Ni}_3\text{P}$  particles increase and then agglomerate and coarsen with increas-

ing temperatures, as a result the coatings soften and the hardness decreases.

(4) The existence of SiC particles has no effect on the structure of the coatings and do not participate in the transition of the structure.

(5) The addition of RE raises the crystallizing temperature of the coatings.

#### REFERENCES

- 1 Wu Yichen. New Technology and New Process, (in Chinese), 1991, (2): 18.
- 2 Tang Zhiyan *et al.* Electroplating and Pollution Control, 1991, 11(6): 14.
- 3 Kalantary M R *et al.* Trans Inst Metal Finish, 1993, 71(2): 55.
- 4 Guo Zhongcheng. Materials Protection, (in Chinese), 1991, 24(11): 19.
- 5 Guo Zhongcheng. Materials Protection, (in Chinese), 1992, 25(5): 34.
- 6 Guo Zhongcheng. Acta Metallurgica Sinica, 1996, 9(1): 1.

(Edited by Li Jun)