

# Preparation and Characterization of Highly Conductive Nickel-coated Glass Fibers

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## Abstract

In this work, we employed an electroless nickel plating on glass fibers in order to enhance the electric conductivity of fibers. And the effects of metal content and plating time on the conductivity of fibers were investigated. From the results, island-like metal clusters were found on the fiber surfaces in initial plating state, and perfect metallic layers were observed after 10 min of plating time. The thickness of metallic layers on fiber surfaces was proportion to plating time, and the electric conductivity showed similar trends. The nickel cluster sizes on fibers decreased with increasing plating time, indicating that surface energetics of the fibers could become more homogeneous and make well-packed metallic layers, resulting in the high conductivity of Ni/glass fibers.

**Keywords :** *Electric conductivity, Nickel coating, Glass fibers*

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## 1. Introduction

All of electric devices and systems such as television transmitters, police radios, and cellular phones can cause electromagnetic interference (EMI) due to the frequencies of their switching rates [1-3]. It is a well-known fact that EMI can cause monitors and other medical devices, such as pacemakers, to malfunction. To shield EMI, traditionally, antistatic or electric materials have been strongly pursued by many researchers [1-6]. In practical application, some composite materials, which have fillers with low electric resistance, for the case of electric devices, can partially shield EMI. This is why many researchers try to develop highly conductive fibers or powers [4,5,8,9].

Conductive fillers-reinforced composites (CFRCs) can be actively applied in PTC materials, stealth aircrafts, sensors, and other many electric devices. The method to reduce electric resistance at room temperature of conductive fillers is regarded as one of key technologies in CFRCs [7-10].

Glass fibers are widely used as reinforcements in polymer matrix composites. Due to good mechanical properties and wide application area of glass fibers-reinforced composites, glass fibers are steel attractive materials to researchers. If glass fibers have a good electric conductivity, the application of glass fibers must become much wider. Conductive glass fibers-reinforced composites can be easily applied in EMI shield or stealth materials.

In this point of view, we prepared highly electric conductive glass fibers by an electroless nickel plating as a good filler material of above application area mentioned. The effects of nickel content and thickness of nickel layers on the electric conductivity were investigated.

## 2. Experimental

The glass fabrics (23×23 count/inch, 248 g/m<sup>2</sup>) used in this work were supplied from Hyun Dai Fiber Co. of Korea. For an electroless nickel plating, nickel chloride (NiCl<sub>2</sub>·6H<sub>2</sub>O), and sodium hypophosphite (NaH<sub>2</sub>PO<sub>2</sub>·H<sub>2</sub>O), respectively, were used as the molten salts and reducing agent in this system. In Table 1, chemical composition and plating condition of electroless nickel plating bath were listed in detail. The nickel plating was carried as a function of plating time, and each sample was named as as-received (non-plated), GFs/Ni-10 (10 min), GFs/Ni-30 (30 min), and GFs/Ni-60 (60 min) [7].

In order to observe the microstructures of metallic nickel plated, wide angle X-ray diffraction patterns of the GFs/Ni samples were obtained with a Rigaku Model D/MAX-III B diffraction meter equipped with a rotation anode using CuKα radiation (λ=0.15418 nm) [9,10]. A Hitachi S-2400 scanning electron microscope (SEM) was also used to observe the surface morphologies and cross-section of GFs/

**Table 1.** Chemical Composition of Electroless Ni Plating Bath

Chemical	Formula	Concentration
Sodium hypophosphite	$\text{NaH}_2\text{PO}_2 \cdot \text{H}_2\text{O}$	10.5 g/l
Nickel chloride	$\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$	28.5 g/l
Sodium, citrate	$\text{NaC}_6\text{H}_5\text{O}_7 \cdot 2\text{H}_2\text{O}$	43.5 g/l
Ammonium chloride	$\text{NH}_4\text{Cl}$	25.0 g/l
Sodium hydroxide	$\text{NaOH}$	pH 8.0

