



## Effect of an alternating electric field on the atmospheric corrosion behaviour of copper under a thin electrolyte layer

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### ARTICLE INFO

#### Article history:

Received 23 March 2013

Accepted 27 May 2013

Available online 4 June 2013

#### Keywords:

A. Copper

B. Polarization

B. SEM

C. Atmospheric corrosion

### ABSTRACT

The effect of an alternating electric field (AEF) on the atmospheric corrosion behaviour of copper under a thin electrolyte layer (TEL) was investigated by potentiodynamic polarization and SEM/EDS analyses. Results indicate that the corrosion rate of copper increases with increased AEF amplitude and frequency. Furthermore, copper corrosion is more severe under a square-wave AEF than under a sinusoidal AEF. The increase in copper corrosion can be due to the damage inflicted by AEF to the oxide film on the copper surface. With the AEF, copper corrosion under a TEL significantly differs from that in bulk solution.

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### 1. Introduction

Metals are prone to corrosion because of their surrounding environment. An external alternating current (AC) that superimposes or directly flows through a metal may significantly affect the electrochemical corrosion process of the metal [1]. Metal corrosion under AC differs from that under a direct current (DC). The direction of a DC that superimposes through a metal is always the same. When anodic DC flows through a metal, the metal dissolves. When the metal connects with the negative pole, the metal becomes protected. However, when a corrosion cell is under an external AC surrounding or directly connected with AC power, the direction and amplitude of current rapidly vary with time.

In bulk electrolyte solutions, AC markedly affects the electrochemical corrosion process of metals. Kim and Koerts [2,3] performed a valuable literature on metal corrosion under AC. Generally, metal corrosion under an AC can be attributed to the stray current generated by the external AC and to the asymmetry of the anodic and cathodic polarizations of the metal [4–14]. This phenomenon results in the destruction of passive film, shifting of corrosion potential, change in polarization behaviour, and increased corrosion rate. The parameters affecting metal corrosion are the amplitude; frequency, duty cycle, and waveform of AC.

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Different parameters differently affect metal corrosion. An AC generally increases the metal corrosion rate, but the mechanism is different for different corrosion systems. In general, the effect of an AC on metal corrosion in bulk electrolyte solutions is complicated and the underlying mechanism is not clear. The effect of an AC on metal corrosion and the pertinent mechanism under a thin electrolyte layer (TEL) may differ from those in bulk electrolyte solutions; however, related studies are limited.

Electronic components in integrated circuits (ICs) are the key components of electronics and communication technology [15]. Relative humidity (RH) and air pollutants are the main factors affecting the corrosion of electronic materials. The atmospheric corrosion of electronic components in ICs generally occurs under a TEL. At RH < 100%, the thickness of a TEL is <1 μm [16]. Copper is a critical electronic material and prone to atmospheric corrosion [17–20]. Chloride, especially from polymeric packaging materials, is an important natural aggressive contaminant for enhancing metal corrosion [21]. In communication and electronic industries, copper is often used to connect various electronic chips in an IC. When the IC is used, a strong electrical field forms among the copper wires. The different corrosion behaviour of copper are expected under an electric field because the electric field affects the transfer process of ions in a TEL. The electric field pattern also affects the metal corrosion behaviour. When an external direct current electric field (DCEF) is imposed on a corrosion cell, the DCEF inevitably affects the migration of ions, the metal corrosion behaviour, and the underlying mechanism. Our previous investigation has indicated that a DCEF markedly affects the atmospheric corrosion

