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Research Article

Fabrication of Silver Interdigitated Electrode by a Stamp Method

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A stamp method was developed in this study to fabricate interdigitated electrodes (IDEs) on glass substrate from a 37.5 wt% silver ink. This method is simple and fast. A small amount of silver ink was first dripped into an IDE-patterned sponge of a stamp and then one could stamp out the desired IDE pattern made of nanosized silver colloids on a glass substrate, which was subsequently sintered at 280°C for 10 minutes to obtain the final silver IDE. Our brief study showed that when a large stamping force was used, more ink would be stamped out in the beginning and it decreased after each usage. However, if the force was too small, there would not be sufficient ink for a complete IDE. There existed therefore an optimal force to fabricate IDEs with minimal changes from sample to sample. The average dimension of an IDE when the applied force was 102 gm was roughly $403 \pm 20\,\mu$m in width and 1154 ± 153 nm in height, and the average final electrical resistivity was about $10 \times 10^{-6}\,\Omega$-cm.

1. Introduction

Interdigitated electrodes (IDEs) are widely used for various sensor applications, such as gas sensor, humidity sensor, biosensor, and so forth [1–10]. The IDE is often chosen as a component for those sensing operation, where electrical signals generated by the sensing material have to be detected via IDEs. In many of these examples, the IDE was fabricated by photolithography in a lift-off process. In some cases, very fine lines, in the range of 250–500 nm in width, can be produced in high density in this manner. The number of fingers can be up to 2000. More often, the width of the digit (finger) is on the order of 3 to 15 μm and the number of fingers is around several hundred for this method. Several different metals had been used for this application, for example, Au, Pt, and Pd-Ag, which were often deposited by sputtering or e-beam evaporation and its thickness is in the range of 30 to 300 nm.

The photolithography process consists of many steps and requires the use of special equipment. Therefore, there are a few efforts in recent years to try to simplify the fabrication process for IDEs. For example, Kim et al. [11] used a laser-printing technology with silver ink on a glass substrate. By adjusting printing parameters, the authors were able to produce IDEs having width between 6 and 28 μm and thickness below 1 μm. The resistivity of the resulting Ag IDE was ~20 $\mu\Omega$cm. Screen printing was another technique adopted to fabricate usable IDEs for various sensor applications [12, 13]. On the other hand, Tseng et al. [14] used ink jet printing to first prink Pd colloids, followed by electroless plating of Ni on polyethylene terephthalate (PET) substrate. Successful patterns could be obtained when the line width was above 30 μm. However, they have to perform a gold displacement process afterwards to improve the electrical conductivity of the interdigitated sensors.

The objective of this work is to develop a simple method to fabricate an IDE on glass substrate by using a stamp and silver ink. The concept of using a stamp to produce desirable pattern had been reported for several different systems [15–18]. The dimensions of final patterns depend on the methods for producing similar patterns in the stamp. Here, we will use a relatively fast and cheap method to produce the stamp to be used in association with silver ink to fabricate interdigitated electrodes. We will demonstrate the feasibility of this process and also report the dimensions of the resulting IDEs, which can be used for various sensor studies in the future.

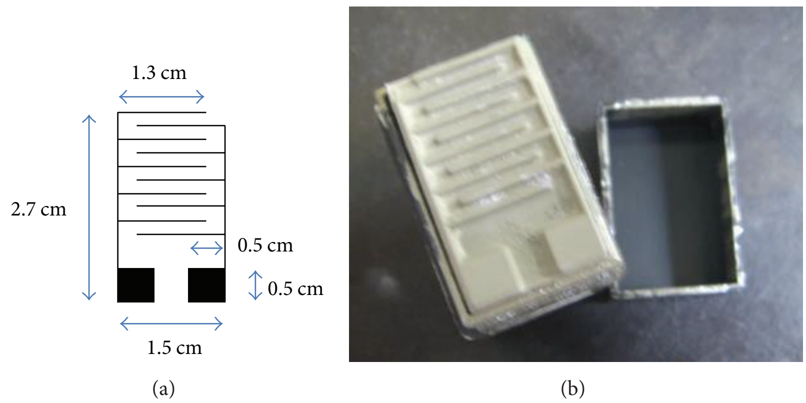


FIGURE 1: Schematic diagram of the dimensions of interdigitated electrode and the actual stamp with IDE pattern.

