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Fabrication of metal electrodes on flexible substrates by controlled deposition of conductive nano-ink

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ABSTRACT

In this study, a novel process was developed for the fabrication of ultrafine electrodes on flexible substrates. Conductive fine electrodes using silver nano-ink on polyimide (PI) film were obtained by means of plasma-enhanced superhydrophobic technology. The plasma etching conditions were optimized for the formation of a superhydrophobic layer on the surface of the PI film. A micro-trench on the hydrophobic PI film was then formed by mechanical scratching, thus imparting hydrophilic properties only to the trench area. Finally, the fine electrode was realized by the selective deposition of aqueous silver nano-ink on the trench region. The electrical properties of the conductive electrodes fabricated using silver nano-ink with an average particle size of 50 or 200 nm were investigated and the microstructure of the electrodes was observed using an electron microscope at sintering temperatures ranging from 150 to 400 °C. In addition, the addition effect of silver nanowire to silver nano-ink was examined to assess the improvement on the conductive properties of electrode.

1. Introduction

Substrates with fine metal electrodes can be assembled with inorganic devices by various printing technologies and the final structures can be utilized for displays and solar cells [1–3]. Particularly, metal electrodes with ultrafine pitches and widths can be used as essential components for various devices, such as flexible printed circuit boards (FPCBs), radio frequency identification (RFIDs), and light emitting diodes (LEDs). For these applications, it is necessary to fabricate fine electrodes for the transmission of electrical signals in flexible electronics and to develop durable electrodes that work under the harsh conditions associated with the bending or stretching of flexible substrates [4,5].

Over the past few decades, complex and expensive methods involving the use of precise exposure facilities, high vacuum systems and deposition equipment have been applied in the fabrication of fine electrodes for flexible displays. However, conventional fabrication technologies are very limited when used to manufacture ultra-fine electrodes with micro-sized widths due to the technical limits during the etching process. The damascene process as an advanced semiconductor manufacturing method also requires multiple steps, including a chemical mechanical polishing (CMP) process with associated disadvantages such as material loss and the generation of harmful wastes products [6–8]. Therefore, direct printing technologies such as inkjet and roll-to-roll printing are under development at present. However, these methods also have limitations related to electrical conductivity, the quality of the electrode, accuracy, productivity rates, and cost. Thus, it is necessary to develop an advanced processing technology for ultrafine patterning [2,3].

In this study, a novel process was developed to form fine trenches on flexible substrates treated by plasma etching and then to deposit a fine electrode using metallic nano-ink consisting of metal nanoparticles or nanowires. Using mechanical scratching, a hydrophilic trench region was fabricated on a flexible substrate with a superhydrophobic surface prepared by a sequential plasma treatment. A controlled deposition process of aqueous metallic nano-ink was then performed only on the trench region to fabricate conductive electrodes. The effects of the sintering temperature, particle size of the ink, and the addition of nanowires on the electrical conductivities of the electrodes were studied.

2. Material and methods

50-μm thick polyimide (PI) films with high thermal resistance were used as flexible substrates (UPILEX-50S, UBE). Aqueous silver nanoparticle suspensions with average particle sizes of 50 or 200 nm (PI-015, PS-004, PARU) were used as the conductive ink materials for the formation of the electrodes. The aqueous silver

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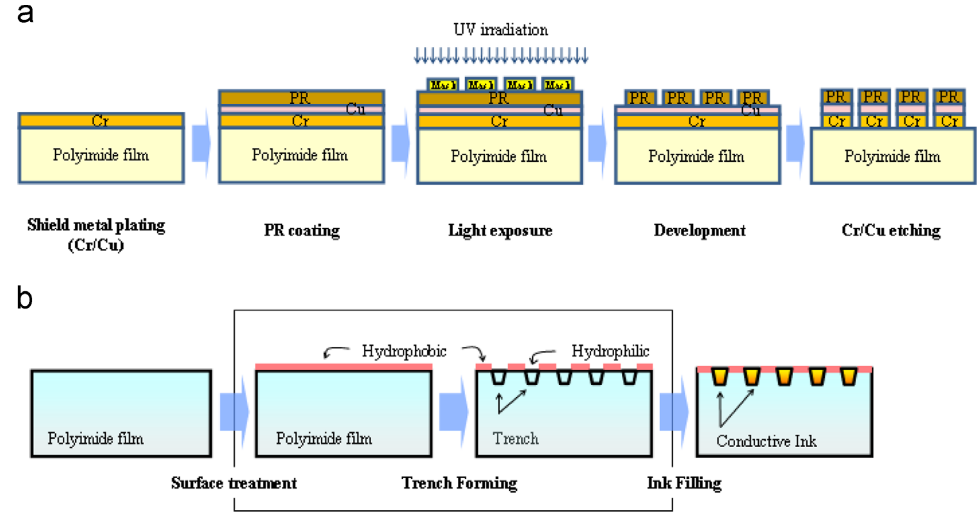

Fig. 1. Schematic diagrams showing the fabrication process of an electrode on a substrate: (a) the conventional lithography process and (b) the trench-based scheme proposed in this study.