**Table 2.** Electrical Properties of Electroless Ni-plated Glass Fibers

	Plating time (min)	Ni thickness ( $\mu\text{m}$ )	Specific resistance ( $\Omega \cdot \text{cm}$ )
As-received	0	0	$> 10^6$
GFs/Ni-10	10	0.3	$3.8 \times 10^{-4}$
GFs/Ni-30	30	1.0	$1.5 \times 10^{-5}$
GFs/Ni-60	60	1.2	$0.4 \times 10^{-5}$

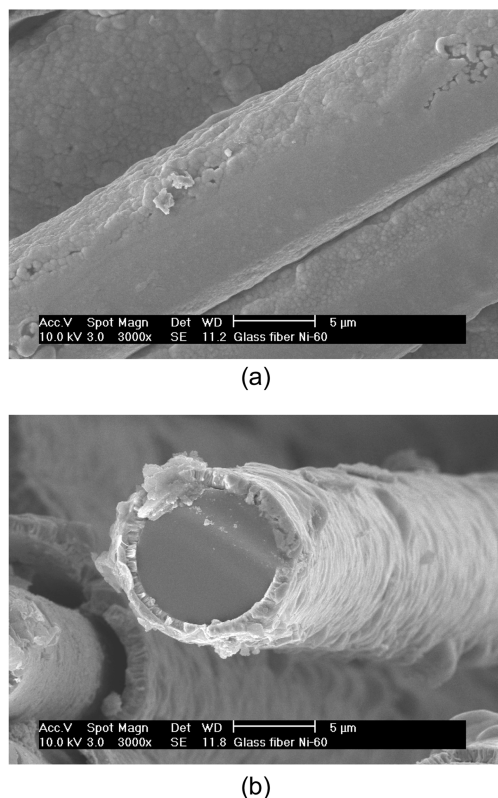
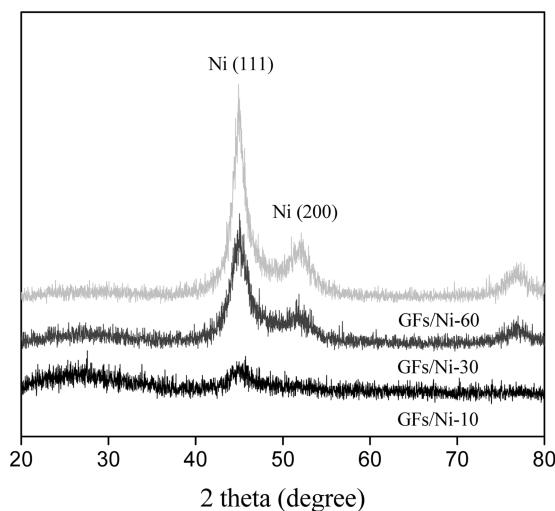
Ni samples. The electric resistivity of the GFs/Ni samples was determined by measuring the volume resistivity, which was measured at room temperature using a digital multimeter (MCP-T610, Mitsubishi Chemical Cooperation of Japan) [8].

### 3. Results and Discussion

Table 2 lists the nickel layers and specific resistance of nickel-plated glass fibers as a function of plating time. It was found that the thickness of nickel layers was almost linearly proportion to plating time. In case of specific resistance of GFs/Ni samples, the electric resistance were not decreased before 10 min of plating time, but it severely decrease after 10 min and showed equilibrium state after 30 min of plating time, indicating that metallic nickel layers were not formed before 10 min of plating time (Island-like metallic clusters were probably formed) and the layers could be perfect and dense after 30 min of plating time, resulting in the equilibrium state of electric resistance.

Figure 1(a) shows a side-view and (b) is a cross-section of GFs/Ni-60 sample. It was found that the diameter of glass fibers is around  $7 \sim 8 \mu\text{m}$  and the thickness of nickel layer is  $1.0 \sim 1.3 \mu\text{m}$ . The metallic nickel was observed to form a perfect layer, resulting in the formation of electric networks and the saturation state of electric resistivity.

Figure 2 shows XRD patterns of GFs/Ni samples as a function of plating time. It was found that Ni (111) and Ni (200) peaks increased with increasing plating time. It is interesting to note that peaks of GFs/Ni-10 samples are very broad and weak. In Table 2, the specific resistance of the GFs/Ni-10 was severely decreased compared with that of as-received sample, indicating that the electric network on fiber surface were already formed in the GFs/Ni-10 sample, but nickel peaks were too weak. From the pattern of the GFs/Ni-

**Fig. 1.** SEM images of electroless Ni-plated glass fibers; (a) a side view of GFs/Ni-60 sample, (b) a cross-section view of GFs/Ni-60 sample.**Fig. 2.** XRD patterns of electroless Ni-plated glass fibers as a function of plating time.

