Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

Nanocoating Application for the Prevention of Flow Accelerated Corrosion in Secondary System of Nuclear Power Plants

Seung Hyun Kim, Jae Hoon Huh, Jin Sung Kwak, Soon-Yong Kwon and Ji Hyun Kim
Ulsan National Institute of Science and Technology, Banyeon-ri, Eonyang-eup, Ulju-gun, Ulsan, Korea

1. Introduction

Flow accelerated corrosion (FAC) is a corrosion process in which a normally protective oxide layer on a surface dissolves in a fast flowing water. In other words, FAC is a complex corrosion process combined with mechanical reaction with fluid. Therefore, to mitigate FAC process on a surface of pipelines in the secondary system of nuclear power plants, off-line coating with nano particle is adopted. Compared to traditional coating process, it is estimated that a friction between pipeline and fluid will be greatly reduced if nanoparticle is adopted.

In this paper, graphene which is synthesized on a copper by rapid thermal annealing (RTA) method is adopted as coating material. RTA method can give more precise, reliable and reproducible graphene layer compared to chemical vapor deposition (CVD) method. To examine the corrosion resistance of graphene, electrochemical experiments including cyclic voltammetry, Tafel's plot and electrochemical impedance spectroscopy (EIS) were performed in NaCl solution under room temperature condition.

For a future work, other kinds of nanoparticle including graphene, graphene oxide, silicon carbide and titanium oxide will be examined in simulated secondary system of nuclear power plants with flowing of water.

2. Methods and Results

Graphene is synthesized and prepared by J.H. Huh, J.S. Kim and S. Kwon so this paper will focus on the corrosion resistance performance of graphene.

2.1 Rapid Thermal Annealing

For the large amount of fabrication of graphene, CVD method [1] is widely used which is based on the vapor deposition of hydrocarbon gas on a metal surface. However, this method is not suitable for the control of thickness of graphene layer and strongly depends on the chamber size, hydrocarbon gas composition and gas flow rate. In other words, CVD grahpene is very sensitive to synthesis conditions.

Compared to CVD method, RTA method guarantees more precise, reliable and reproducible graphene layer as shown in Fig. 1. As implanting carbon ion on the surface of metal substrate, carbon atoms diffuse into the gap between a metal and a substrate.

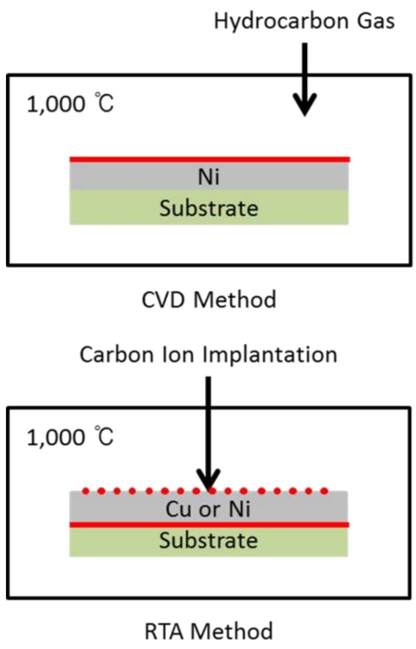

Fig. 1. Schematic of graphene synthesis by CVD and RTA method.

2.2 Electrochemical Experiments

To examine the corrosion resistance performance of RTA graphene, cyclic voltammetry, electropolarization (Tafel's plot) and electrochemical impedance spectroscopy were performed. The test solution in 0.1 M NaCl solution with Pt counter electrode and SCE reference electrode. Whole experiments were performed after N_2 purging for 30 mins and ECP was measured for 24 hrs.

Cyclic voltammetry result show that both cathodic and anodic reaction are greatly reduced due to graphene layer as shown in Fig. 2. Cathodic and anodic reactions are described as followings.

$$Cathodic: Cu \rightarrow Cu^{2+} + 2e^{-} \quad (1)$$
$$Anodic: O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-} \quad (2)$$

Tafel's plots are plotted to calculate corrosion current (I_{corr}) and polarization resistance (R_P) as shown

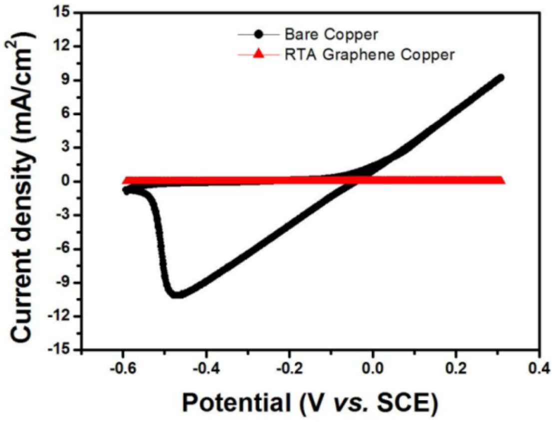

Fig. 2. Cyclic voltammetry results of bare and RTA graphene copper.

