Published in final edited form as:
Proc SPIE Int Soc Opt Eng. 2021 March ; 11587: . doi:10.1117/12.2584039.

A 2D Refreshable Braille Display Based on a Stiffness Variable Polymer and Pneumatic Actuation

Zhixin Xie, **Jinsung Kim**, **Zihang Peng**, **Yu Qiu**, **Qibing Pei**
Soft Materials Research Lab, Department of Materials Science and Engineering, University of California, at Los Angeles, 420 Westwood Plaza, Los Angeles, CA, USA 90095

Abstract

Visual impairments limit a person's ability to process information such as obstacles, environments, reading and especially multimedia content (e.g., photographs and videos). In this work, we present the design and operating mechanism of Braille PolyPad, a prototype 2D refreshable braille display featuring 4×10 braille cells, enabling the transformation of images to 2D braille information. The Braille Polypad is based on a miniature pump enabled pneumatic actuation of Braille pins. The encoder transformed the pattern information to a heating circuits to trigger the softening of a stiffness variable polymer, allowing for large pneumatic actuation in the softened pin area. The braille pattern can switch on and off in 0.5s each regardless of the number of braille cells and pins, with low operation voltage and low power consumption. The technical features in this work could enable low-cost, large-size matrix refreshable braille displays in compact form factor. Full development of the prototype device is still ongoing, including materials optimization, actuation uniformity, and improvement of user-friendly control interface.

Keywords

2D Braille display; visual impairment; pneumatic actuation; stiffness variable polymer

1. Introduction

Vision impairment limits a person's ability to communicate, learn, work, and travel. It is estimated that there are 36 million blind people and additional 216.6 million severely visually impaired (SVI) patients around the world [1]. In the United States alone, there are more than 1 million legally blind. Braille book has been the primary means for visually impaired individuals to read for over a century. However, Braille devices are generally bulky and expensive. Devices based on piezoelectric bimorph or unimorph actuators [2,3] are typically expensive, due to the sophisticated mechanical elements and high operating voltage (100–300V) [4]. Shape memory alloy (SMA) coils actuators also suffered from low portability and high working temperatures [5]. Electromagnetic (EM) actuators composed of the voice coil and permanent magnet were also investigated for Braille display [5,6]. The trade-off of EM devices is that to maintain the protruding force, the generated magnetic field needs to be held at a certain level, but if too strong, it would negatively affect the surrounding pins. Other challenges include the heat dissipation and power consumption. For instance, constant current flow through the coils while maintaining the position of pins increases the power consumption. All these considerations add to the complexity of the design.

We are living in an era of information explosion. The information we receive is not limited to text, but more multi-media based. The traditional actuator technologies used to display a single line of braille alphabets are difficult to expand into 2D, to display images and videos. There is an urgent need to develop a 2D Braille display technology that enables multi-media communication. As 90% of the visually impaired people live in developing or underdeveloped countries [7], low cost is also an important factor to consider in developing the new braille technology.

This work is aimed to develop a refreshable tactile display “PolyPad” based on pneumatic membrane actuators. Traditionally, pneumatic actuators are bulky because of the flow channel and air compressor. By use of a variable stiffness polymer membrane we recently developed [8], we can control each dot individually or control multiple dots at the same time without a complex air channel design. The large stiffness variation allows for large-strain deformation in the softened state by relatively low pneumatic pressures, and for high shape fixation rate and supporting force in the rigid state without the need for continuous powering. A 2D braille display panel could be assembled using mostly off-the-shelf components.

2. Design Principle

The proposed prototype of PolyPad is shown in Fig. 1(a). It comprises a 6×10×4 braille pixel dots matrix with an outer shell and PCB control system. Each dot has a 1.5 mm diameter with 2.5 mm dot center-to-center distance (designed according to the Braille standard). The device consists of three major parts: a PCB with chips for controlling the voltage output, a pneumatic system and a thin stiffness variable membrane that can be thermally controlled to soften locally. The pneumatic system consists of a pneumatic chamber and a miniature pump to provide pressurized air for actuation. The working principle is shown in Fig. 1(b). Each Braille dot can be individually controlled by heating and deforming the stiffness variable membrane with patterned Joule heating electrode. Then the corresponding pin will be lifted to interface with the end user. Upon cooling within 2 seconds, the dot position can be fixed due to polymer’s increased stiffness. No more power is needed for maintaining the “up” state of the pins. The rapid actuation and instant fixation enable high refresh rate, making it promising for large-scale Braille matrix applications.

