Deformable single wall carbon nanotube electrode for transparent tactile touch screen

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With a patterned transparent electrode and compressive-elastic gel material, a multi-input transparent touch screen, which detects touch location and touch force, has been realised. The input device of this touch screen is composed of a flexible upper single wall carbon nanotube electrode (SWCNT), a lower indium tin oxide electrode layer, and a silicone gel layer between two electrodes. When a touch force ranging from 0 N to 5 N was applied to the surface of the upper electrode film, the silicone gel was compressed to change the distance between the two electrodes, which resulted in a capacitance change ranging from 1.92 to 3.42pF. The SWCNT electrode on the polyethylene terephthalate showed sufficient flexibility and robustness for mechanical deformation.

Introduction: The continuing rapid development of portable electronics products demands more intuitive transparent touch input devices. Virtually all touch screens in the market today sense only touch position and duration. Touch force sensing is more intuitive and less cumbersome, since it enables paper-like hand-writing and drawing input, for example by modifying line width depending on the applied force. Several technologies have been proposed to achieve force-sensitive touch screens by using strain gauges or quantum tunnelling composite materials [1, 2]. The position of touch can be determined by the ratios of force read from each of the four corners. However, these technologies cannot sense both multi-touch location and force simultaneously. This Letter describes a simple fabrication method for a transparent force sensing tactile touch screen which can detect both multi-touch location and force by using a single wall carbon nanotube (SWCNT) electrode with good mechanical robustness and flexibility. The SWCNT has attracted great interest because of its many potential applications such as flexible and transparent conductive film (TCF) [3–6]. The conductivity of SWCNT TCF has been improved substantially and nowadays it approaches that of indium tin oxide (ITO) and hence many applications have been intensively studied in the field of touch screen, thin-film transistor, and sensor applications. In particular, the flexibility of the SWCNT makes it possible to develop a novel type of tactile touch screen device and accelerate the development of flexible and unbreakable electronic products on plastic substrates [7–10].

Material and methods: The fabricated transparent tactile touch screen is composed of an upper SWCNT TCF electrode, a lower ITO electrode, and a silicone gel layer between the upper and low electrodes (see Fig. 1). The presence of the silicone gel layer between the upper and lower electrodes makes it possible to change the gap between electrodes by an applied pressure, resulting in electrode capacitance change. The upper SWCNT electrode on the polyethylene terephthalate (PET) is deformed by an applied touch force, and is restored by the compressive-elastic silicone gel.

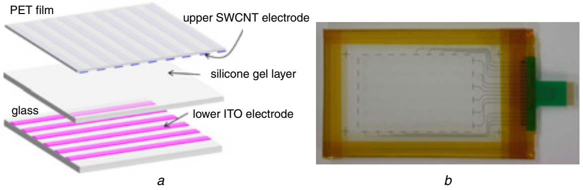

Fig. 1 *Structure of tactile touch screen*

a Upper SWCNT electrode on PET, lower ITO electrode on glass, and silicone gel between electrodes
b Transparent SWCNT tactile touch screen module

In the preparation of the SWCNT electrode, an arc-discharging produced and thermally purified SWCNT was dispersed in deionised (DI) water by sonication with the aid of surfactant, sodium dodecylbenzenesulfonate. The dispersed SWCNT coating solution contained 0.05 wt% of the SWCNT and 0.5 wt% of sodium dodecylbenzenesulfonate. The residual metal catalysts and aggregated SWCNT bundles in the SWCNT coating solution were removed by a centrifugal separator.

Before coating the SWCNT, a PET substrate was oxygen plasma treated, and a gold (Au) signal trace line was deposited and patterned by thermal evaporation and photolithography process, respectively. The SWCNT coating solution was then sprayed on the PET substrate using spray coating equipment. During the spray coating process, the temperature of the PET substrate was maintained at 90°C to evaporate the sprayed water droplet. To remove residue surfactant in the TCF, the sprayed SWCNT TCF was dipped in distilled water and dried with N_2 blowing. The SWCNT TCF was then patterned by the laser scribing method. Laser scribing cuts off the electric pathway of the SWCNT TCF, and makes electrically isolated SWCNT patterns (see Fig. 2).