2. Materials and Methods

Shown in Figure 1 is a schematic diagram about the dimension and structure of the IDE (with five fingers) fabricated in this work. Spacing between fingers was designed at about 2 mm. However, in reality, after the ink was pushed out of the stamp, the silver colloids usually spread a little bit so that the spacing would be shortened to 1.3 to 1.5 mm.

This IDE pattern was first carved via hot metal plate into an ordinary stamp. To begin the experimental procedure, 0.15 mL of 37.5 wt% silver ink (Da-Shuan Applied Material, Hsinchu, Taiwan) (viscosity 6.3 centipoise) was uniformly dripped into the stamp. After about 10–15 minutes, when all the ink was completely soaked by the stamp, patterns of IDE could be stamped onto glass substrates (two IDEs on each substrate). About 40–50 patterns could be consecutively produced with this amount of ink. Two different forces, 102 g and 152 g, were tested in this study. These two forces were generated by simply glue several glass slides together. The stamp was pushed straight down with the above force for about 1 second to let ink flow onto the substrate before lifting. These samples were subsequently sintered at 280°C for 10 minutes to obtain the final IDEs.

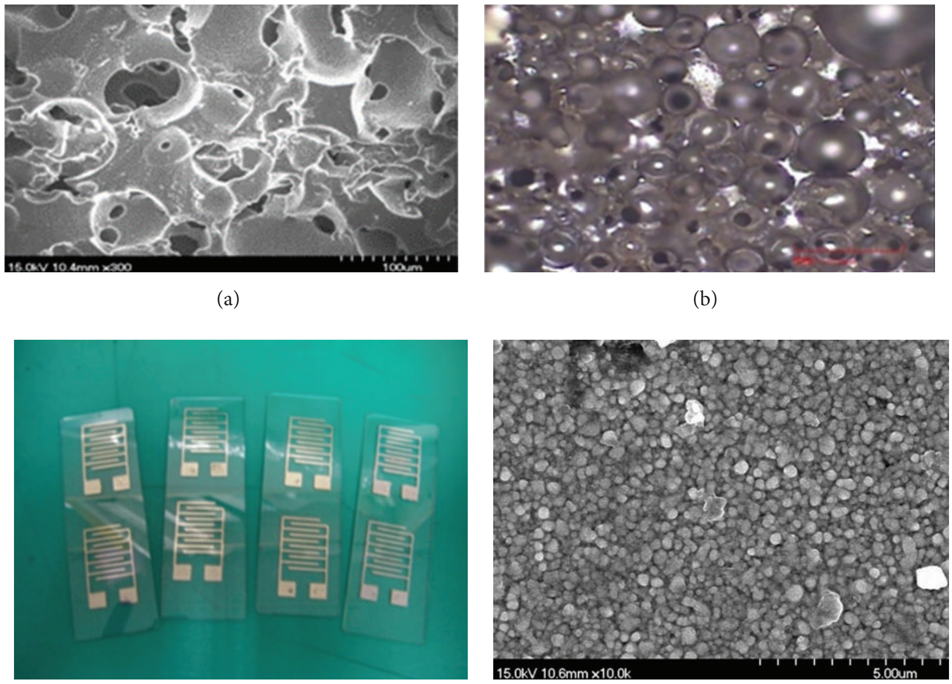
α-step (Dektek 150, Veeco, USA) was used to measure the profiles (width and height) of the IDE fingers. Here, the width was measured in micron and height in nm. These measurements were repeated three times for each sample and averages were recorded. The surface morphology was observed by scanning electron microscopy (SEM, S-4700 I, Hitachi, Japan) and the volume resistivity determined from data by 4-point probe (2400-C SourceMeter, Keithley, USA) and α-step measurements.

3. Results and Discussion

Shown in Figure 2 are the pictures of the sponge Figure 2(a), sponge loaded with silver ink Figure 2(b), and the final IDEs on glass substrate Figure 2(c). The color of the sponge changed somewhat after ink loading. When the stamp was pushed down by a suitable force, a certain amount of ink could flow out of the sponge onto the glass substrate to form the desired pattern. The surface morphology after sintering was exhibited in Figure 2(d). The silver colloids were connected by the heat treatment to provide passage for electrical conduction. There might be some small sunken area (upper left region in the picture) probably caused by the lift action of the stamp. However, it is expected not to influence the electrical conductivity of the IDE.