The materials enabling the controlled actuation include a stiffness variable polymer named “BSEP” (bistable electroactive polymers) and a Joule heating electrode. BSEP is a phase-changing polymer that exhibits stiffness change by 3 orders of magnitude in a narrow temperature range of less than 10 °C. Fig. 2(a) shows the mechanical properties of a BSEP membrane measured on a dynamic mechanical analyzer (DMA). At room temperature, the BSEP possesses a modulus of 200 MPa and behaves as a rigid plastic capable of providing a high blocking force. Above its transition temperature, which is around 44°C, the polymer becomes soft and stretchable, with its modulus decreasing to 0.2 MPa. In its soft state, the pneumatic pressure needed to displace 0.5 mm can be as low as 20kPa. It also has excellent stretchability with more than 300% elongation (Fig. 2(b)).

The transition temperature of the BSEP was designed to be only slightly above the room temperature, so that the required Joule heating energy for the stiffness transition can be reduced. Besides, the reversible phase transition allows for bistable actuation; the stiffened deformed state can keep the pin at the raised state without energy input. Furthermore, the raised Braille dots are rigid and strong, which are essential for the Braille cell legibility.

To realize the controlled localized Joule heating with high precision, a matrix of a highly compliant single wall-carbon nanotubes (SW-CNT) electrodes are patterned in a serpentine shape on the surface of the BSEP film. The thermal stability, mechanical compliance, and chemical resistance of CNTs made it an ideal choice as the Joule heating electrode. The BSEP with the CNT electrode is attached to the PCB and pneumatic chamber to ensure the chamber's airtightness. The rigid chamber covers, pneumatic pump and other components are then assembled for test.

3. Device Fabrication and Performance

The serpentine CNT Joule heating electrode is designed as shown in Fig. 3(a). In one cell, there are 6 small round areas for heating, and one bus line connected to the ground. The line thickness of the Joule heating electrode is 0.08 mm. A custom fabricated printed circuit board (PCB) was used to drive the Braille cells according to the geometry of Braille spacing standard as shown in Fig. 3(b). The control unit input voltage is 3.3V.

The preparation of patterned CNT electrode on BSEP was briefly illustrated in Fig.3 (d). 5 mg of P3-single wall carbon nanotube powder was mixed with 1 mL of water and 20 mL of IPA by sonication. Large aggregates were removed using a centrifuge at 8500 rpm for 10 min. The resulting CNT supernatant was then spray coated onto clean glass substrate, patterned on a Epilog laser engraver. A thin polyurethane acrylate layer (PUA) was spin coated onto the CNT.

A BSEP monomer solution was made by mixing stearyl acrylate (SA), urethane diacrylate (Sartomer CN9021), acrylic acid, 2,2-Dimethoxy-2-phenylacetophenone (DMPA) and benzophenone (bp) at the weight ratio of 80:20:10:1:0.5. The monomer solution was injected between a pair of glass slides on a hot plate with two strips of tape as spacers. The thickness of the liquid layer was defined by the thickness of the spacers. In the device assembly, 170 μm thick spacers were used to fabricate the BSEP film. Next, the prepolymer was cured through a UV curing conveyor equipped with a Fusion 300S type "H" UV curing bulb for about 2 min. The cured film was gently peeled off the glass slide after it cooled down to room temperature. The patterned CNT was transferred to the BSEP film, as shown in Fig. 3(e). The sheet resistance of the CNT coating was measured to be ~2.0 kΩ/sq. The resistance could be adjusted by the spray coating amount of carbon nanotubes. Lower resistance leads to faster heating or lower driving voltage. However, as the thickness of the CNT increases, the risk of crack formation introduced by large deformation also increases.