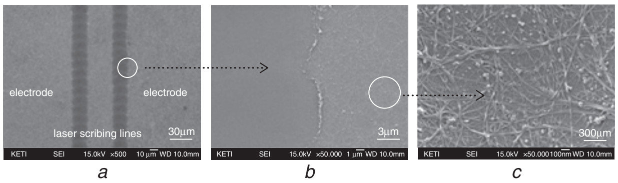

Fig. 2 *SEM imges of SWCNT pattern on PET*

a Laser scribing lines and patterned SWCNT electrode. To make sure to cut off electric pathway between SWCNT elelctrodes, SWCNT film was doubly scribed by laser
b Interface of scribed line and SWCNT electrode
c SEM morphology of SWCNT electrode on PET

The tactile touch screen module was fabricated by a packaging process as shown in Fig. 3. The packaging process consists of dam bonding, injection of compressive-elastic materials, and an ACF bonding process. The corner-opened dam was attached to the lower ITO electrode glass where chromium (Cr) trace lines and ITO patterns were formed on the glass by photolithography and wet etching process. The upper SWCNT electrode film was bonded with the dam-attached glass. The organic silicone gel was injected between the upper and lower electrodes through the opened area in the corner. Table 1 shows the properties of silicone gel such as 527, 528, 1891, X3-6211, and 3-4154 supplied by Dow Corning for use in the compressive-elastic materials [9]. The injected gel was cured at 40°C for 24h, and a flexible printed circuit board (FPCB) was bonded to the terminals of the tactile screen with anisotropic conductive film (ACF).

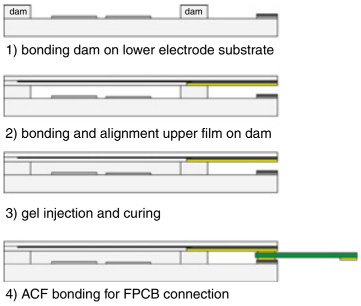

Fig. 3 *Schematic drawing of procedure for packaging of tactile screen module*

Results: In the upper electrode, the SWCNT TCF deposited on a PET substrate showed sheet resistance of 590 Ω/sq, which was measured with a four-point probe, and UV-Vis-NIR spectroscopy (Jasco V-670) analysis showed light transmittance of 86.1% at 550 nm wavelength.. The laser scribing method cuts off only the electric pathways without removing any SWCNT TCF region except the scribing line itself, which minimises the colour difference caused by patterning. Doubly scribed SWCNT patterns shown in Fig. 2*a* were electrically isolated, and the measured resistance across the scribed line patterns was over 50 MΩ. The patterned SWCNT electrodes have a rectangular geometry of 5 mm width and 60 mm length. The resistance of these patterned electrodes was about 7 kΩ.

Table 1: Properties of silicone gel such as 527, 528, 1891, X3-6211, 3-4154, supplied by Dow Corning

Model name	527	52S	X3-6211	1891	3-4154
Viscosity (P)	4.75	4	9.25	4.4	5.5
Mix ratio	1:1	1:1	1 com.	1:1	1:1
Penetration (1/10 of mm)	45	95	50	45	50
Gel hardness (g)	120	55	105	–	110
Specific gravity	0.95	0.97	0.99	0.99	0.97
Cure time (min)	210 100°C	80 120°C	3sec 3J/cm^2	30 60°C	180 80°C
Dielectric constant	2.85 (100 kHz)	–	–	–	2.87 (100 kHz)

Fig. 4*a* shows a schematic picture of the force sensitive touch screen and cross-section of the deformed unit cell of the tactile touch screen. Two crossing 5 mm wide bar-type electrodes were separated by approximately 500 μm-thick silicone gel. Fig. 4*b* shows the dependence of the compressed thickness of the silicone gel layer between the upper and lower electrodes by compressive-elastic deformation caused by the applied force. The compressive-elastic dielectric gel material used was 527, 528, 1891, X3-6211, or 3-4154, all products of Dow Corning. Their compressed thicknesses are approximately 324, 432, 372, 313, and 258 μm at 5 N force, respectively. The elastic-compressive characteristic of the 3-4154 product is relatively better than the others in the range of 0–5 N applied forces. Therefore, the 3-4154 gel was selected for the tactile touch screen application.

