A LOW VOLTAGE CAPILLARY MICROGRIPPER USING ELECTROWETTING

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ABSTRACT

We present a new microgripper utilizing a liquid droplet to pick up and release micro objects. Lifting force is evolved from a liquid bridge formed between the gripper surface and an object. Electrowetting is used to dynamically change the capillary lifting forces and enable object release. The driving voltage is applied to a pair of coplanar interdigitated electrodes. A Barium Strontium Titanate (BST) insulation layer is used to lower the driving voltage. Experiments indicated that the lifting forces can be as high as 213μN at a driving voltage of 28V. Experiments also demonstrated the picking-up and releasing of micro glass beads.

KEYWORDS

Electrowetting, Microgripper, Microassembly, Micro-manipulation, Capillary Force

INTRODUCTION

Current MEMS devices are generally fabricated by well established monolithic micromachining where the micro parts are fabricated in one sequential process. However, more complex hybrid microsystems which have complex 3-D geometries and multiple micro components may use diverse materials and conflicting fabrication processes, and thus cannot be manufactured by monolithic micromachining. For these situations, microassembly using microgripping tools is necessary to integrate various components to a complex functional system. A few conventional mechanical grippers have been developed for micorassembly, including pneumatic grippers [1], piezoelectric grippers [2], shape memory alloy actuated grippers [3] and bimorph structured micro-fingers. These microgrippers typically generate high forces during contact causing indents and destroying critical features on the component during assembly. In addition, the assembly of micro parts can be hindered by undesired surface adhesion caused by electrostatic forces, van-der-Waals forces and capillary forces.

The capillary and surface forces can be utilized as a gripping mechanism. Capillary grippers take advantage of capillary lifting force evolving from a liquid bridge between two surfaces [4]. Electrowetting is a well-known phenomenon utilized to manipulate the contact angles of a liquid by applying an electric potential. Recent simulation [5] has suggested electrowetting is feasible for dynamically adjusting capillary force induced by a liquid bridge. Here we present a low-voltage capillary microgripper that can pick up and release micro glass beads simply by electrowetting. A high dielectric constant metal oxide thin film, Barium Strontium Titanate (BST), was used as the insulator to significantly reduce the applied voltage.

DESIGN

Figure 1 illustrates a typical capillary microgripper. A liquid bridge formed between the gripper surface and the object surface generates a capillary lifting force. The liquid bridge forms contact angles (θ_1) and (θ_2) with the gripper surface and the object surface. The capillary lifting force evolving from the liquid bridge between the two surfaces can be estimated by [6]:

$$F_{capillary} = \frac{\gamma_{lv}(\cos\theta_1 + \cos\theta_2)A}{d} \quad (1)$$

Where γ_{lv} is the surface tension of the liquid droplet, d the length of the liquid bridge and A the surface area.

Electrowetting is used here to vary the contact angle (θ_1) thus varying the capillary lifting forces (figure 2). The lifting forces is minimum (F_{min}) at the largest contact angle (θ_1), increases as θ_1 is reduced, and reaches maximum (F_{max}) at the lowest contact angle (θ_1). The capillary forces can be adjusted between F_{max} and F_{min} assuming the weight of the liquid droplet is negligible. Thus an object with weight between F_{max} and F_{min} can be picked up and released.

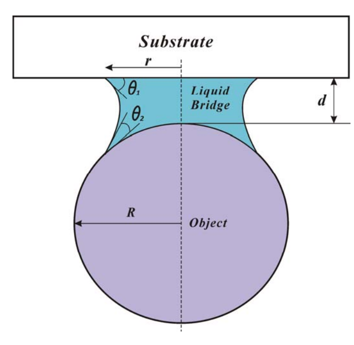

Figure 1: Illustration of a typical capillary microgripper.

The schematic of our microgripper design is illustrated in Figure 3(a). The device consists of interdigitated radial coplanar gold electrodes across which a driving voltage is applied. A 0.5 μm thin layer of Barium Strontium Titanate (BST), a good electrical insulation material (dielectric strength > 300 v/μm [7]) is employed as the dielectric insulation layer. The dielectric constant of BST is approximately 50 [8]. A thin Teflon film is used to provide a hydrophobic surface.