After the CNT patterned BSEP membrane was prepared, it was laminated onto the PCB, with the CNT dots on the membrane and copper contact points on the PCB aligned with each other to form electrical connection in the z direction. The adhesion was enhanced by heating the BSEP with a heat gun for 30 seconds. The natural tackiness of the BSEP at its soft state ensures a good adhesion between the board and the film. Fig.3 (f) shows the image after the alignment. The misaligned dots can be inspected under IR camera with voltage on and fixed by peeling off and re-alignment.

The blocking force of the Braille dots was measured by a force sensor. The films were all actuated to a raised height of 0.5 mm. Force was incrementally applied to press on the tip of the raised dots until the dots became flattened. The result is shown in Fig.4 (a). The measured blocking force at 0.5mm displacement is 95 grams for the BSEP membrane with thicknesses of 170 μm. The blocking force decreases with decreasing membrane thickness. The required blocking force in typical tactile devices is 15 g [9].

Fig.4 (b) shows the IR image of a Braille dot during Joule heating before and during its actuation. The temperature in the center area is above 60 °C, ensuring the fully softening transition of the BSEP membrane. During the actuation at the height 0.5mm (which corresponds to area expansion of ~65% in the BSEP membrane), the temperature remains similar, showing that the CNT electrode was able to maintain its resistance at such large strains.

Different heating voltages were applied to study the heating speed of Braille dots of one cell, as the heating speed is closely related to the refresh rate of the device. At 30V, it takes ~0.5 s to reach the transition temperature of the BSEP membrane, while at 25V it takes 0.6 s. Further lowering the heating voltage to 20V slows the heating transition time to 0.7s, but it can reduce the power consumption by ~54% per dot.

Braille pins placed on the BSEP membrane were used as the tactile interface. In the PolyPad prototype, the pins were 3D printed using Formlabs SLA 3D printer and then assembled into the chamber cover. The chamber for air pump was sealed and tested for airtightness. The pneumatic actuation is achieved by a miniature pneumatic pump with the dimension of 32mm×8mm×18mm. The maximum output pressure is 40kPa.

Fig.5 (a) shows the IR image of one line Braille cells being Joule heated at 30V. All dots are heated above the 45°C transition temperature within 0.5s. The power consumption at this voltage for heating 60 dots was estimated to be ~0.6W. Fig.5 (b) shows the actuation of one line Braille cells of the PolyPad.

The first generation of the PolyPad designs features 10×4 Braille cells. The preliminary experimental results have demonstrated the capability of using the stiffness variable polymer combined with a miniature pneumatic pump for the 2D Braille display. Through materials selection and electrodes design optimization, we addressed the challenge of CNT-based microelectrodes printed on BSEP membranes to realize efficient and fast Joule heating. The displacement and blocking force generated by the actuators are sufficient to satisfy the Braille standards. The proposed actuation mechanism and the fabrication process are expected to be scalable for high density tactile arrays.

4. Conclusion

We proposed a new 2D Braille display PolyPad based on the variable stiffness polymer BSEP coupled with pneumatic pumping. The BSEP membrane has reversible modulus change from 200 MPa to 0.2 MPa controlled by temperature. In preliminary prototype fabrication of the PolyPad, we successfully demonstrated the actuation mechanism and pixel addressability through the patterned Joule heating electrodes. Rapid actuation and height fixation of the Braille dots indicate the Polypad may have a fairly fast refresh rate. The heating and actuation uniformity among the Braille dots still need further improvement.

Work is ongoing to improve the performance of devices from three perspectives: 1. Enhance the Joule heating electrode reliability and robustness; 2. Improve airtightness of the device assembly such that the pneumatic pump may be further shrunk in size and power. 3. Add more features and controls to the device by designing PCB and encoders with more sophisticated functions, so that graphical images can be translated into 2D Braille dot patterns.

Acknowledgement:

This work was supported by NIH National Eye Institute award # 1R01EY030246-01A1. The authors acknowledge the use of instruments at the Electron Imaging Center for NanoMachines supported by NIH (1S10RR23057 to ZHZ) and CNSI at UCLA. J.K. acknowledge fellowship support from UCLA. Q.P. has financial interest in Juda Optoelectronics.

