Microelectronics Reliability 63 (2016) 120–124

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/mr

Effects of oxidation on reliability of screen-printed silver circuits for radio frequency applications

Dae Up Kim [a], Kwang-Seok Kim [a,*], Seung-Boo Jung [b,*]

[a] Carbon & Light Materials Application Group, Korea Institute of Industrial Technology, 222 Palbok-ro, Deokjin-gu, Jeonju 54853, Republic of Korea
[b] School of Advanced Materials Science and Engineering, Sungkyunkwan University, 2066 Seobu-ro, Jangan-gu, Suwon 16419, Republic of Korea

ARTICLE INFO

Article history:
Received 15 February 2016
Received in revised form 27 May 2016
Accepted 27 May 2016
Available online 5 June 2016

Keywords:
Screen-printed silver
Radio frequency
Scattering parameter
Oxidation
Printed electronics

ABSTRACT

High reliability has become one of the crucial requirements for portable electronic devices, due to the high dependence of their radio frequency (RF) characteristics on the end-user's surroundings. The RF characteristics of screen-printed silver (Ag) circuits were investigated after a steady-state temperature and humidity storage test. A conductive paste containing Ag nanoparticles was screen-printed onto a silicon (Si) substrate and then sintered at 250 °C for 30 min in air. The printed Ag circuits were placed in a chamber at 85 °C/85% relative humidity (RH) for various durations: 100, 300, 500, 1000 h. The microstructural evolution and thickness profiles of the Ag circuits were observed with field emission scanning electron microscopy and α-step, respectively. The oxidation of the printed Ag circuit surface was analyzed with Auger electron spectroscopy. A network analyzer and Cascade's probe system in the frequency range of 40 MHz to 40 GHz were employed to measure the scattering parameters of the Ag circuits. The experimental results showed that the insertion losses at higher frequencies increased with increasing durations of exposure to the 85 °C/85% RH environment, due to the thicker specific layer for oxidation on the circuit surfaces. The oxide layer was the dominant factor affecting the RF characteristics of the screen-printed Ag thin circuits. Therefore, it is essential to control the oxidation of printed circuits for versatile RF applications.

1. Introduction

In the last few decades, lithography technology that enables millions of transistors to be compacted on a fingernail-sized chip has allowed the development of portable or mobile electronic devices that are small, light-weight, and multi-functional [1–3]. Today, portable electronic devices such as smartphones, laptops, personal digital assistants, etc., operate in the high frequency bands to allow for a high rate of information transfer in the communication system [4,5]. Simultaneously, their ease of mobility makes these portable electronic devices more likely to face various environmental stresses. For these reasons, the high demand for portable electronic devices in the mass consumer markets is driving the electronic packaging industry toward high performance and reliability.

For low-cost radio frequency (RF) integrated circuits and systems, direct printing techniques such as inkjet, gravure, and screen printing are considered as an alternative to construct RF circuits on account of their high process efficiency, short design-to-production turnaround time and environmental friendliness [6–9]. While photolithography and the conventional etching process are based on a subtractive manufacturing process, direct printing is an additive manufacturing process performed by placing conductive nanomaterials, such as nanopaste and nanoink, at the designated positions only [10,11]. Because of these benefits, the RF properties of directly printed circuits have been reported in to an attempt to expand the RF application areas of these printing methods [12–16]. However, the high reliability of directly printed circuits is certainly required for the commercialization of feasible RF applications, e.g., cellular phones, Bluetooth modules, and tablet personal computers, etc. This means that there has been an insufficient research related to the reliability of printed electronics [17].

We focused on the RF characteristics of screen-printed silver (Ag) circuits under the accelerated environmental conditions of the reliability test. The effect of the various durations of the environmental reliability test on the scattering parameters (S-parameters) of the screen-printed Ag circuits was investigated. The measured S-parameters were compared with those calculated by a computer simulation using the high frequency structure simulator, HFSS, which is a commercial finite

* Corresponding authors.
E-mail addresses: ore21@kitech.re.kr (K.-S. Kim), sbjung@skku.edu (S.-B. Jung).