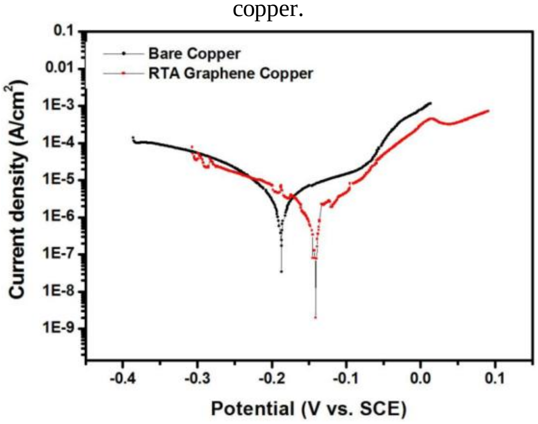

Fig. 3. Plotted Tafel's plot by electropolarization tests.

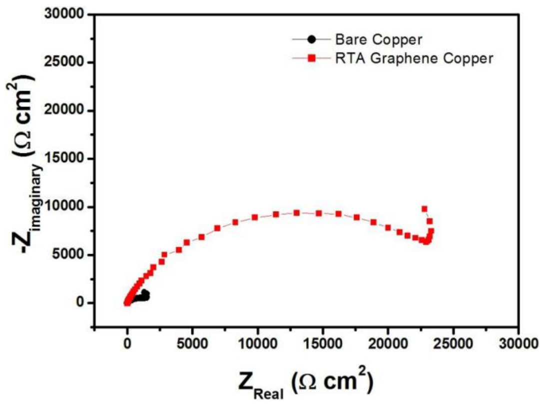

Fig. 4. Nyquist plot of bare and RTA graphene copper.

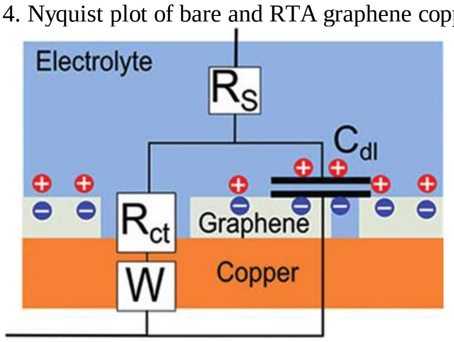

Fig. 5. Equivalent circuit for graphene coated copper [2].

in Fig. 3. It is observed that I_{corr} of graphene copper is greatly reduced compared to bare copper. Measured corrosion current and polarization resistance is described in Table I.

Table I: Corrosion current and polarization resistance

	I_{corr}, A/cm^2	Rp (Ω /cm^2)
Bare Cu	5.99*10^{-6}	4353
Graphene Coated Cu	3.33*10^{-6}	7820

The Nyquist plots which is given by electrochemical impedance spectroscopy shows that the great difference of charge transfer resistance (R_{ct}) between bare and graphene coated copper. To establish the resistance values, equivalent circuit is established [2]. Solution and charge transfer resistance of equivalent circuit is described in Table II.

Table II: Solution and charge transfer resistance.

	Rs (Ω /cm^2)	Rct (Ω /cm^2)
Bare Cu	29.87	1853
Graphene Coated Cu	30.07	25540

As summary of electrochemical experiments, RTA coated graphene shows superior corrosion resistance in room temperature conditions with NaCl solution. Polarization resistance of the coated copper is twice bigger than that of copper.

3. Conclusions

Graphene synthesized by RTA method shows the outstanding corrosion resistance performance in NaCl solution according to our electrochemical experiments. However, for the application in secondary system of nuclear power plants further studies and experiments are required especially in high temperature over 373 K.

As future work, various kinds of nanoparticle coatings such as graphene oxide, silicon carbide and titanium oxide will be examined in simulated FAC conditions.

ACKNOWLEDGEMENT

This work was supported by the the Human Resources Development of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea Government Ministry of Trade Industry and Energy (MOTIE)

REFERENCES

[1] R.K. Singh Raman et al., Protecting copper from elecrtrochemical degradation by graphene coating, Carbon 50, p. 4040, 2012

[2] D. Prasai et al., Graphene: Corrosion-Inhibiting Coating, ACS Nano, 6 (5), p. 4540, 2012