References

[1]. Bourne RR, Flaxman SR, Braithwaite T, Cicinelli MV, Das A, Jonas JB, Keeffe J, Kempen JH, Leasher J, & Limburg H Magnitude, temporal trends, and projections of the global prevalence of blindness and distance and near vision impairment: a systematic review and meta-analysis. The Lancet Global Health, 5(9), e888–e897. (2017). [PubMed: 28779882]

[2]. Cho H-C, Kim B-S, Park J-J, & Song J-B Development of a Braille display using piezoelectric linear motors. Paper presented at the 2006 SICE-ICASE International Joint Conference. (2006).

[3]. Velázquez R, Hernández H, & Preza E A portable piezoelectric tactile terminal for Braille readers. Applied Bionics and Biomechanics, 9(1), 45–60. (2012).

[4]. Leonardis D, Claudio L, & Frisoli A A survey on innovative refreshable braille display technologies. Paper presented at the International Conference on Applied Human Factors and Ergonomics. (2017).

[5]. Bettelani GC, Averta G, Catalano MG, Leporini B, & Bianchi M Design and validation of the readable device: a single-cell electromagnetic refreshable braille display. IEEE transactions on haptics, 13(1), 239–245. (2020). [PubMed: 32012027]

[6]. Kim J, Han B-K, Pyo D, Ryu S, Kim H, & Kwon D-S Braille display for portable device using flip-latch structured electromagnetic actuator. IEEE transactions on haptics, 13(1), 59–65. (2020). [PubMed: 31940550]

[7]. Adnan ME, Dastagir NM, Jabin J, Chowdhury AM, & Islam MR A cost effective electronic braille for visually impaired individuals. Paper presented at the 2017 IEEE Region 10 Humanitarian Technology Conference (R10-HTC). (2017).

[8]. Qiu Y, Lu Z, & Pei Q Refreshable tactile display based on a bistable electroactive polymer and a stretchable serpentine Joule heating electrode. ACS applied materials & interfaces, 10(29), 24807–24815. (2018). [PubMed: 29968468]

[9]. Runyan NH, & Carpi F Seeking the ‘holy Braille’display: might electromechanically active polymers be the solution? Expert review of medical devices, 8(5), 529–532. (2011). [PubMed: 22026617]

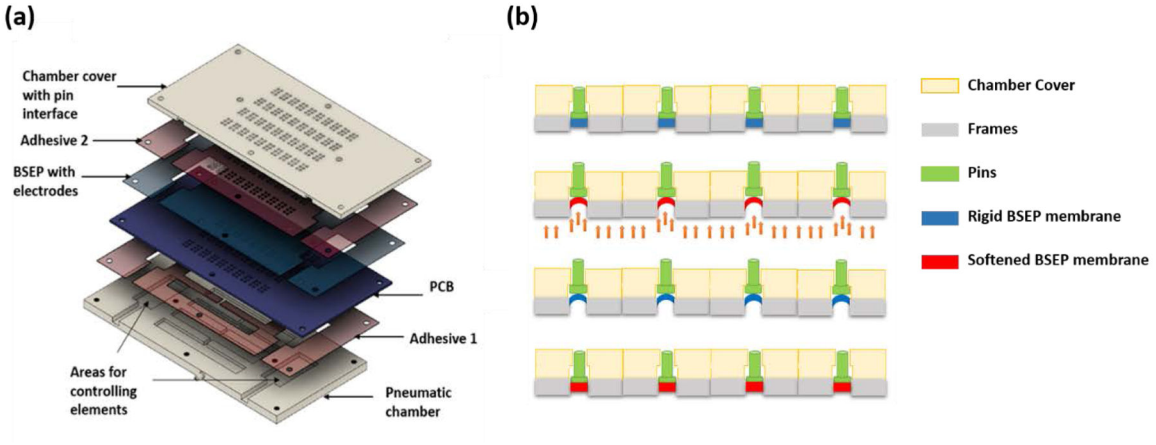

Figure 1.

(a) Schematic illustration of the structure of the Braille PolyPad and **(b**) the cross-sectional view of the braille dots.

