

Micro-fabrication of Flexible Coils with Copper Filled Through Polymer Via Structures

Q. S. Zhu^{1,2}, A. Toda³, Y. Zhang^{1,2*}, T. Itoh^{1,2}, R. Maeda^{1,2}

¹NMEMS Technology Research Organization, Japan

²National Institute of Advanced Industrial Science and Technology (AIST),
Japan,

³Meltex Inc., Japan

Email: yi.zhang@aist.go.jp

Abstract. In this work, we present one flexible 3D micro-coil. This 3D micro-coil is successfully prepared in a thin polymer film with a thickness of 120 μ m. The flexible coil is expected to be used in current sensing and energy harvesting MEMS those require a large deformation degree to wrap target object. A typical micro-machined 3D coil is composed of bottom, vertical and top windings. We firstly adopt through polymer vias (TPVs) and metal filling technology to fabricate the vertical windings. A high-speed copper electrodeposition technology of TPVs is developed to obtain void-free vertical windings.

1. Introduction

A high performance inductor is the key component for various radio frequency (RF), sensor, and energy harvesting MEMS. Silicon-based technologies are the mainstream for integrated circuit designs catering to both mass consumer and commercial applications. For the last two decades, polymer materials have been gaining more attention in inductor fabrication technology for their merits in some factors. The application of low-loss polymer materials can be an alternative solution to achieve improved Q-factor and lower self-resonance frequency (SRF). In addition, the low stiffness and excellent flexibility can be especially attractive in the applications where the MEMS devices are directly paste or wrap the elements, such as insulated electrical wire surface for non-touch current sensing. In the fabrication of MEMS-based inductors, planar structure is usually adapted. Micro solenoid-type coils are often prepared by using wire wound coils, but this method will be limited in smaller feature size.

Recently, the 3D micro-coil fabrication has been exploring by different approaches. K. Kratt et al have successfully prepared the solenoid micro coils by using a wire bonder [1]. Zhang et al developed a micro coils on a fiber below 100 μ m diameter using a rotation lithograph method [2]. Recently, an air core power inductors was fabricated by metal encapsulated polymer via [3]. Using laser irradiation, T. Kikuchi et al. also successfully fabricated a platinum grid-shaped microstructure, a micro-spring, and a cylindrical network microstructure with 50-100 μ m line width [4]. Matsumoto et al. [5] developed a three-dimensional X-ray lithography method using X-rays from a synchrotron radiation facility as a light source for lithographic exposure and an X-ray mask for patterning cylindrical micro-coil structures with a high aspect ratio. However, these methods for a 3D micro-coils structure through



lithography method are usually involved of expensive equipments or limited resolutions. Therefore, it is necessary to explore a relatively cheap and easy approach to produce the 3D micro-coils structure. In this study, we developed a 3D micro-coil in the polymer film using through polymer vias (TPVs) and metal filling method.

2. Design of 3D micro-coil structure

As shown in Fig.1, a flexible sensor is aimed to freely wrap the conductor wire. The intended functions of current sensing and self-powering are based on the Faraday law of electromagnetic induction. The embedded 3D micro-coil within a flexible polymer film is designed. This 3D coil comprises top windings, bottom windings, and vertical windings. The metal filled through polymer via (TPVs) structure is designed to use as the vertical windings. The top and bottom windings are micro-fabricated by the metal film patterning method.