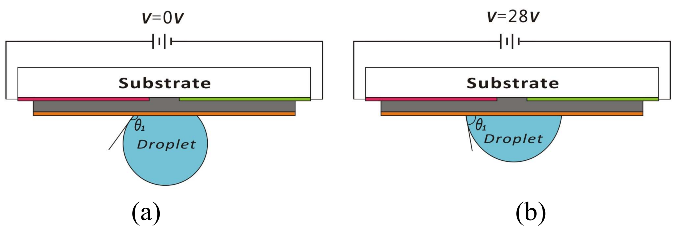

Figure 2: Schematic of electrowetting of a liquid droplet from (a) hydrophobic to (b) hydrophilic state using interdigitated coplanar electrodes.

Figure 3(b) is the schematic top view of the radial coplanar electrode. The gap between the driving and the reference electrode is t =20µm. Note that the coplanar electrode design was previously demonstrated for transporting droplets in microfluidic channels [9]. The electrowetting of a liquid droplet on the gripper surface is illustrated in Figure 2. When a voltage is applied, the contact angle of the liquid is decreased (figure 2(*b*)) from its initial contact angle (figure 2(*a*)).

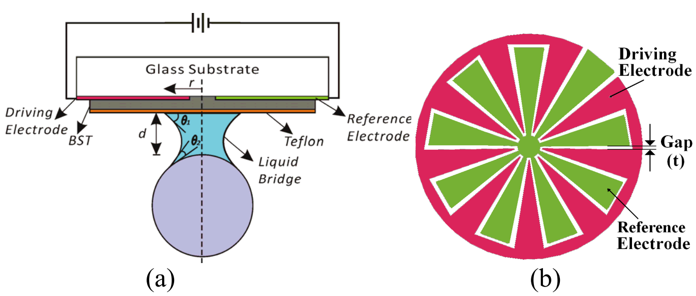

Figure 3: Microgripper design (a) Schematic of the microgripper using coplanar electrodes, (b) Coplanar electrode design for the microgripper (top view)

The relation between the applied voltage and the contact angle is given by the modified Young-Lippmann equation [9] as:

$$\cos(\theta_V) = \cos(\theta_0) + \frac{\varepsilon_0 \varepsilon_r}{2d\gamma_{LV}} \left[\frac{A_d}{A_t} \left(\frac{A_d}{A_d + A_r} \right)^2 + \frac{A_r}{A_t} \left(\frac{A_d}{A_d + A_r} \right)^2 \right] V^2 \quad (2)$$

In eqn. 2 θ_V and θ_0 are the final and initial contact angle, ε_0 is the dielectric constant of air, ε_r is the dielectric constant of BST, d is the thickness of Teflon AF® film, γ_{LV} is the surface tension of the liquid droplet, and V is the applied voltage. The terms A_d, A_t and A_r represent the area of the driving electrode, the reference electrode and the total area respectively.

The proposed micromanipulation using the microgripper consisting of four steps is described in the following and are sketched in Figures 4 (a)-(d).

Step 1: The Teflon gripper surface is initially hydrophobic. A liquid droplet is placed on the center of the gripper. With an applied voltage across the electrodes, the surface becomes hydrophilic and the contact angle is decreased due to electrowetting effect. The gripper approaches the object vertically from the top.
Step 2: As the gripper moves down, the droplet contacts the object and forms a liquid bridge between the object and the gripper surface. The capillary lifting force evolving from the liquid bridge acts as the lifting force to pick up the object.
Step 3: Once the object is picked up and placed in desired position, the voltage is reduced. Due to the electrowetting effect, the contact angle (θ_l) increases, leading to a decrease in the lifting force. As a result, the liquid bridge is elongated.
Step 4: As the voltage is further decerased, the capillary lifting force decreases to a point where the weight of the object overcomes the lifting force. The liquid bridge ruptures and the object is released.