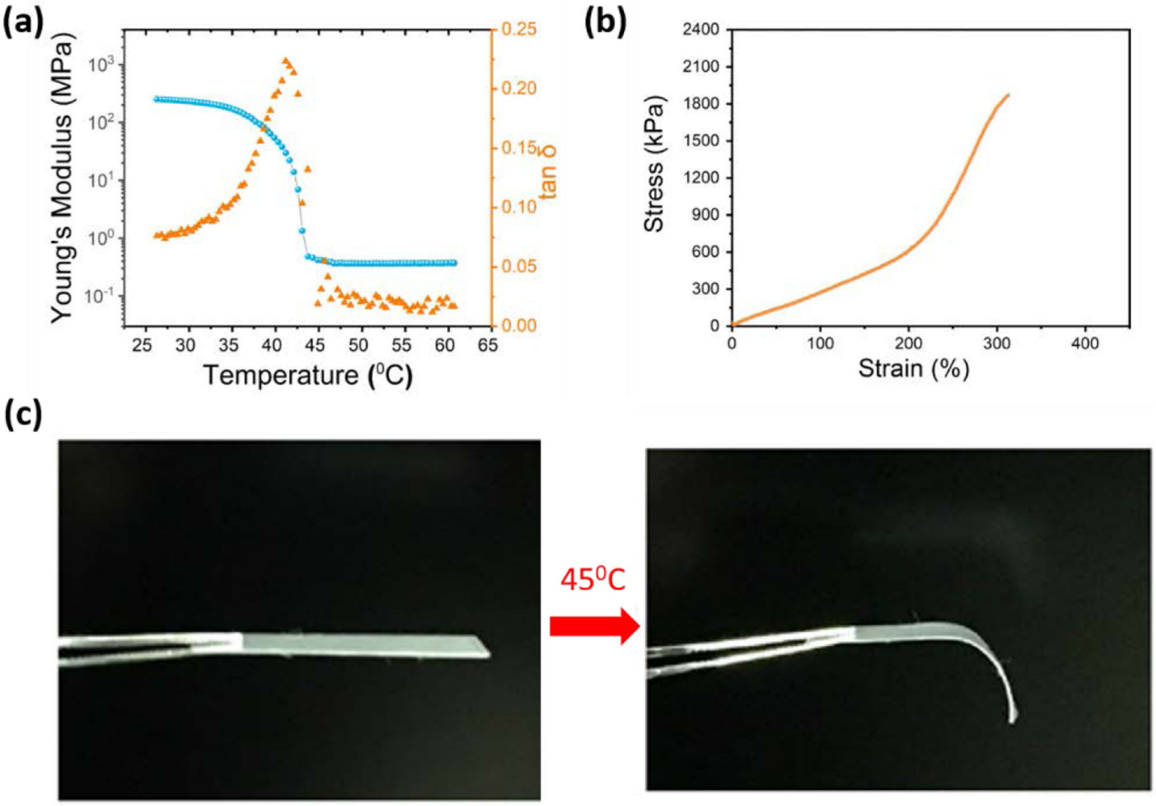

Figure 2.

(a) Storage modulus and tan δ versus temperature profile of the BSEP. **(b)** Stress strain curve of the BSEP membrane. **(c)** Photos showing the softening transition of a BSEP membrane upon heating to 45°C