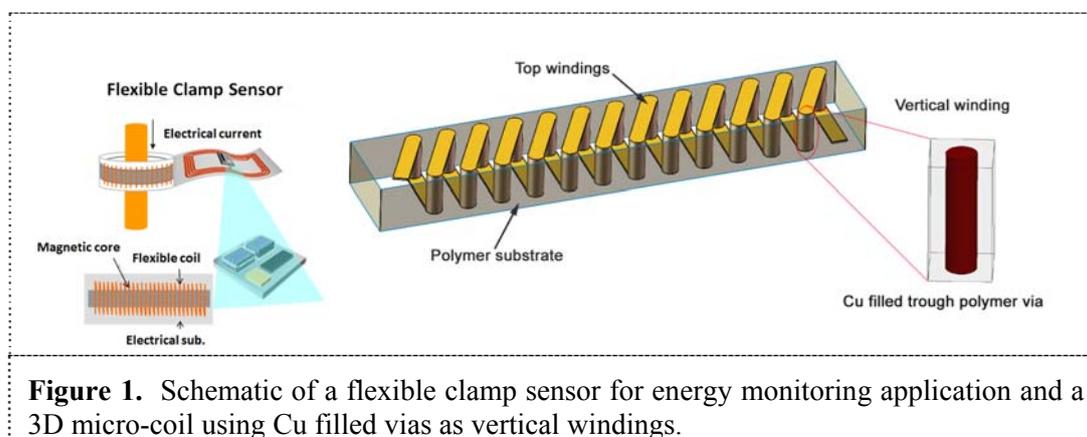


Figure 1. Schematic of a flexible clamp sensor for energy monitoring application and a 3D micro-coil using Cu filled vias as vertical windings.

As shown in Fig.1, a flexible sensor is aimed to freely wrap the conductor wire. The intended functions of current sensing and self-powering are based on the Faraday law of electromagnetic induction. The embedded 3D micro-coil within a flexible polymer film is designed. This 3D coil comprises top windings, bottom windings, and vertical windings. The metal filled through polymer via (TPVs) structure is designed to use as the vertical windings. The top and bottom windings are micro-fabricated by the metal film patterning method.

3. Experimental

The fabrication process of this 3D micro-coil is illustrated in Fig.2. The flexible polyimide sheet with a thickness of 120 μm was selected to use as the substrate. The through polymer vias (TPVs) were micro-fabricated through laser drilling process. The polymer sheet with the formed via array was shown in Fig.3. The diameter and pitch of the via were designed to be 30 μm and 60 μm respectively. A defined "two-step" Cu electro-deposition formula was used to fill the TPVs. In this process, a Cu seed layer with a thickness of 100nm was sputtered in advanced on the bottom surface. Then the Cu electrodeposition was firstly performed on the pre-sputtered bottom side using a relatively higher current density until the vias entrances were completely blocked. Following that, the second-step electrodeposition was carried out on the top side to obtain a complete copper filling within the vias. Then the Cu overburden on the surface was removed through a chemical-mechanical polishing process to avoid the interconnect between the adjacent vias.

The top and bottom windings were micro-fabricated by lithograph process. In this process, a 20 nm Cr film and 180 nm Au film were firstly sputtered on the top and bottom surface respectively. A resist was sprayed on both sides and one side were patterned after lithography. After removing the resist and etching Cr/Au layers, the layout of parallel metal lines with a width of 20 μm was fabricated, where the line was precisely located in order to interconnect the terminals of the vertical windings. This

finished side was protected by the resist in advanced, and then the other side was metal patterned by the same way.