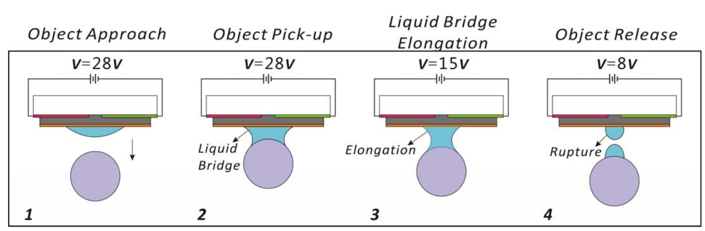

Figure 4: Schematics of the four steps for micromanipulation using the capillary micro gripper.

MICROFABRICATION

The use of a coplanar electrode design simplified the device fabrication to a single mask fabrication process. The electrodes are fabricated from a gold coated glass substrate (Evaporated Metal Films, NY). The patterns are transferred onto the gold substrate using photolithography with an OAI-200 mask aligner (OAI, CA). Wet etching in KI:I2 potassium iodine complex was followed to form the electrodes (see Figure 5(a)). BST thin films were fabricated by spin coating (WS-400B-6NPP/LITE, Laurell Technologies Corp.) the BST precursor solution (Gelest, Inc.) onto the electrode at 2000 rpm for 60 seconds to obtain uniform thin films. The spin coated slide was kept at ambient temperature for 10 minute to remove the volatile components of the solution. The amorphous film was then heated to a temperature of 400°C at a rate of 5°C/minute, annealed at 400°C for 10 minutes, and was cooled down to room temperature at the same rate. The BST film was measured to be approximately 50nm in thickness by a Dektak 150 surface profilometer (Veeco, CA). This coating of BSF thin film was repeated 10 times to form a stack of BST films with a thickness of 0.5µm. Next, a thin layer of Teflon AF was spin coated onto the BST film (5000rpm for 60 seconds) and cured on a hot plate (250°C for 5 minutes) to provide the hydrophobic surface. The thickness of the Teflon AF layer was approximately 0.1µm. Figure 5(b) shows a picture of the microgripper with the electrical connections.

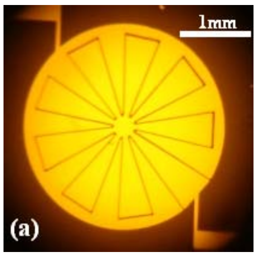

Figure 5: (a) the microscopic picture of the fabricated electrodes. (b) Picture of the fabricated microgripper.

TESTING AND RESULTS

Contact Angle Manipulation

Experiment was conducted to validate the contact angle change by electrowetting with the coplanar electrode. Figure 6 (a) and (b) show the contact angle change of a 0.1µL droplet of de-ionized water at 0 V and 28 V respectively.

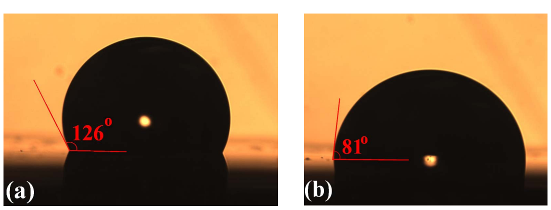

Figure 6: Contact angle change at different applied voltages

Contact angles were measured using a contact angle goniometer (Rame-Hart, NJ) when the applied voltage was increased from 0 V to 36 V (contact angle receding) and then decreased from 36V to 0 V (contact angle advancing). Figure 7 shows the experimental data of contact angle measurement and the theoretical prediction from the modified Young-Lippmann equation.

Two phenomena were observed: 1) the receding contact angle measurements agree well with the theoretical prediction as the applied voltage is increased from 0 to 36 V; the contact angle saturated at 81° at approximately 28V; 2) hystersis between the advancing and receding contact angle was observed. The hysteresis observed can be attributed to properties of the dielectric and the hydrophobic surfaces including surface roughness, charge trapping, charge injection at the insulator surface and porosity of the insulator [10]. The existence of hysteresis in contact angle causes a reduction in lifting forces according to Equation 1.