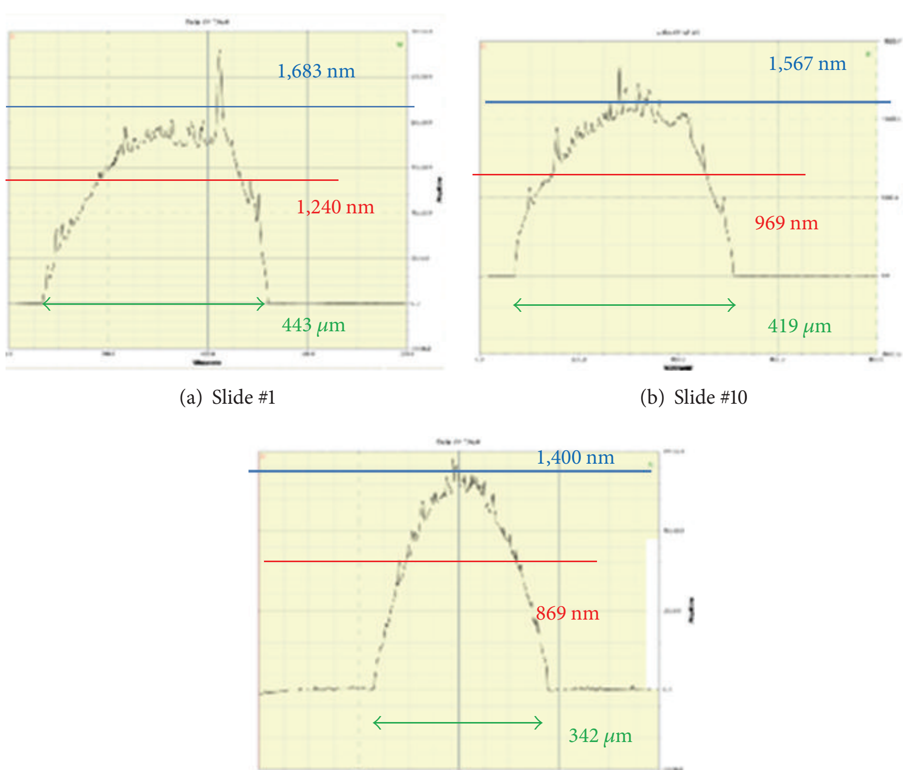
3.1. Effect of Applied Force. Preliminary studies indicated that the amount of ink which was pushed out of the stamp was not enough to form a continuous pattern of IDE when the applied force was less than 100 gm. Results from two different forces, that is, 102 and 150 g, were presented here. First, shown in Figure 3 are examples of these profiles from α-step measurement. These schematic profiles were not drawn in proportion. The units for width and height were in μm and nm, respectively. The maximum height, average height, and average width were shown for each profile. Average height was determined by dividing the total area under the profile by the average width, which was performed by the instrument itself. These data will be used for correlation with sample numbers.

Next, shown in Figure 4 are the correlations of average height and average width with sequence number of samples for the two cases of different applied forces. Clearly, in both cases, the width and height decreased with sequence number. However, the decreasing trend is smaller when the applied force was 102 gm. Using a larger force, more ink will flow out of the stamp in the beginning and decreased at a more rapid rate after each usage. As a result, both average height and width decreased more noticeably with usage as shown in these figures. Since the stamping action was manual, there were some inevitable fluctuations as expected. Nevertheless, they were within the range of expectations. When the applied force is 102 gm, we could not get conductive samples after number 20 due to insufficient ink being pushed out of the stamp. In view of these results, one can therefore in the future devise a scheme where the applied force is increased gradually, or stepwise, to minimize the differences between samples.



(a) (b) (c) (d)

Figure 2: Photographs of (a) sponge of the stamp; (b) sponge loaded with silver ink; (c) final IDEs obtained in this work; (d) SEM of top surface of silver electrode after sintering.



(a) Slide #1

(b) Slide #10

(c) Slide #20

Figure 3: Representative results of profiles from α-step measurement. top: max height, middle: average height, and bottom: average width.

Table 1: Volume resistivity of a few IDE samples.

