Study on the manufacturing process of polymer microfluidic chip with integrated Cu micro array electrode

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Abstract: To produce perfect polymer microfluidic chip with integrated metal micro array electrode, an oxygen-plasma assisted manufacturing process was developed. The Cu micro array electrodes on the poly substrate was formed by photolithography, sputtering and wet etching; the micro channels on the polymer plate were hot-embossed using metal master; the bonding of cover plate and substrate using thermal bonding. The surface of the polymer plate with micro channels was treated by oxygen-plasma before thermal bonding. The oxygen-plasma treatment could decrease thermal bonding temperature from 100 °C to 85 °C. The bonding of this chip is complete, the micro electrode array keeps its integrity, and the micro channel is not distorted obviously.

Introduction

In recent years, considerable interesting was centered on the fabrication of integrated microfluidic chips[1]. Microfluidic chips have been integrated with micro electrodes as sensitive detector or electro-osmosis pump[2], and many of them have been fabricated from either silicon-based or glass-based. Silicon-based chips are not transparent which limited their applications on inspection[3]. Glass-based chips do not have this limitation, but are more difficult to bond[4]. Hence, it is worthy to establish microfluidic chips changing from silicon-based or glass-based materials to other materials. More recently, polymers have been pursued as an alternative substrate for microfluidic chips[5], because they offer a wider range of physical and chemical properties (such as low electrical conductivity and high chemical stability), and also have the advantages of low cost and easy processing for mass production[6].

To date, fabricating polymer microfluidic chip has been the most popular method since they allow the same material to be used for microfluidic substrate layers[7], ensuring homogeneity in surface properties for all micro channel walls[8]. However, fabricating of polymer microfluidic chip with integrated metal micro array electrode suffers from several disadvantages[9]. Because the substrates must be heated at or slightly near their glass transition temperature to achieve a strong interfacial bonding[10], micro channels would become deformed or collapsed[11], and the electrode on the polymer substrate would be fractured, so the integrity of micro channel and the strength of electrode are very important[12]. In this paper, an oxygen-plasma assisted manufacturing process of polymer microfluidic chips was developed to keep the micro channel and array electrode integrity.

Experiment and results

The polymer microfluidic chip with integrated micro asymmetric comb array electrodes was designed. It includes four reservoirs and three micro asymmetric comb array electrodes. The array contains 30, 90 and 120 repeats of the asymmetric comb pair of electrodes respectively. Fig.1A shows the microfluidic chip with asymmetric comb array electrodes. Fig.1B and Fig.1C are the micro channel and electrode array respectively.
Electrode arrays were fabricated on a 1mm thin polymer substrate of dimensions 51×51mm. A 200nm thick layer of copper was deposited on the substrate by magnetron sputtering. Standard photolithography for patter transfer from an electron-beam written chromium mask to the substrate was used. Fig.2 and Fig.3 showed the schematic of fabricated process for substrate with integrated electrode and the photo of substrate with integrated electrodes respectively.

Replication of the channel by hot embossing was performed using PMMA substrate on hot embosser. The replication in polymer is performed about 120°C with embossing pressures of about 3MPa. After replication, each polymer substrate had four Ø3mm holes which drilled at the inlet and outlet positions of each channel.

The oxygen-plasma treatment was performed using the following condition: 13.56MHz excitation frequency and 60W RF power; the pressure of the treatment was kept at 200Pa by a mechanic pump; the mass flow controller maintained about $2.5\times10^{-7}\text{ m}^3\text{s}^{-1}$ gas flux and the treatment time was 2min.

Thermal bonding of the polymer chips was performed using a thermal bonding apparatus. Platen parallelism was checked before bonding to ensure the uniform force distribution. The platens were pre-heated to 85°C, followed by an application of a pressure of 1.5MPa for 6min. Fig.4A, Fig.4B and Fig.4C are the photos of the microfluidic chip with asymmetric comb array electrodes, asymmetric comb array electrodes and cross-section of the channel respectively.

**Fig. 1** Schematic of microfluidic chip with integrated electrode

**Fig. 2** Schematic of integrated electrode

**Fig. 3** Photo of substrate with integrated electrode

**Fig. 4** Photos of microfluidic chip with integrated electrode
Thermal bonding temperature and thermal bonding pressure have significant influence on the electrodes. High temperature and high bonding pressure can make bonding easy. But it will bring some problems to the microfluidic chip. Because of different expansion ratios between polymer and copper and the deformation of the polymer substrate will lead to electrode fracture. Fig.5 and fig.6 showed the stress concentration in the electrode and fractured electrode respectively. After a series of experiments, it was found that the thermal bonding temperature must not be higher than 85°C and pressure must be controlled at about 1.5MPa to achieve the best bonding results.

The contact angle decreases dramatically due to the oxygen plasma treatment, the values of contact angle from 73° before treatment to 43.6° after treatment, so the oxygen-plasma treatment could decrease the bonding temperature, but the contact angle of the modified cover plate would increase when it is heated. To demonstrate the effect of the temperature on the contact angle, the contact angle of the treated polymer cover plate is measured immediately after it is heated to a given temperature. Fig. 7 showed the effect of the temperature on the contact angle of modified PMMA. It is clearly that the contact angle increases dramatically when the temperature is above 82 °C, and it is up to 54.1° when the temperature is 90 °C. So the bonding temperature should not higher than 82 °C, after several trials around 82 °C, 85 °C is finally chosen for the thermal boning temperature. A complete bonding is achieved, and the Cu electrode keeps its integrity.
Conclusions

An oxygen-plasma assisted manufacturing process of microfluidic chip with metal micro electrodes is studied. The Cu micro array electrodes on the poly substrate was formed; the micro channels on the polymer plate were hot-embossed; the effect of the temperature on the contact angle of treated polymer is investigated, and then the thermal bonding temperature is optimized; a polymer substrate plate with Cu electrode and polymer cover plate with micro channels treated by oxygen-plasma was bonded at low temperature. The fabricated chip is complete, and the Cu electrode is not fractured.

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