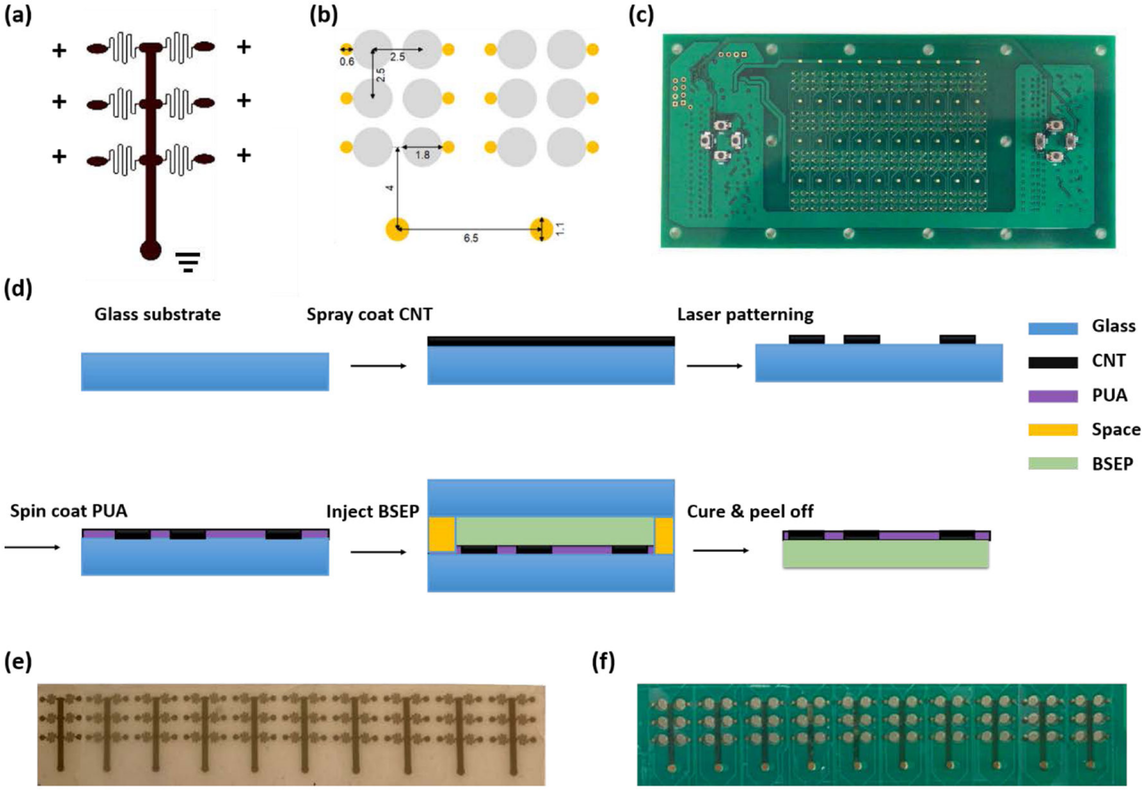

Figure 3.

(a) Design of the serpentine carbon nanotube (CNT) electrode for localized Joule heating. **(b)** Design and dimension of the PCB top side for Joule heating control (Yellow: copper contact. Gray: Air channel). **(c)** Fabrication process of the CNT pattern BSEP membrane. **(d)** Image of 10 cells fabricated BSEP membrane cells with pattern CNT electrodes. **(e)** Image of one line of BSEP membrane laminated on a PCB.

