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A laser microwelding method for assembly of polymer based microfluidic devices

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ABSTRACT

This paper presents the development of a laser microwelding method for assembly and packaging of polymer based microfluidic devices. In this approach a diode laser was used to weld two poly(methyl methacrylate) (PMMA) substrates together at the interface using a thin film metal spot based intermediate layer design as a localized absorber. A broad laser beam with a top-hat profile was used to carry out the laser microwelding work. The effects of laser power and processing time on the resultant heated affected zone (HAZ) and the melted zone were investigated. For large area welding, a 2×2 array of thin film metal spots were used to investigate the effect of separation between the spots on the resultant interfacial bond between the two polymer substrates. For comparison, a large area titanium film with a comparable size to that of the 2×2 array was also studied. The results show that the discrete film pattern based design is better than a single large area film in order to reduce the effect of substrate distortion resulting from the higher temperature rise associated with the latter. The tensile strength of the laser welded joints was determined to be about 6 MPa for a sample produced using the 2×2 array of circular titanium spot pattern design. The laser microwelding method has been demonstrated successfully in leak-free encapsulation of a microfluidic channel.

1. Introduction

Microfluidic devices have found various applications in life science, chemical engineering and many other areas over the past decade. Originally, glass and silicon were used as the main materials for fabrication of these devices due to the available micromachining methods. However, there has been an increasing interest in polymers for microfluidic devices. The advantages of polymers are low cost, chemical inertness, bio-compatibility and light weight. Polymers, such as poly(methyl methacrylate) (PMMA) [1], polydimethylsiloxane (PDMS) [2], SU-8 [3] and polycarbonate (PC) [4], have been used to fabricate microfluidic devices. However, there is still a challenge in sealing and encapsulation of microfluidic devices without damaging or suffering from channel filling problems. Some methods, such as solvent bonding [5,6], adhesive bonding [7,8] and surface modification based approaches [9,10], have been investigated with varying success. However, there are issues with these methods such as low bond strength and structure distortion. Recently localized bonding methods such as ultrasonic welding [11], microwave welding [12], induction welding [13] and laser welding [14] have been investigated for fabrication of microfluidic devices. These methods are suitable for processing of thermoplastic polymers. An ultrasonic welding method has been used to bond PMMA and PEEK (Polyaryletheretherketone) materials for fabrication of microfluidic devices [11]. This work was carried out using a pneumatic standard ultrasonic welding equipment at a generator frequency of 35 kHz. The energy directors and structures were machined into a microchannel chip and a cover plate to guide the melt flow during bonding. In the microwave welding method, two PMMA substrates each with a 100 nm thick gold film were welded together using a microwave source operating at 2.4 GHz [12]. The corresponding power and processing time were 10 W and 120 s respectively. In the induction based welding method a closed loop thin film nickel track was necessary for efficient welding of two PMMA substrates. A film thickness of 7.5 μm was also required to obtain efficient induction heating to bond the substrates [13].

Laser transmission welding methods have been developed for sealing of microfluidic devices due to the advantages of localized heating and therefore minimizing the heat affected zone, fast processing time and good bond strength [14]. This method is a one step process in which heating and welding of the polymer substrates occur concurrently. In this process usually one polymer substrate has high transmittance at the laser wavelength and the other one has high absorptance. The latter absorbs the laser radiation to produce the necessary temperature increase at the interface to cause one or

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both substrates to melt to produce a resultant bond between the substrates. While this configuration is convenient and does not require additional material for laser welding, it requires a suitable combination of dissimilar materials. Second it is not suitable for fabrication of transparent microfuidic devices since an opaque substrate is necessary to absorb the laser radiation to realize welding of the substrates. On the other hand, transparent microfluidic devices are desirable in many applications that require measurement of optical transmission for medical testing and diagnostics. In the previous work a thin film of carbon layer was used as an intermediate absorbing layer in laser welding of polymer substrates for microfluidic applications [15–17]. The layer of carbon black was deposited on a microfluidic substrate by spin-coating [15,16] or by vacuum deposition [17] prior to fabrication of the microchannels on the polymer substrate, then a cover substrate is attached to the microfluidic substrate by a laser welding method [15,16]. Recently a laser welding method has been used successfully to construct a micropump for lab-on-chip applications using two polycarbonate substrates and a weldable thermoplastic elastomer based intermediate layer [18]. Although it is possible to achieve laser transmission welding of transparent polymers without using additional absorbers at the interface of the two substrates, a fiber laser with a suitable wavelength around 1.7 μm is required and tight control of beam focus at the substrate interface is necessary [19]. The more absorption at the interface due to the focussed laser beam (high intensity) at the interface results in a higher temperature increase and thus cause polymer welding at the interface of the substrates. The disadvantage is that a broad beam cannot be used in this method resulting in a narrow welding line with limited bond strength.