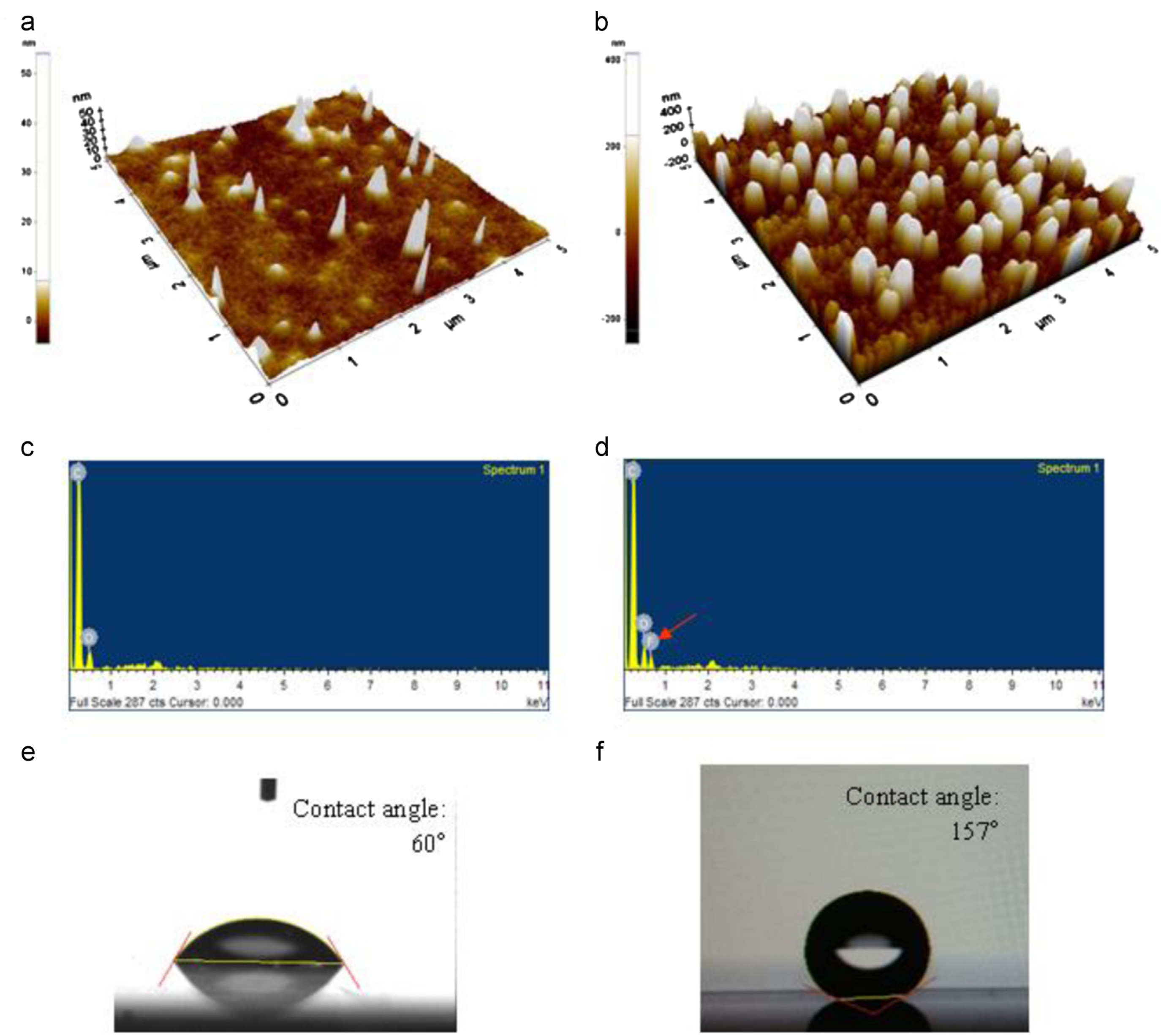

Fig. 2. Surface properties of a polyimide film sample before and after the plasma treatment: (a) and (b) AFM analysis results, (c) and (d) element analysis results (EDS), (e) and (f) contact angle measurements of water droplets.