http://dx.doi.org/10.1016/j.microrel.2016.05.016

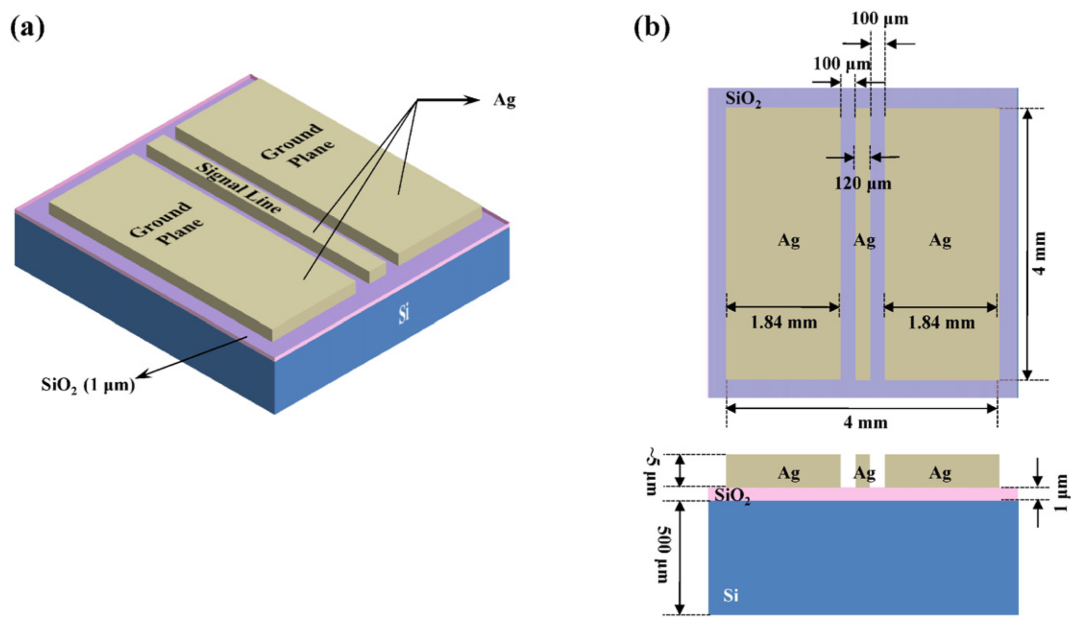

Fig. 1. (a) A 3-D schematic of the CPW-type design and (b) schematics of the sample for measurement of high frequency transmission.

element method solver for electromagnetic structures for design of RF electronic circuit elements including filters, transmission lines, and packaging.

2. Experimental details

The conductive nanopaste was manufactured with Ag nanoparticles using solvents mainly composed of α-terpineol. The mean size of the Ag nanoparticles was approximately 25 nm and their solid loading level was 73% by weight. On the stencil mask, the pattern was designed with a coplanar waveguide (CPW) for electrical characterization under a high frequency signal ranging from 40 MHz to 40 GHz. As shown schematically in Fig. 1, the signal line width and pattern gap between the signal line and ground plane were designed to be 120 and 100 μm, respectively. A screen printing machine (MT-550TV, Microtec, Japan) was used to duplicate the CPW-type circuits using a 400-meshed stencil mask. The Ag nanopaste was printed onto a silicon (Si) substrate passivated with SiO_2. All of the printed films were dried on a hotplate at 70 °C for 10 min and then sintered at 250 °C for 30 min in air, using a box-type muffle furnace (RTA-BRT100, BLS Korea Inc., Korea). After the sintering process, the specimens were placed in a chamber at 85 °C/85% RH for various durations (100, 300, 500 and 1000 h) in accordance with the industrial test standard (EIA/JEDEC A101-B). This steady-state temperature and humidity lifetime test is generally performed to evaluate the reliability of nonhermetically packaged IC devices in humid environments [17]. An Anritsu ME7808A Broadband vector network analyzer and Cascade's probe system over the frequency range from 40 MHz to 40 GHz were used to measure the S-parameters of the Ag thin films

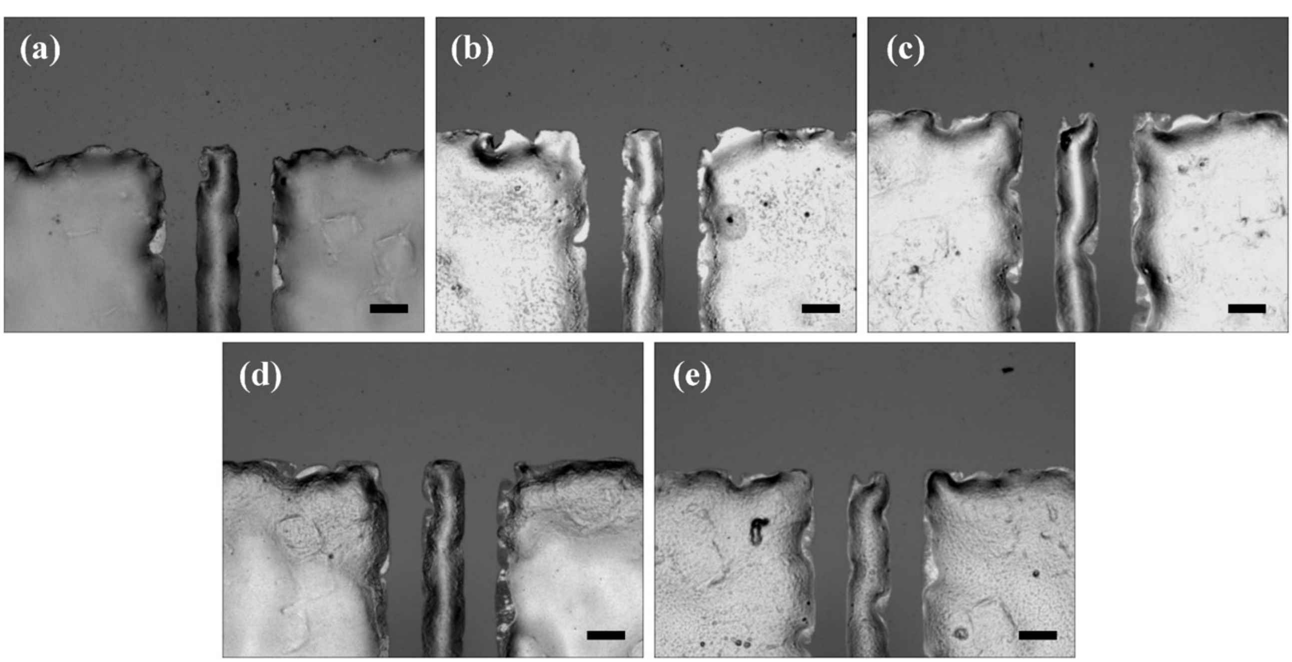

Fig. 2. Optical views of the screen-printed Ag circuits exposed to the 85 °C/85% RH environment for various durations; (a) 0 h, (b) 100 h, (c) 300 h, (d) 500 h, and (e) 1000 h (scale bar = 100 μm).