

Three dimensional multilayer solenoid microcoils inside silica glass

Xiangwei Meng, Qing Yang, Feng Chen*, Chao Shan, Keyin Liu, Yanyang Li, Hao Bian, Jinhai Si, Xun Hou

State Key Laboratory for Manufacturing System Engineering & Key Laboratory of Photonics Technology for Information of Shaanxi Province, Xi'an Jiaotong University, Xi'an 710049, PR China

ARTICLE INFO

Article history:

Received 13 March 2015

Accepted 27 July 2015

Available online 4 August 2015

Keywords:

Femtosecond laser processing

Multilayers microcoils

3D solenoid microcoils

Silica glass

ABSTRACT

Three dimensional (3D) solenoid microcoils could generate uniform magnetic field. Multilayer solenoid microcoils are highly pursued for strong magnetic field and high inductance in advanced magnetic microsystems. However, the fabrication of the 3D multilayer solenoid microcoils is still a challenging task. In this paper, 3D multilayer solenoid microcoils with uniform diameters and high aspect ratio were fabricated in silica glass. An alloy (Bi/In/Sn/Pb) with high melting point was chosen as the conductive metal to overcome the limitation of working temperature and improve the electrical property. The inductance of the three layers microcoils was measured, and the value is 77.71 nH at 100 kHz and 17.39 nH at 120 MHz. The quality factor was calculated, and it has a value of 5.02 at 120 MHz. This approach shows an improvement method to achieve complex 3D metal microstructures and electronic components, which could be widely integrated in advanced magnetic microsystems.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

Microcoils are widely used as the electric-magnetic devices in micro electromechanical systems (MEMS), micro-total analysis systems (μ TAS) and Lab on a chip (LoC) [1–4]. For example, microcoils are used in nuclear magnetic resonance (NMR) and magnetic resonance images (MRI) systems, which can analysis the nucleic structure information and provide the images of the body for chemical applications and medical diagnosis [5–7]. As more practical applications in advanced magnetic microsystems, the stronger and more uniform magnetic field is pursued to keep a high performance, the demand of miniaturization and integration also increases. Although many studies have been reported for the fabrication of the microcoils, such as lithography, wire winding, electroplating and laser direct writing method [8–12], however, most of these works have focused on the single-layer and planar spiral-shaped microcoils.

The multilayer microcoils could increase the value of the inductance and enhance the magnetic field strength, which would improve the sensitivity and reduce the sample volume in the applications. The multilayer solenoid microcoils can generate stronger and more uniform magnetic field to meet the need of the advanced applications. Generally, ultraviolet photolithography is a conventional approach for fabricating microcoils, which was also

improved to fabricate the multilayer microcoils [13,14]. However, the ultraviolet photolithography method requires the expensive equipments and masks with high resolution, complicated procedures, high cost, it is difficult to fabricate the 3D solenoid microcoils and provide a uniform magnetic field. The wire winding and electroplating method have been used for fabricating the multilayer microcoils [15,16]. But the integration in wire winding method and the turns in electroplating method need to be further improved, respectively; it is difficult to embed in the substrate and limit the miniaturization of devices.

Recently, a facile method based on femtosecond laser wet etch (FLWE) and microsolidics has been introduced to fabricate simple microcoils in two steps and under gentle conditions [17]. The extra access ports were introduced to make sure the simultaneity of the etching process and improve the uniformity of the microchannel. In the microsolidics process, the gallium was chosen as the conductive metal. However, the gallium with low melting point (29.76 °C) was easily melted and disconnected by the Joule heat, so the microwire has a low work temperature. Bi/In/Sn/Pb alloy is a kind of fusible metal alloy, which could be used as solder with various melting points (47 °C, 70 °C, 95 °C, 125 °C). In this work, we developed a femtosecond laser wet etch (FLWE) and microsolidics method to fabricate 3D multilayer solenoid microcoils in silica glass. The 3D multilayer solenoid microchannel has the different depth and length between the adjacent extra access ports. So the laser writing each layer with the different power and variable-speed scanning with different focus depth were used in FLWE to improve the uniformity of the microchannel with complex

* Corresponding author. Fax: 86 29 82668420.

E-mail address: chenfeng@mail.xjtu.edu.cn (F. Chen).

structures. As the features of the femtosecond laser processing inside the transparent material [18], the each layer of microchannel is independent without contact and insulated by the silica glass. In the microsolidics process, an alloy with high melting point is used to make the 3D electrical conductors, so the alloy microwire can reduce the impact of the Joule heat and overcome the limit of the low temperature. The alloy microwire can help the devices to get a higher working temperature. The inductance and resistance of the three layers microcoils was measured by an impedance analyzer. The multilayer microcoils with circle cross section could be applied for high performance electric-magnetic devices.

2. Fabrication procedures

Silica glass with dimensions of $10 \times 10 \times 1 \text{ mm}^3$ was used in the experiment. The femtosecond laser in the experiment outputs the pulses with wavelength of 800 nm, pulse duration of 50 fs, and repetition rate of 1 kHz. The laser beam was tightly focused by an objective lens (Nikon, $\times 100$, $\text{NA}=0.90$). The laser writing pattern in the sample was pre-designed by the computer. The pattern of multilayer solenoid microcoils was scanned by the laser, as shown in Fig. 1(a). In the etching process, the hydrofluoric (HF) acid solution with a concentration of 5% was used. The laser-irradiation materials have a higher selective etching rate than the un-irradiation regions. The modified materials were chemically etched out rapidly, and the multilayer microchannel with good uniformity formed gradually (Fig. 1(b)).