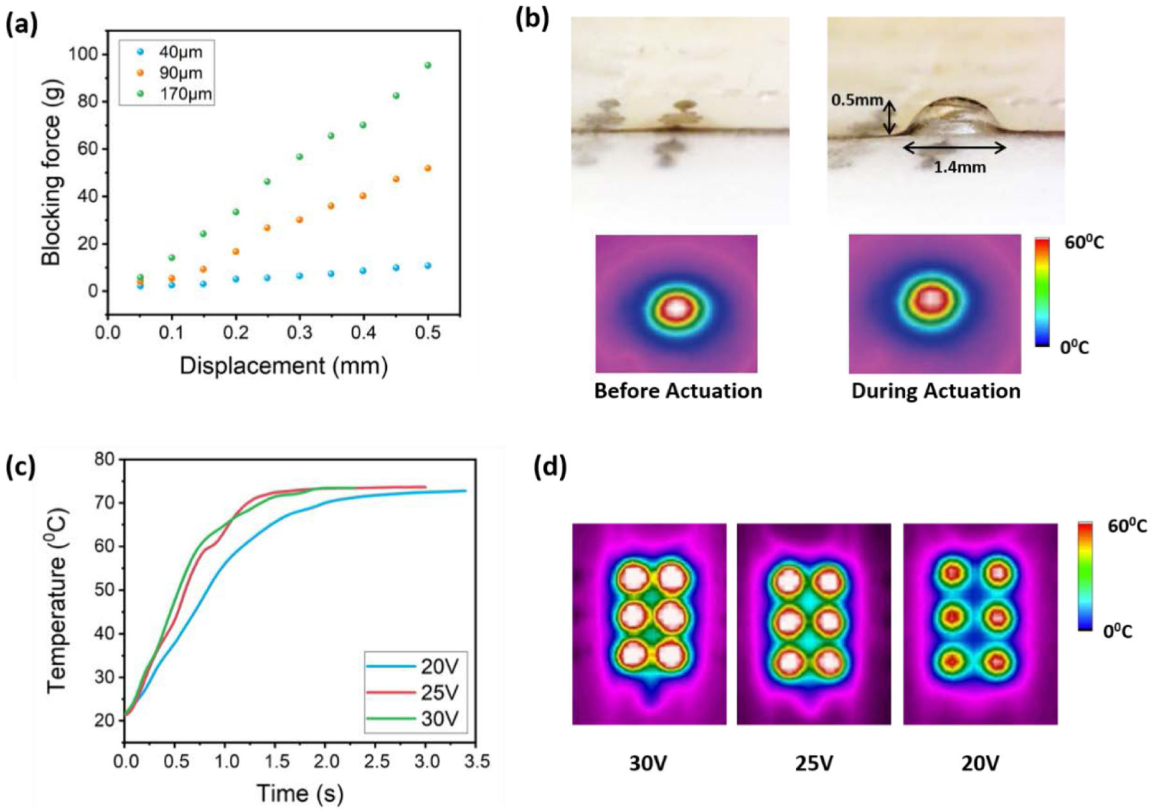

Figure 4.

(a) Blocking force required to completely press down an actuated BSEP membranes of specified thickness. **(b)** Photo image and IR images of a dot before and during actuation. **(c)** Joule heating temperature ramp with different heating voltage. **(d)** IR image of a cell during Joule heating at specified voltages.

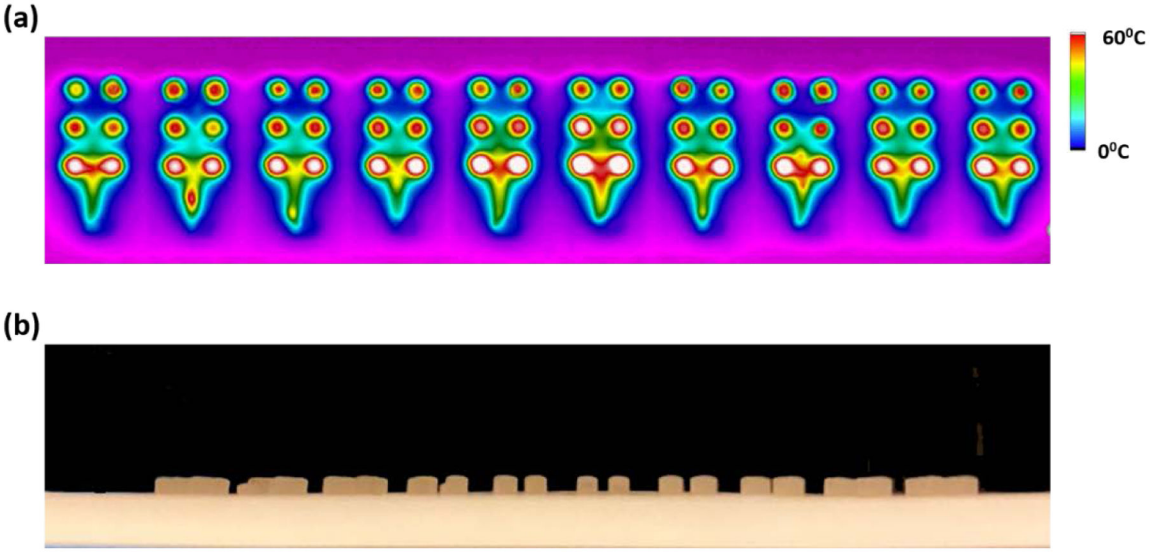

Figure 5.

(a) IR image of one line Braille cells during Joule heating. **(b)** Actuation of one line Braille cells.