10, it is possible to regard that microstructure of metallic nickel layer on the GFs/Ni-10 is not dense and packed, and even cluster size may be bigger than those of other GFs/Ni samples [9].

**Table 3.** XRD Results and Nickel Crystal Size ( $L_c$ ) of Electroless Ni-plated Glass Fibers with Increasing Plating Time

	Brag angle ( $\theta$ )	d (111) ( $\text{\AA}$ )	FWHM	$L_c$ (nm)
GFs/Ni-10	22.48	2.015	0.30	18.82
GFs/Ni-30	22.49	2.014	0.67	12.76
GFs/Ni-60	22.51	2.012	0.68	12.43

In order to understand the microstructure of nickel layers on fibers, we studied the d(111) space and crystal size ( $L_c$ ), and listed them in Table 3. It is very interesting to note that the Brag angles and d(111) space of Ni(111) were changed from 22.48 to 22.51 and from 2.015 to 2.012, respectively, indicating that each nickel layer was packed densely with increasing plating time. The  $L_c$  of GFs/Ni became small from 18.82 to 12.43 nm. Normally, the nuclei for metal clusters on substrates were formed at specifically higher sites in respects of surface energetics. In initial state of the metal plating, the energetic state on glass fiber surfaces must be very heterogeneous due to the micro-cracks or gaps. In propagation state, a very thin nickel layer can be formed and it may play to make the energetic state on fiber surfaces homogeneous. The decrease of crystal sizes of GFs/Ni-10 and Ni-60 samples can be one of the proofs, and the size of Ni-60 is even smaller than that of Ni-30.

As a result, these phenomena mentioned are concluded that electric conductivity can be enhanced by electroless nickel plating when it forms a perfect layer as electric networks. Excessive plating conditions make the microstructure of nickel layers and crystal sizes of metallic nickel particles dense and small, resulting in the good electric conductivity and even saturation state.

#### 4. Conclusions

In this work, we prepared highly conductive glass fibers by electroless Ni plating method. We found that Ni/GFs showed good electric conductivity after forming a metallic nickel layer on fiber surfaces. In case of the nickel cluster size on fibers, it decreased with increasing plating time, indicating that surface energetics of the fibers could become more homogeneous and make well-packed metallic layers, resulting in the high conductivity of Ni/glass fibers.

#### References

- [1] Dhawan, S. K.; Singh, N.; Venkatachalam, S. *Synth. Met.* **2001**, 125, 389.
- [2] Kim, W. M.; Ku, D. Y.; Lee, I. K.; Seo, Y. W.; Cheong, B. K.; Lee, T. S.; Kim, I. H.; Lee, K. S. *Thin Solid Films* **2005**, 473, 315.
- [3] Chen, C. S.; Chen, W. R.; Chen, S. C.; Chien, R. D. *Int. Commun. Heat Mass Transfer, in press*.
- [4] Zhao, X.; Hirigaki, K.; Tabata, I.; Okubayashi, S.; Hori, T. *Surf. Coat. Technol.* **2006**, 201, 628.
- [5] Gawad, O. A.; Tabl, M. H. A.; Hamid, Z. A.; Mostafa, S. F. *Surf. Coat. Technol.* **2006**, 201, 1357.
- [6] Murashita, T. *Ultramicroscopy* **2006**, 106, 146.
- [7] Park, S. J.; Jang, Y. S.; Rhee, K. Y. *J. Colloid Interface Sci.* **2002**, 245, 383.
- [8] Kim, S.; Park, S. J. *Electrochim. Acta* **2008**, 53, 4082.
- [9] Park, S. J.; Kim, B. J.; Lee, Y. S.; Cho, M. J. *Int. J. Hydrogen Energy* **2008**, 33, 1706.
- [10] Park, S. J.; Jin, S. Y. *J. Ind. Eng. Chem.* **2005**, 11, 395.