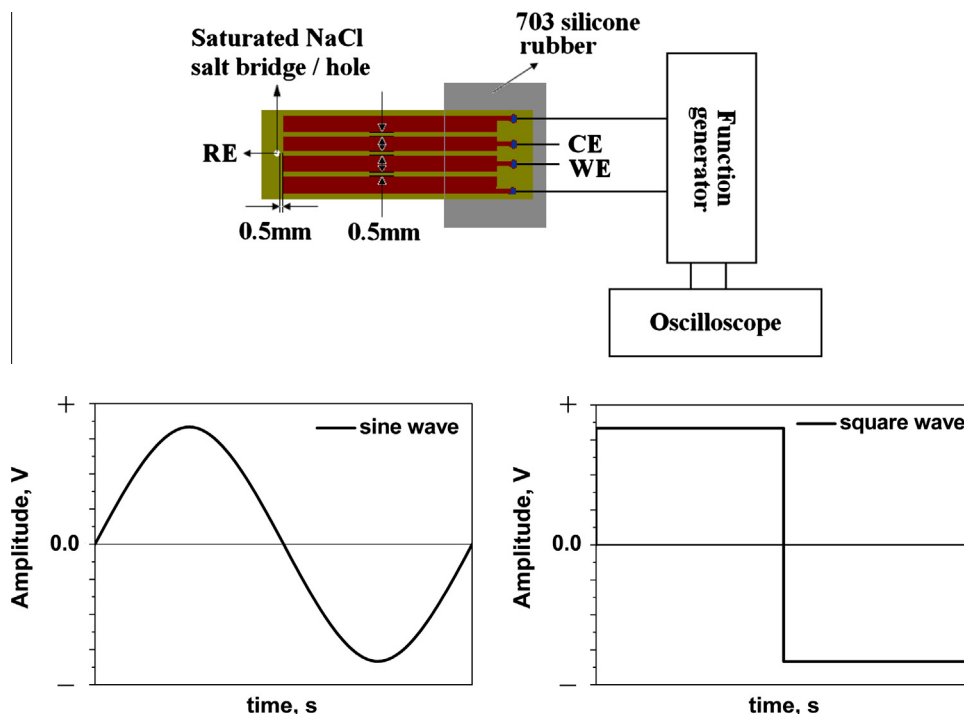


Fig. 1. Schematic diagram of PCB-Cu, AEF and waveform for electrochemical test.

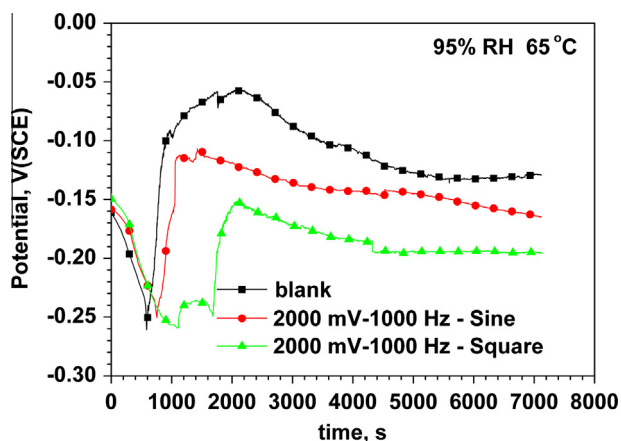


Fig. 2. The change of open current potential of PCB-Cu with time.

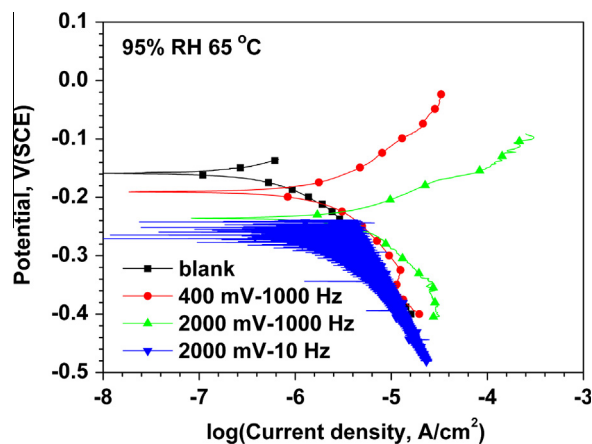


Fig. 3. Polarization curves of PCB-Cu under TEL containing 0.1 M NaCl with and without sinusoidal AEF at 95% RH and 65 °C.

behaviour of a printed circuit board copper (PCB-Cu) and  $\text{Cl}^-$  ion migration under a TEL [22]. However, the direction and strength of an alternating electric field (AEF) vary with time, and the effect of an AEF on the atmospheric corrosion behaviour of PCB-Cu under a TEL has not yet been reported.

In the present work, the effect of an AEF on the atmospheric corrosion behaviour of PCB-Cu under a NaCl TEL was investigated by potentiodynamic polarization and SEM/EDS analyses using a homemade thin-layer electrochemical cell.

## 2. Experimental

To study the corrosion mechanism of PCB-Cu under a TEL by the electrochemical method, a thin-layer electrolytic cell was developed. The experimental setup is shown elsewhere [23]. To study the effect of an AEF on the atmospheric corrosion behaviour of

PCB-Cu under a TEL, four identical PCB-Cu electrodes with dimensions of  $20 \text{ mm} \times 1.5 \text{ mm} \times 0.035 \text{ mm}$  were used (Fig. 1). The distance between any two adjacent PCB-Cu electrodes was 0.5 mm. The two outermost PCB-Cu electrodes, as two poles used to apply the AEF, were connected with a functional generator for the AEF. The two PCB-Cu electrodes in the middle were used as the working (WE) and counter (CE) electrodes, respectively. These electrodes were welded to copper wires to ensure an electric connection for electrochemical measurements, and the weld points were sealed with silicone. The PCB-Cu specimens were embedded in the upper end surface of a plexiglass cylinder. A 2 mm-diameter hole was drilled through the PCB-Cu samples and plexiglass cylinder about 0.5 mm from the WE and CE. Saturated NaCl agar was embedded in the hole as a salt bridge. The bottom of the plexiglass cylinder was connected to a U-shaped tube filled with saturated NaCl solution. A saturation calomel electrode (SCE) was placed at the

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