In this paper we present a laser microwelding technique for assembly of transparent polymer substrates for fabrication of microfluidic devices. Transparent PMMA substrates are welded together using an intermediate titanium thin film spot pattern and a high power diode laser system with a broad top-hat beam profile. In addition in contrast to the previous work in which the bonding contour is determined by scanning a focused laser beam, in our method the bonding line is defined by a predetermined metal film spot based pattern as a localized absorber thus allowing easy control of laser beam alignment in the bonding process. The dependence of the heat affected zone and weld zone on laser power and processing time has been investigated. The results of tensile measurements show that a strong bond between the substrates can be obtained. Leak free encapsulation of a microchannel device has been obtained successfully using the laser microwelding method.

2. Experimental

2.1. Substrate fabrication

Fig. 1 shows a schematic illustration of the deposition process for producing thin titanium film patterns on PMMA substrates (RS Components, UK) using a shadow mask based approach. The titanium deposition work was carried out using an electron beam based vacuum evaporation system and a PMMA based shadow mask with 1 mm diameter apertures. The mask was fabricated using a CO_2 laser based polymer machining system (Epilog Mini 18, Epilog Laser, USA). The thickness of the PMMA plate for mask fabrication is 0.5 mm. Aperture arrays with separations of 0.6, 0.8, 1.0 and 1.2 mm were fabricated to determine the optimum value for continuous joining between the substrates using discrete titanium film patterns. Before film deposition the PMMA substrates were cleaned in Decon 90 in an ultrasonic bath and then dried in an oven. In order to investigate the effect of film thickness on laser welding of the PMMA substrates, titanium films of thicknesses of approximately 500 nm and 1 μm were deposited on the PMMA substrates. The titanium films were deposited using electron beam based thermal evaporation. The chamber pressure was about 1×10^{-6} bar. The beam current and the corresponding deposition rate were 60 mA and 100 nm/min respectively. After film deposition the large PMMA substrates were divided into individual samples for use in the laser microwelding work described in the next section.

2.2. Laser bonding system

A high-power CW diode laser system with a fiber-coupled output at 970 nm (LDM 100, Laserlines, Germany) was used as the laser source in this work. The laser output from the beam delivery fiber was transformed into a large square beam with top-hat intensity distribution [20]. A broad beam allows easy alignment and processing of the substrates in the laser microwelding method. The absorption of the laser beam is determined by the pattern of the thin film titanium spots, the rest of the beam transmits through the PMMA substrates and has negligible effect laser microwelding of polymer substrates. The top-hat beam is desirable for microwelding application since the heat affected zone is small due to the sharp transition of optical intensity in the beam profile and hence the resultant heating effect. The beam profile was produced using a custom-designed beam forming optical element [21]. The beam size is $6 \times 6\ mm^2$ and details of the intensity distribution can be found in [20]. Fig. 2 shows

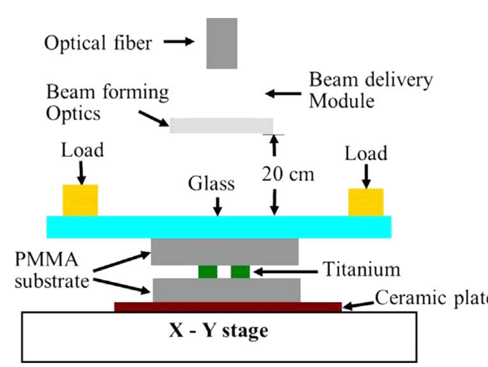

Fig. 2. Schematic setup of the laser microwelding setup.

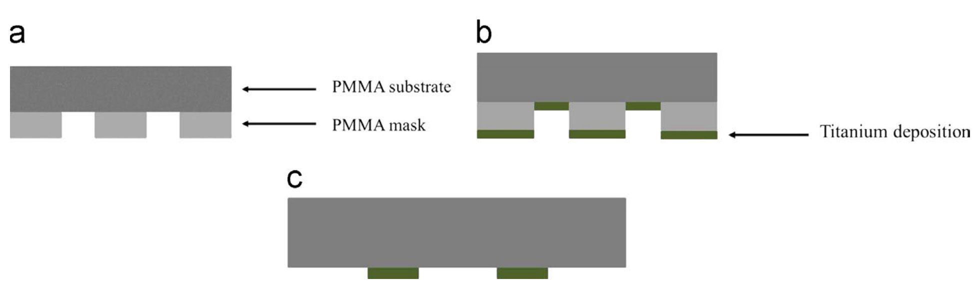

Fig. 1. Illustration of the steps for titanium film deposition on a PMMA substrate using a shadow mask based vacuum deposition method. (a) A PMMA shadow mask on a substrate, (b) titanium film deposition and (c) titanium film spot pattern on substrate after removing the shadow mask.