Sample	1	2	3	4	5	6	7	8	9	10	Average
Volume resistivity 10^{-6} Ω-cm	13.5	13.4	17.3	19.4	5.3	3.2	8.3	2.4	7.3	8.0	10.0 ± 5.8

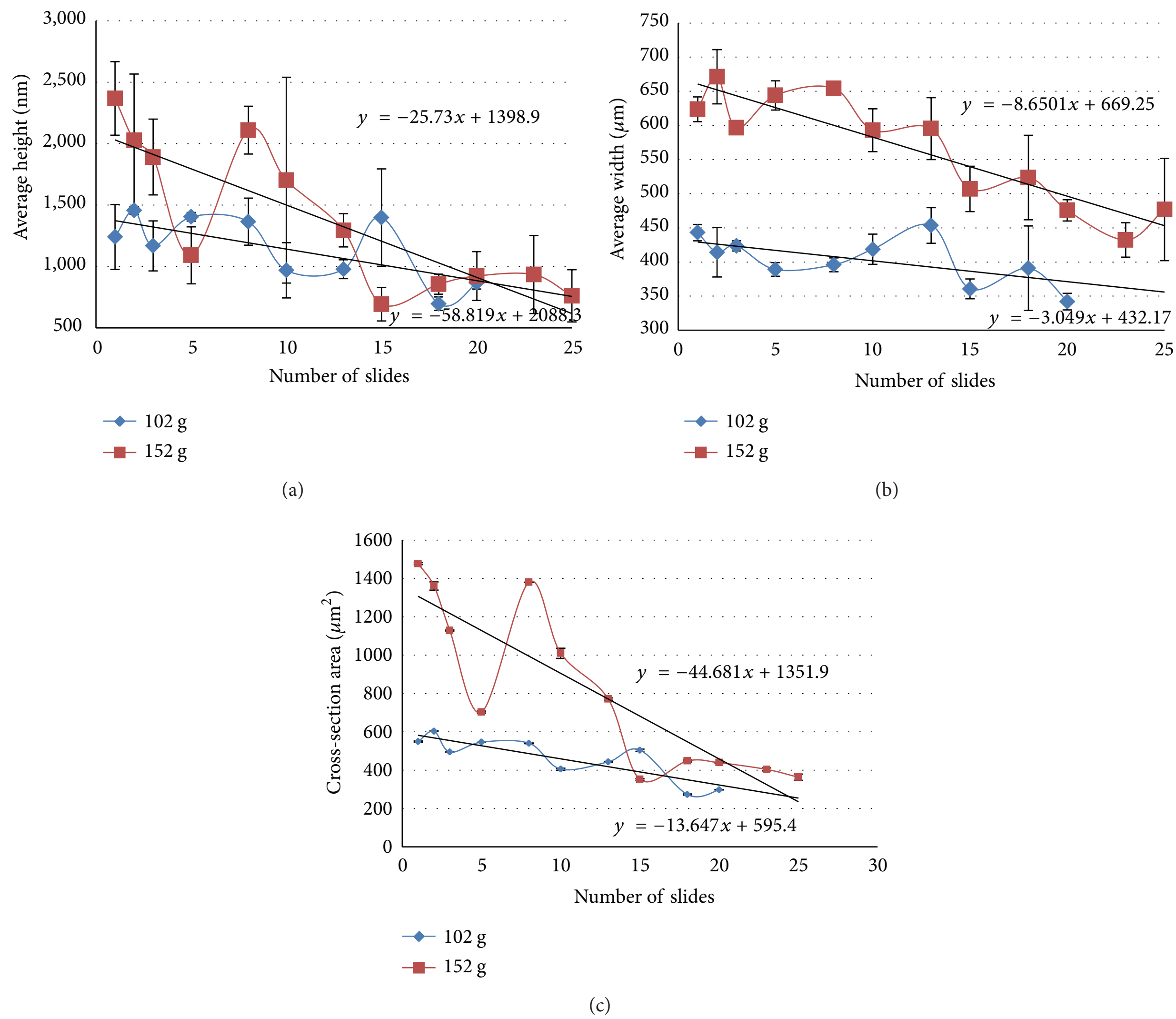


Figure 4: Results of the stamp method to fabricate IDE: (a) average height; (b) average width; and (c) cross-section area of finger in IDE versus the sequence number of slides.

Finally, the electrical resistivity was determined for a few samples and the data were exhibited in Table 1. Some degree of variations was observed, probably due to our manual operation in this study. Nevertheless, the average value at 10 × 10^{-6} Ω-cm of the IDE seemed reasonable for many future potential applications.