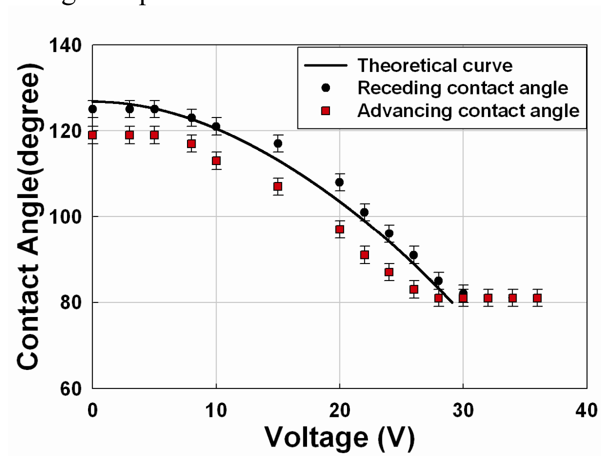

Figure 7: Advancing and receding contact angle measurements of a 0.1µL droplet DI water at different applied voltage.

Lifting Force Measurement

The lifting force of the microgripper was measured using an electronic balance (Sartorius) with a resolution of 0.1µN. The measurement setup is similar to that used by Obata *et al* [11] and is illustrated in Figure 8. The entire set-up was placed in a shielded box to avoid the uncertainty due to airflow.

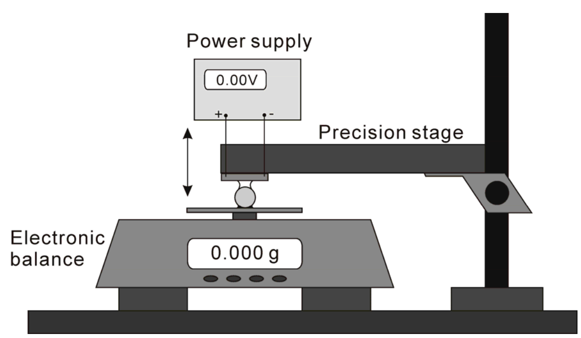

Figure 8: Illustration of lifting force measurement using an electronic balance.

The effect of the liquid bridge height (*d*) on the capillary lifting force was also studied. Measurement were made at three different distances (*d1*=250µm, *d2*=320µm, *d3*=500µm). For each fixed distance, lifting force measurements were made at different voltages. The measurement results are presented in Figure 9.

The maximum lifting force was generated for the smallest distance (*d1*=250μm). At *V*=28V, *d*=250μm, the microgripper is capable of generating a lifting force of 213 μN. The measured advancing contact angles θ_1 (in Fig. 7) were used for the prediction because the object is picked up at a higher voltage and released at a lower voltage. Contact angle θ_2 was measured to be 20° and was approximately constant during the tests. Figure 9 show that the experimental results agree with theoretical predictions well.

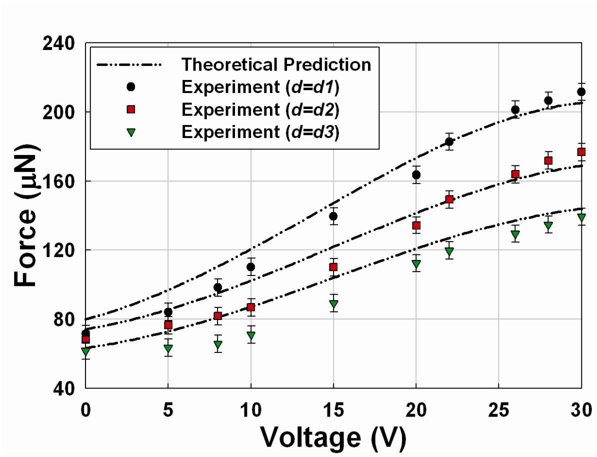

Figure 9: Lifting force generated by the liquid bridge for varying voltage and distances. d1= 250μm, d2= 320μm, d3= 500μm.