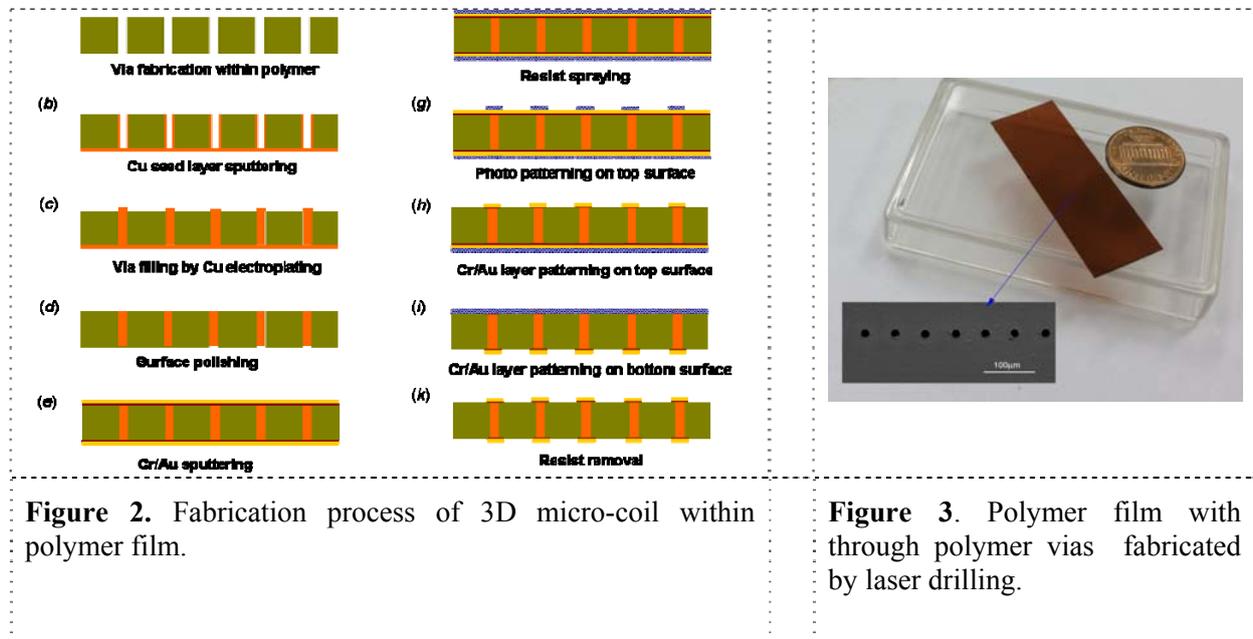


Figure 2. Fabrication process of 3D micro-coil within polymer film.

Figure 3. Polymer film with through polymer vias fabricated by laser drilling.

4. Results and discussion

During a "two-step" Cu electrodeposition process for filling the vias, a rapid deposition was firstly performed on the back side for the below considerations. Firstly, the entrances at the bottom are blocked so that a TSV-like electrodeposition filling process can start at the front entrances. Secondly, a "V" growth profile was aimed to obtain, which is needed for a void-free filling. As expected, the highest current density occurred at the entrance and decreased from back to front side during the first-step deposition. Then a "V" filling profile was formed while the back entrance had been completely sealed. In the second-step deposition, the formed "V" filling profile increased the step coverage value, which made it possible to fill completely at deeper location before the sealing of the entrance. Fig.4(a) shows the front surface after the second-step deposition. The Cu grew from the bottom to up and overflow the vias to form the interconnection between the adjacent vias. Fig.4(b) shows the cross-section of the through polymer holes after the second-step deposition. A complete and void-free filling effect was obtained using this "two-step" deposition formula. This void-free filling effect would effectively increase the electrical conductivity and reliability of such a micro-coil structure. After mechanical polishing process, the growth "overburden" on the surface was completely removed. The surface after polishing process is shown in Fig.4(c). The interconnection was removed to avoid "short circuit" between the adjacent vias.

Fig.5 shows the finished top and bottom windings after the patterning process. The lines were precisely aligned to contact the terminal of the filled vias. Of course, due to the slightly etching effect to the Cu during Au and Cr etching process, a shallow indentation could be observed at the junctions, which might bring the risk of poor contact or even disconnection. In the following improvements, the line sizes at the junctions will be enlarged to cover the via, avoiding the Cu etching during the top and bottom windings fabrication process.

