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Transparent force sensing arrays with low power consumption using liquid crystal arrays

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ABSTRACT

A transparent force sensing array with low power consumption is developed from a 3 × 3 liquid crystal (LC) array. As force is applied to the LC array, the force-dependent capacitance curve of a sensor pixel under a higher voltage will shift to larger capacitance. Accordingly, the force range of the LC array can be divided into many sub-ranges at one of the capacitance values. The number of the input voltage is equal to that of the output capacitance in each of the sub-ranges, and the voltage-to-capacitance number is small (large) in the high (low)-force sub-range. The sensing array measures force in terms of the voltage-to-capacitance number. The transparent force sensing array shows potential as a touch panel, while it is immune to the need of rectifying the nonlinear relation between the applied force and the output capacitance using complex algorithm via high-end microcontrollers.

1. Introduction

Touch panels have attracted considerable attention in mobile devices due to their intuitive operation and immunity to use any additional input devices such as mice or keyboards. Recently, in-cell touch technology which integrates touch devices into liquid crystal (LC) panels has been proposed [1–6]. This technology brings the LC panels with touch function and makes the touch LC panels slim and lightweightover add-on-type touch panels since it does not need to bind and assemble the touch devices and LC panels. The touch LC panels detect force through the measurement of light intensity, resistance or capacitance, and these approaches still exhibit many challenges on resolution, reliability, fabrication, and low power consumption. Up to now, mobile devices such as smart phones and tablet personal computers could not sustain a long-term operation time because the touch LC panels in the mobile device consume most of battery energy. An intriguing approach to extend the operation time of a mobile device is to develop touch LC panels with low power consumption for mobile devices.

In this paper, we develop an LC cell with elastic spacers for investigation of the dependence of capacitance versus force under various bias voltages. By using a gray scale sensing concept, the LC cell provides the information of gray scale number, giving voltage-to-capacitance relationship, derived from the force-dependent capacitance curve to measure objects of mass ranging from 0 to 14.3 g. As such, it avoids a need to rectify the nonlinear relation between the applied force and the output capacitance using complex algorithm via high-end microcontrollers [7,8]. Because of no microcontroller used, the proposed LC cell has potential to be developed into a touch panel with low power consumption. A 3 × 3 array by the dependence is made to demonstrate its commercialization viability. The LC array can determine force up to 360 mN and provides several promising features such as transparency, easy fabrication, low cost, and low power consumption.

2. Preparation of LC cell and array

An LC cell with elastic spacers is used to study the dependence of capacitance on force at the various voltages. The LCs are used because its capacitance can be controlled by varying the applied voltage to it. The elastic spacers are used to enhance the deformation of the cell gap in order to obtain the obvious variation in the capacitance of the LC cell. An empty cell is fabricated using an indium tin oxide (ITO) glass and an ITO polyester (PET) film, and they are separated by two elastic spacers of approximately 33 μm thick, as shown in Fig. 1(a). The ITO glass and PET film are pre-coated by polyvinyl alcohol (PVA) and rubbed in anti-parallel directions to form a homogeneously aligned cell. The elastic spacers are made from a mixture of polydimethylsiloxane (PDMS) prepolymer and its curing agent (Sylgard 184A and 184B, Dow Corning Co.) at a ratio of 10:1. After that, LCs (E7, Merck Co.) are injected into the empty cell. To frame the LCs, epoxy glue is used to seal the LC cell. Finally, the homogeneous alignment in the LC cell is verified using a conoscope.

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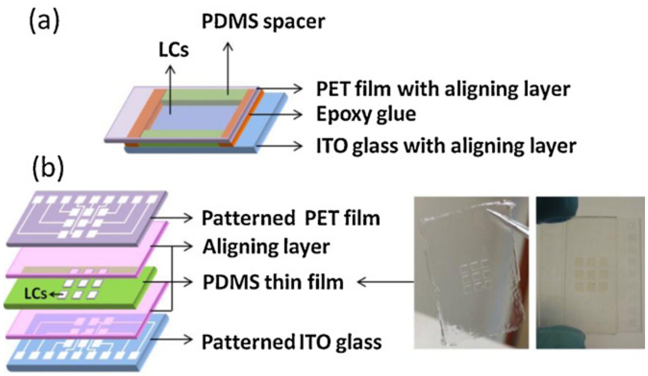

Fig. 1. (a) Schematic drawing of LC cell with elastic spacers. (b) Schematic diagram of LC array.

A 3 × 3 LC array is fabricated to realize a force sensing array. Fig. 1(b) shows the schematic diagram of the LC array. The structure of the LC array consists of a patterned ITO PET film/aligning layer/PDMS thin film with square holes/aligning layer/patterned ITO glass. The ITO electrode structures on the PET film are patterned by oxalic acid with photoresist as the etching mask. Similar patterning process is also used to create the ITO electrode patterns on the glass substrate. The PDMS film with square holes is fabricated by SU-8 mold processing, and the thickness of the film is about 65 μm. The dimension for each hole is 2 mm × 2 mm, and the distance between any two neighboring pixels is 1 mm. The PDMS film with the square holes plays a key role in the development of the multi-pixel force sensing array. A common clamping method is used to fabricate the PDMS film in this study [9]. By using such method, the dimension of the square holes can be reduced to 100 μm × 100 μm in future work [9]. The PDMS film is bonded on the ITO glass by oxygen plasma, and the square holes are filled with the E7 LCs. After the ITO PET is bounded on the PDMS film, the 3 × 3 LC array is formed.

