Au and Ag sputter deposition on printer paper

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Abstract. We study metal-coated paper for low cost sensor applications. Sputter deposition is used to coat commercially available stationary printer paper with Au or Ag thin films. Two kinds of substrates are used: copy paper and glossy photo paper. The surface morphology, coating structure and electrical resistivity of the samples is studied. We find that after deposition of a nominally 100 nm thick metal layer the templates retain their initial morphology, which is fibre-like at the copy paper and flake-like at the photo paper. The metal-coated paper is conductive in both cases, with resistivity a few times higher than the bulk value. The photo paper samples have lower resistivity than the copy paper ones. Moreover, no observable resistivity variation is observed after 8 weeks of room temperature storage in a desiccator.

1. Introduction

Paper is a low-cost, foldable, lightweight, environmentally-friendly material that can be fabricated at thin sheets, easily stackable, stored and transported; it is currently being investigated as substrate for inexpensive healthcare sensors fabrication [1, 2] and for foldable electronics applications [3, 4]. In most cases, metal-coated paper-sheets are used as electrodes. The main approaches for metalizing paper include physical vapor deposition [2-4], conducting inkjet printing [4], and electrodeposition [5], while various types of paper substrates and metal coatings have been studied [2-5].

In this work we study common stationary paper, sputter-coated with Au or Ag. The advantage of sputter-deposition is that allows for the metallization of paper substrates without using liquid solvents that could degrade paper properties. Additionally, the use of stencil masks with μm-size features during deposition could allow for the creation of patterns without using lithography-based patterning that includes lift-off processes and wet etching [2]. Finally, sputtering is an industry-compatible technique, allowing for the deposition of large area coatings. Thus, a totally dry process may be developed for fabricating micro-patterned sensor arrays on paper.

2. Experimental

Paper substrates were coated at room temperature using an ultra-high vacuum (base pressure 1.5×10⁻⁹ Torr) magnetron sputtering system (ATC 2200-V, AJA Inc., USA). Significant degassing was observed during load-lock pump-down, due to the porous morphology of the paper substrates which results in high water absorption. The source material was metallic Au or Ag (99.995% purity) and the working gas was high purity Ar at 3 mTorr pressure. Direct Current (DC) power was applied to the
target (7.5 W/cm²), leading to a growth rate of 0.48 nm/s. The substrates used were commercially available copy paper (density: 80 g/m², thickness: 100 μm), or glossy photo paper (density: 200 g/m², thickness: 200 μm). Test samples were deposited side-by-side on Si(100) substrates for comparison purposes.

The surface morphology of the samples has been studied using optical microscopy and Atomic Force Microscopy (AFM). A Bruker Icon AFM has been employed using commercial AFM probes (Nanosensors PPP-FMR). X-ray diffraction (XRD) structural analysis has been performed using a Siemens D500 diffractometer with Cu-Kα radiation, in steps of 0.03° and counting time 12 s/step. The room-temperature film resistivity has been determined by Van der Pauw (VdP) measurements performed on square samples using a programmable current source (Keithley 220) and a multimeter (Keithley 2000). Electrical contacts were made at the sample edges using silver paint.

3. Results and discussion

Figure 1 shows the surface morphology characterization as obtained by optical microscopy and AFM. In figure 1a Au-coated copy paper is shown; its morphology is dominated by the highly-entangled cellulose fibers of the paper substrate, revealing the high porosity of copy paper. Figure 1b shows an AFM image of the copy paper: the apparent metal coated fibers have diameters of several μm and the surface roughness is approximately 1 μm. Figure 1c shows an AFM image of the photo paper surface before metal deposition. The surface is substantially smoother compared to the copy paper, with sub-μm flake-like features dominating its morphology. No considerable alteration of the surface morphology is observed after deposition of a 100 nm thick Au layer (figure 1d); the surface roughness is approximately 60 nm before and after deposition. It should be noted that similar results are also obtained for Ag-coated paper substrates (data not shown).

![Figure 1](image-url)

*Figure 1* (a) Optical micrograph and (b) AFM image of Au-coated copy paper. AFM images of (c) photo paper and (d) Au-coated photo paper.
The fabrication of high sensitivity and accuracy sensors for quantitative analysis requires the patterning of μm or sub-μm features with sharp edges. From the surface morphology characterization of our samples, it becomes immediately apparent that the fibrous morphology of copy paper renders it unsuitable for such applications and it could only be used as a substrate for fabricating mm-sized qualitative indicators. However, the highly porous morphology of copy paper would be advantageous for applications that require high effective metalized surface area, e.g. for the fabrication of paper-based super-capacitors [5]. On the other hand, the much smoother surface morphology of photo paper allows for the patterning of μm-scale features and the fabrication of more complex configurations.

Figure 2 shows XRD graphs of the samples. The XRD graphs of uncoated copy and photo paper show the characteristic calcite peaks (indicated by stars), due to the calcite additives used for paper manufacturing. The XRD graphs of the test coatings on Si show the characteristic peaks of Au or Ag crystallized to fcc structure. Furthermore, the Si(100) substrate gives rise to the strong peak at around 68°. All paper samples were mounted onto Si substrates for facilitating handling; this explains the Si peak present at the copy paper samples. However, no Si peak appears at the photo paper samples, as it has twice the thickness of the copy paper. In all cases, the characteristic peaks of fcc Au or Ag are apparent at the coated-paper samples, revealing the polycrystalline microstructure of the deposited coatings.

**Figure 2** XRD θ-2θ graphs of the studied samples: (left) Au-coating, (right) Ag-coating. The substrates used were Si, copy paper (paper-80), and photo paper (paper-200).

Figure 3 shows the resistivity of the samples as determined by Van der Pauw measurements. For comparison, the bulk Au and Ag resistivity values are also shown. The resistivity increase observed at the 100 nm thick films deposited onto Si is due to the additional electron scattering at the top and bottom film interfaces. Resistivity further increases at the metal-coated photo paper samples: it reaches 10.4 μΩ·cm for Au coating and 4.1 μΩ·cm for Ag coating; this increase is attributed to the flake-like morphology of these samples which results in higher defect density and thus higher electron scattering. Finally, resistivity increases even further at the metal-coated copy paper samples it reaches 17.5 μΩ·cm for Au coating and 12.1 μΩ·cm for Ag coating; in this case, the fibrous morphology of the samples probably results in longer conducting paths, in addition to the increased defects density. It should be noted that the resistivity of the samples has been measured after 8 weeks of storage in a desiccator and no variation is observed, within the experimental error of the measurement method (data not shown). Since metal-coated paper substrates are studied for use as electrodes in sensors and electronic circuits, low resistivity is important for minimizing resistive heating and power dissipation.
upon device operation. In this context, metal-coated photo paper is more suitable for use as a flexible, low cost, environmentally friendly, and conductive substrate.

![Resistivity values of the coated samples](image)

**Figure 3** Resistivity values of the coated samples

4. Conclusions
We have studied Au or Ag coated copy and photo paper. It is shown that metal-coated photo paper is more suitable for flexible electronics and inexpensive quantitative sensors applications due to its low roughness, which allows for patterning μm-scale features and also results in lower resistivity. On the other hand, metal-coated copy paper would be more suitable for large-area qualitative indicators, easily detected by the naked eye, or for applications that require high effective surface.

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