Demonstration of Pick-up and Release

Figure 9 implies that objects having weight in the range of the lifting force can be picked up and released. Next we demonstrated the pick-up and release of micro glass beads (77μN to 136μN) using the microgripper. The microscopic pictures of the 4-step pick-up and release procedure of a 13.9 milligram (136μN) glass bead are shown in Figure 10.

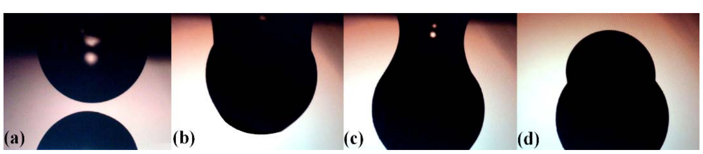

Figure 10: Microscopic pictures of the four steps of pick-up and release of a micro glass beads using the capillary micro gripper. (a) the gripper approaches object (V=28V); (b) the object is picked at a high voltage (V=28 V); (c) the liquid bridge is elongated due to the reduction of applied voltage; (d) the object is released at a low voltage (V=8V, release voltage).

CONCLUSION

In this paper a novel low-voltage capillary force microgripper for gripping micro objects is presented. Electrowetting on dielectric (EOWD) has been used here to manipulate the lifting forces of a capillary liquid bridge, to pick up and release micro objects. The use of coplanar gold electrodes greatly simplified the micromachining of the device. The use of BST as the dielectric insulation permits a low actuation voltage for microgripping. Experiments have demonstrated that the lifting forces can be manipulated simply by varying the applied voltage on the electrodes. The pick-up and release of a variety of micro glass beads with different mass were demonstrated.

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REFERENCES

[1] Y.W. Lua, C. J. Kim, 2006, Microhand for biological applications, *Applied Physics Letters*, 89, 164101.

[2] M. Weck, C. Peschke, 2004, Equipment technology for flexible and automated micro-assembly, *Microsystem Technologies*, 10, p. 241–246.

[3] J. H. Kyung, B. G. Ko, Y. H. Ha, G. J. Chung, 2008, Design of a microgripper for micromanipulation of micro components using SMA wires and flexible hinges, *Sensors and Actuators*, A, 141, p.144–150.

[4] M. Tichem, F. Bourgeois, P. Lambert, V. Vandaele, D. Lang, 2005, Capturing Micro-Assembly Process Windows on Process Data Sheets, *The 6th IEEE International Symposium on Assembly and Task Planning: From Nano to Macro Assembly and Manufacturing*, p. 74–79.

[5] S. Chandra, 2007, "A numerical study for liquid bridge based microgripping and contact angle manipulation by electrowetting method," Ph.D. thesis, The University of Akron.

[6] F. Bohringer, R. S. Fearing, K. Y. Goldberg, 1998, The Handbook of Industrial Robotics, 2nd edition. (Wiley, New York).

[7] H. Moon, S. K. Cho, R. L. Garrell, C-J Kim, 2002, Low voltage electrowetting-on-dielectric, *Journal of Applied Physics*, 92, 7.

[8] Y. Kobayashi, Y. Iizuka, T. Tanase, M. Konno, 2005, Low-Temperature Synthesis of Single-Phase Barium Strontium Titanate Thin Film with a nm-Seeding Technique and Its Dielectric Properties, *Journal of Sol-Gel Science and Technology*, 33, p. 315–321.

[9] U-C Yi, C-J Kim, 2006, Characterization of electrowetting actuation on addressable single-side coplanar electrodes, *J. Micromech. Microeng*, 16, p. 2053–2059.

[10] Herberth U; 2006; "Fluid manipulation by Means of Electrowetting-On-Dielectrics", PhD Thesis, University of Freiburg.

[11] S. Saito, T. Motokado, K. J. Obata, K. Takahashi, 2005, Capillary force with a concave probe-tip for micromanipulation, *Applied Physics Letters*, 87, 234103.

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