The bonding of hydrophobic PDMS and hydrophilic PVA is not good in many cases. In our case, the oxygen plasma treatment makes PDMS hydrophilic [10]. By using this treatment, the PDMS molecules are able to bond with the PVA molecules due to hydrogen bonding. However, the hydrogen bonding in the LC array becomes weak after ∼100 times of testing and induces the array to lose its functions. The authors will improve the samples in the future.

3. Experimental setup

A force instrument with 1 mN resolution (Instron 5548) is used to determine the force that is applied to the LC cell, as shown in Fig. 2. A round flat-headed copper probe (diameter = 4 mm) is mounted on the sample holder of the force instrument so as to press the PET film while the LC cell is fixed on the translational stage of the instrument via a piece of double-side tape. As the LC cell touches the copper probe by the translational stage, the sensor of the force instrument located at the side of the sample holder can measure the force that is applied to the cell. Due to the adhesion force of the tape, the weight of the device is not considered in the force measurement. The capacitance is measured by an LCR meter (Agilent 4284A) at an AC probe voltage (50 mV, 1 kHz) superimposed on a DC driving voltage.

4. Results and discussion

Fig. 3 shows the force-dependent capacitance curves of the LC cell at the various voltages, V = 0 V, 1.0 V, 1.8 V, 2.0 V, 2.2 V, 2.4 V, 2.6 V, and 2.8 V. In the each case of the applied voltages, the capacitance of the LC cell increases with the force exerted by the

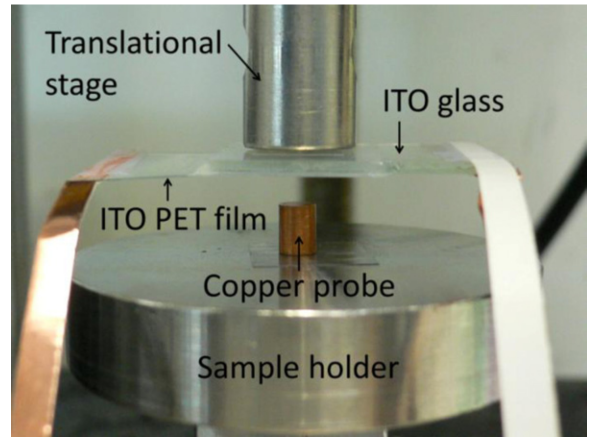

Fig. 2. Experimental setup for the dependence of capacitance on force at the various voltages.

copper probe on the PET film. This is attributed to the fact that the LC cell can act as a plate capacitor. The capacitance formula for the LC cell is expressed as:

$$C = \varepsilon_{\text{eff}} \frac{A}{d} \quad (1)$$

where ε_{eff} is the effective dielectric constant of the LCs; A and d refer to the area and thickness of the LC cell, respectively. As the force is applied to the LC cell, the thickness (area) of the LC cell decreases (increases) since the LCs are incompressible and the PDMS spacer is elastic. Accordingly, an increase in the force makes the capacitance larger. Regarding the force-dependent capacitance curves at V = 0 V and 1 V are superimposed because the threshold voltage of the LC cell is close to 1.0 V [11]. The LC cell can measure force because the capacitance of the cell changes upon touching it. When there is no applied voltage, the sensitivity in force is 0.34%/mN for the LC cell. The force sensitivity derived in our investigated LC cell is higher than those reported data, i.e., 0.016%/mN [12] and 0.19%/mN [13]. However, the LC cell is unlikely to be commercially successful products since the relation between the input force and the output capacitance requires a calibration process to rectify the nonlinear correspondence using complex algorithm via high-end microcontrollers [7,8]. Such calibration procedures lead the LC cell to consume a lot of energy. An improved approach to reduce

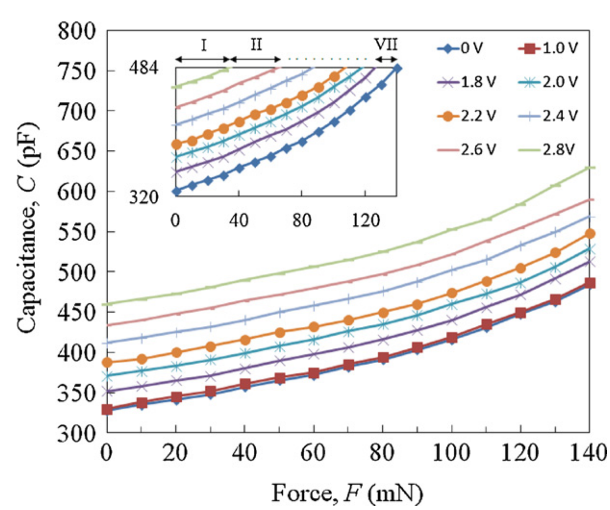

Fig. 3. Force-dependent capacitance curves of the LC cell at the various voltages. The inset shows 7 continuing sub-ranges from I to VII as C = 484 pF is set as the maximum.