4. Summary

A simple stamp process was demonstrated to be feasible to quickly generate IDEs with reasonable electrical conductivity. All what were needed were silver ink and a patterned stamp. Our results indicated that when the applied force was 150 gm, the amount of ink being pushed out of the stamp decreased more rapidly than the case when the force was only 102 gm (i.e., variation between samples being larger). The average dimension of an IDE when the applied force was 102 gm was roughly 403 ± 20 μm in width and 1154 ± 153 nm in height, and the average electrical resistivity was about 10 × 10^{-6} Ω-cm. These IDEs can be used in future sensor studies. In theory, the important parameters of this method include at least magnitude of applied force, duration of pressing, and dimension of patterns on the stamp. The dimension of IDEs fabricated by this method may be further decreased if one can generate finer IDE pattern on the stamp; increase ink viscosity by increasing solid content in the ink; and so forth. Moreover, the variation between samples can be minimized if the operation can be performed automatically instead of manually. More studies are obviously needed to understand more details about this new and simple technique.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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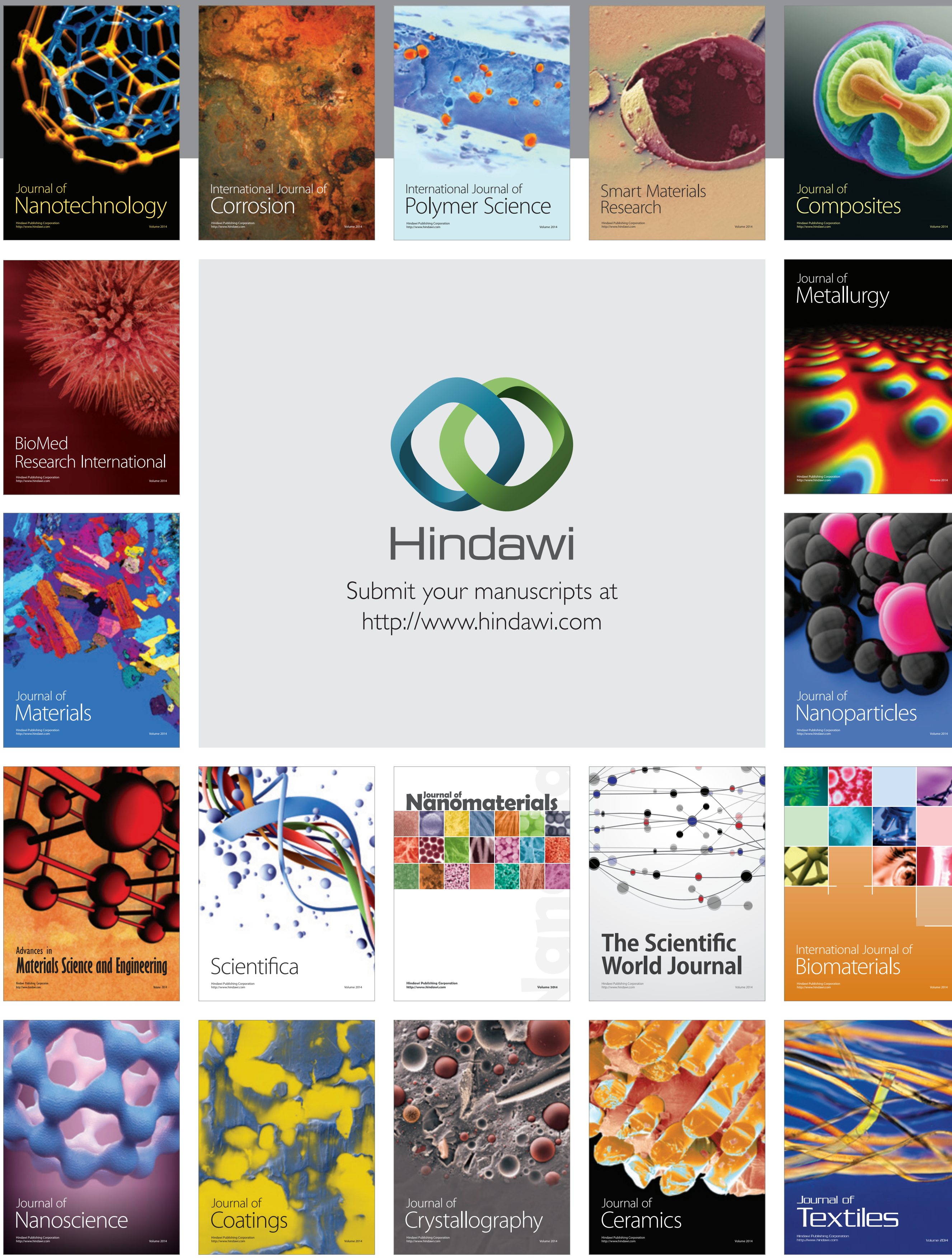
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