In the microsolidics process, a polydimethylsiloxane (PDMS) film was used to seal the extra access ports. In order to overcome the limitation of the work temperature, an alloy (Bi/In/Sn/Pb) with high melting point (95°C) and good electrically conductive was chosen as the metallic conductors in this experiment. We put the microchannel devices and the alloy in the electrically heated drying oven; the temperature of the oven was 30°C higher than the melting point of the alloy. The liquid alloy with high viscosity is difficult to flow in slim microchannel, so we applied a high positive pressure to squeeze the liquid metal at the inlet and a high negative pressure to suck at the outlet. The liquid metal was injected into the microchannel to achieve the conductor microwire. After the metal was cool and solidification, the 3D multilayer microcoils embedded in the silica glass were achieved. Then the inductance and resistance of three layers microcoils is measured by an impedance analyzer. The measure results demonstrate the electromagnetic property of the 3D multilayer microcoils.

3. Results and discussion

To successfully fabricate the multilayer microcoils in the microsystem, the insulation between the coil layers is a key challenge. Silica glass is an excellent insulation material, which can

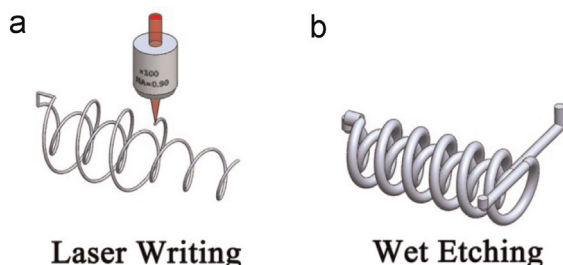


Fig. 1. Schematic of the two layers microchannel fabrication process. (a) Laser writing process. (b) Wet chemical etching process.

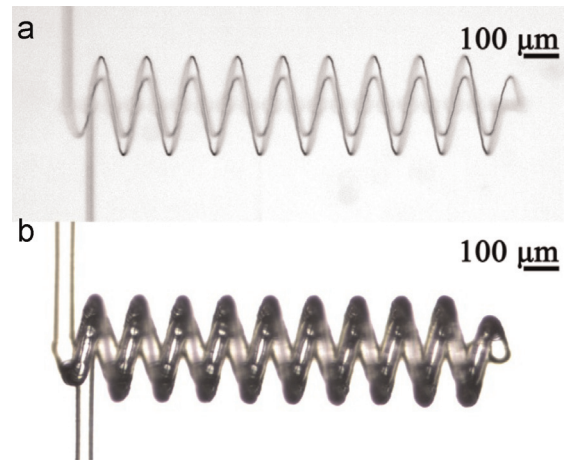


Fig. 2. The laser writing and the wet etching process. (a) Optical micrograph of the two layers solenoid line embedded in silica glass. (b) Optical micrograph of the two layers solenoid microchannel.

insulate the different coil layers. Due to the femtosecond laser processing features, the multilayer solenoid line was written without any intersection and insulated by silica glass. Fig. 2 shows that the two layers solenoid microchannel embedded in the silica glass was fabricated by the femtosecond laser wet etching method. In the laser-irradiation process, the inner layer solenoid line was written firstly and the outer layer solenoid line was written subsequently with the contrary winding way. The number of turns of each layer is 10 and the length of the two layers solenoid is $1200 \mu\text{m}$. The coil radius of the inner layer and the outer layer are $75 \mu\text{m}$ and $125 \mu\text{m}$, respectively. The pitch of solenoid is $60 \mu\text{m}$. The uniformity of the microchannel in the silica glass is the main challenge for the FLWE method, which is pursued by many groups [19,20]. In our previous work, to overcome the limitation of the length-diameter ratio and achieve the good uniformity of the microchannel, the extra access ports were introduced [21]. The perpendicular lines were written by femtosecond laser to connect the top of every turns with the sample surface. The modified materials have a higher selective etching rate in the wet etching process. The modified materials in the perpendicular line were solved rapidly and the extra access ports gradually form and get large. Hence, the fresh HF solution can flow into the solenoid line through the extra access ports to guarantee continuous reaction. In the wet etching process, the simultaneous etch can greatly improve the uniformity of the microchannel [17]. To guarantee the simultaneity etching in all parts of microchannel, extra access ports with moderate distance between adjacent ones were introduced in the every turn of the solenoid line. The limitation of the length-diameter ratio of the microchannel is overcome and the multilayer microchannel with good uniformity and high aspect ratio is achieved in the experiment, as shown in Fig. 2(b). The surface of the microchannel is smooth [22]. To reduce the impact of the extra access ports on the microcoils performance, the length of the extra access ports should be as short as possible, so the solenoid line is written closer to the surface of the silica glass. After the etching process, the extra access ports can be polished away by polishing machine.

At the basis of the fabrication two layers microchannel, the three layers solenoid microchannel could be also fabricated by the similar method. As shown in Fig. 3(a), the inner layer solenoid line was written firstly, the middle layer solenoid line was written subsequently with the contrary winding way and the outer layer with the same winding way of the inner layer last. The number of turns of three layers is 30 and the length of the three layers solenoid is $1800 \mu\text{m}$. The radiuses of the three layers are $60 \mu\text{m}$,

Download English Version:

<https://daneshyari.com/en/article/738950>

Download Persian Version:

<https://daneshyari.com/article/738950>

[Daneshyari.com](https://daneshyari.com)