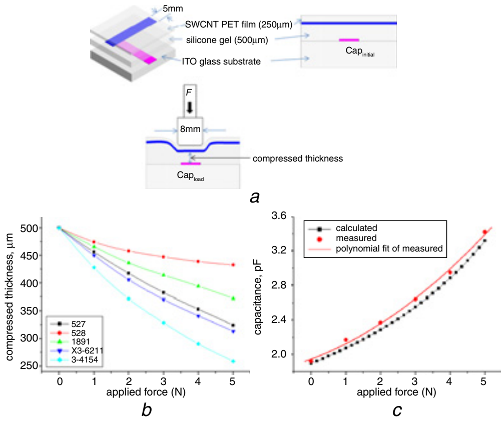

Fig. 4 *Characteristics of tactile touch screen*

a Schematic of fabricated specimen and cross-section of deformed unit cell with applied force by 8 mm diameter rod
b Compressed thickness of silicone gel layer for various applied forces
c Measured capacitance and calculation result of fabricated tactile touch screen for various touch forces

The fabricated capacitive tactile touch screen consists of a cross-array of rectangular transparent electrode patterns, where cross electrode area *A* is separated by distance *D* with silicone gel of relative dielectric constant ε_r. The capacitance between crossed electrodes is described by (1), where ε_0 is the permittivity of free space:

$$C = \varepsilon_r \varepsilon_0 \frac{A}{D} \qquad (1)$$

The gap between the flexible touched upper electrode and the lower electrode can be changed by an applied force, and hence the capacitance change is obtained with compressive-elastic deformation of the silicone gel. The theoretical capacitance was calculated using (1), where *A* is the crossed area (5 × 5 mm) between the electrodes in Fig. 4*a*, ε_r is 2.87 in Table 1 and *D* is the compressed thickness with applied force of 3-4154 silicone gel in Fig. 4*b*. The capacitance of the fabricated tactile touch screen was measured at various applied forces using a precision LCR meter (HP 4284A). The measured capacitance curve is quite similar to that of the calculated capacitance curve, except that the measured value is a little higher than the calculated one, as shown in Fig. 4*c*. It is believed that this difference resulted from the fact that the calculated value obtained from (1) considered only the crossed area *A* between the two electrodes not including parasitic capacitance such as fringe, coupling, cross-over capacitance, etc. The capacitance of the fabricated tactile screen increased from 1.92 to 3.42pF when the applied force varied from 0 to 5N, as shown in Fig. 4*c*. The compressive-elastic layer is one of the most important parts for high sensitivity of the tactile touch screen with force sensing. The less the compressed distance per applied force between crossed electrodes by compressive-elastic deformation, the more improved the sensitivity is by the high rate of the capacitance change. According to (1), sensitivity also can be improved if the compressive-elastic gels with high dielectric constant are employed for the capacitive tactile touch screen and the initial distance between electrodes decreases.

The fabricated transparent tactile touch screen module showed light transmittance of 81% at 550 nm wavelength, which was measured by a UV-Vis-NIR spectroscopy (Jasco V-670).

Conclusion: A transparent multi-input SWCNT tactile touch screen, which can detect touch force and touch location, was successfully fabricated and its characteristics were evaluated for the first time. The SWCNT electrodes of the tactile screen have sufficient flexibility and robustness for mechanical deformation, and did not show any cracked and stretched area. This tactile touch screen makes it possible to provide a solution for a novel type of transparent touch screen for electronic devices.

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