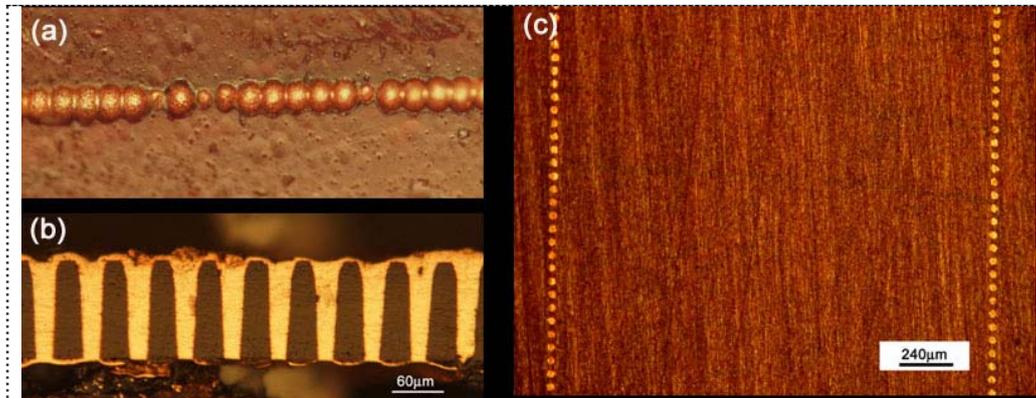


Figure 4. Optical image of vertical windings with copper filled trough polymer vias: (a) surface after Cu electrodeposition, (b) cross-section of filling TPVs, (c) surface after polishing.

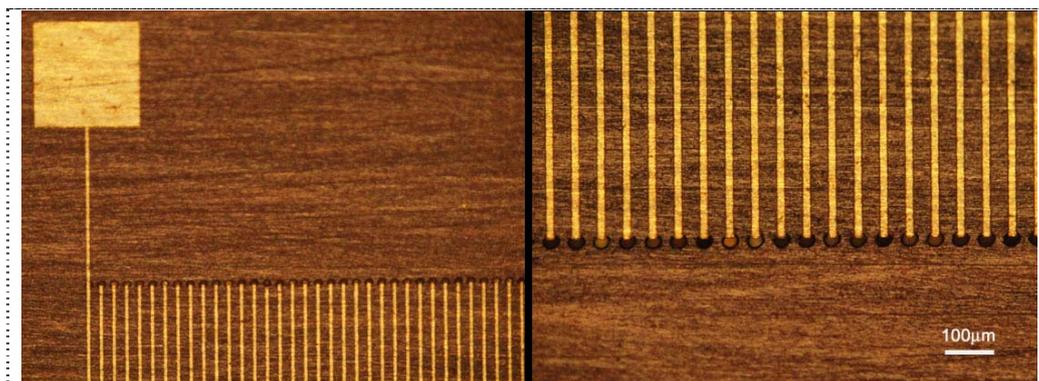


Figure 5. Surface windings fabricated using a lithography method.

5. Conclusions

In this work, we presents one fabrication method of 3D micro solenoid-type coils which is intended to use as current sensing or self-powering module. The 3D micro-coil was fabricated in a thin polymer film with a thickness of 120 µm. The vertical windings were realized through laser-drilled through polymer vias (TPVs) and the following via filling process. A complete and void-free filling effect was obtained using a "two-step" Cu electrodeposition formula. The top and bottom windings were fabricated by a metal patterning process. After a precise alignment, the surface windings connected with the terminals of the filled vias, producing a 50-turn 3D micro-coil within polymer film substrate.

Acknowledgments

This work is supported by New Energy and Industrial Technology Development Organization (NEDO). One of authors, Zhu, also acknowledges International Affairs Division, National Institute of Advanced Industrial Science and Technology (AIST) for offering a fellowship.

References

- [1] Kratt K, Seidel M, Emmenegger M, Wallrabe U, 2008 Technical Digest MEMS 996.
- [2] Zhang Y, Lu J, Hiroshima H, Itoh T, Maeda R, 2009 Technical Digest Power MEMS 253.
- [3] Kim J, Herrault F, Yu XH, Kim M, Shafer RH, Allen MG, 2013 J. Micromech. Microeng 23 1.
- [4] Kikuchi T, Takahashi H, and Maruko T 2007 Electrochim. Acta 52 2352.
- [5] Matsumoto Y, Setomoto M, Noda D a As part of the production system for *Journal of Physics*.