Preparation and property of novel CMC tactile sensors

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Abstract

In this study, carbon microcoils (CMCs) which could be extended and contracted were used to manufacture thin film CMC/polysilicone composite sensor elements that was found to have a very high tactile sensor performance. This is because the extension of CMC was very highly sensitive to an applied load. That is, inductance (L) capacitance (C), and resistance(R) of CMC/polysilicone composites extensively changed with the extension and contraction of the composite under applied loads.

CMC tactile sensors could detect very low applied loads on milligram orders. The sensitivity of CMC sensors is 1,000-10,000 times higher than that of commercially available tactile sensors. Accordingly, the CMC tactile sensors have potential applications to various medical instruments such as endoscopes, catheters, manipulation sheets, etc., or as artificial skin of humanoid robot, etc.

1 ITRODUCTION

Carbon microcoils/nanocoils (CMCs) have an interesting morphology with a 3D-herical/spiral structure similar to DNA or proteins. The super-elastic CMCs (SECMCs) have a double-helix conformation with a coil diameter of 10-20 μm as shown in Figs. 1-2. The SECMCs have a very high elasticity, and their electrical parameters; inductance (L), capacitance (C) and electrical resistivity (R), are changed by the extension and contraction. It is well known that the Meissner's corpuscles, which is the most important tactile receptor of human skin and have helical forms of micron sizes. It is considered that CMCs can be used to manufacture artificial tactile sensors due to their similar helical forms [1]. In this study, novel CMC tactile sensor elements were prepared by embedding 1-5 wt% CMCs in elastic polysilicone resin. The changes of LCR parameters of the CMC sensor elements under applying static loads or other stimulations, were measured using an impedance analyzer.

2 EXPERIMENTAL

CMCs can be synthesized by catalyzed CVD process using acetylene as a carbon source and sulfur compounds as an impurity at reaction temperature 700-800 ℃. By the standard reaction conditions, the obtained CMC were usually regular coiled with a constant coil diameter of 1-6 μm, a coil gap of nearly zero through a coil length, and a coil length of 1-5 mm in 2hrs reaction time. Fig. 1 shows the representative regular flat-fiber CMCs with a coil diameter of about 4 μm obtained using Ni powder catalyst at 750-800℃. The double-helix structure can be clearly seen from the cross-section image.

On the other hand, the CMCs with a large coil diameter of 10-20 μm could be obtained at lower reaction temperature of 700-730℃ and lower gas flow rates. Their representative images and the enlarged view are shown in Fig. 2. Because of the super elasticity, this kind of CMCs is referred to as super-elastic CMCs (SECMCs).

In this study, only SECMCs were used. Two kinds of sensor elements were prepared: (1) CMC composite sheets(sheet sensor elements): CMCs were embedded into polysilicone (Shin- Etsu, KE-103) by 1-5wt%, and obtained the CMC composite sheets of 10x10x2mm^3. The CMCs were uniformly dispersed in the polysilicone matrix, and respective CMCs did not contact each other, and percolation structure was not observed. (2) CMC composite thin films sensor elements: including random-CMC sensor films and array-CMC sensor films (sensor elements). For the latter, because SECMCs are relatively easily arrayed among polysilicone resin by extension (Fig. 2b), thus, array-SECMCs/polysilicone composites were manufactured, and whose structure is similar to skin.

The measurement of sensor properties was carrying out as the following: loads were applied vertically on the CMC sensor elements by a manipulator, AC voltage of 5V (200 KHz) was applied on the sensors through two electrodes (separation: 2.5 mm), and the output was measured using impedance analyzers, Agilent 4294A or Agilent OSCILLOSCOPE 54621. When using the former, L, C, R can be produced respectively; when using the latter the respective parameters were transformed into a DC voltage output of (LC) and R respectively. The image of the array-CMCs among the matrix was observed by microscopic OLYMPUS U-LH100-3.

3. RESULTS AND DISCUSSION

3.1 Sheet sensor elements

A load of 5 g was applied on the surface of composite sheets of 10x10x2 mm^3 through a wood needle controlled by a manipulator and output change was measured by Agilent OSCILLOSCOPE 54621. From Fig. 3, it can be seen that a strong output (voltage, i.e.V) of the (LC) and R parameters significantly produced as soon as the loads were applied. It can be seen that very sharp output peaks can be obtained when the CMC sensor element was touched by a needle, and that the sharp output signal line quickly decreased and disappeared after releasing the applied load. The response time was on a millisecond order. A continuously applied load resulted in a continuous shift in the output lines. It is noticed that the intensity of R peaks are stronger than those of LC peaks.

Fig. 4 shows the changes of C parameter under applying various loads on the mgf～gf order. It can be seen that C parameter was dramatically changed under applying a load. When the load was as small as 10 mg, the output is 12 pF. The outputs increased with the load increase slightly in gf order.

3.2 Film sensor elements

Very thin CMC sensor elements with different array of the CMCs in the matrix were manufactured with a size of 2x2x0.1 mm^3. A load of 5 g was applied to the sensor element using a wood rod with a diameter of 1 mm. For the random-CMC elements, the output of the (LC) parameter was about 1 V, although the R parameter output was small (Figure is omitted). For array-CMC sensor, in which the slightly extended CMCs were embedded in the matrix (The image of extended SECMCs among polymer matrix is shown in Fig.5c.), the CMCs were vertically arrayed in the matrix (Set A) or parallel (Set B) to the direction of the electrodes as shown in Fig. 5 (arrayed-CMC sensor). When the CMCs were partly arrayed in the vertical direction to the electrodes, the LC parameter output was 5v, and the R parameter output was 0.5v. However, when the arraying direction of the CMCs was parallel to the electrodes, no output was observed. This results indicates that by arraying the CMCs vertical to the electrodes, very high tactile sensor properties can be obtained.

M. Konyo et al. proposed that for high CMC addition, resistance is more important than capacitance, while for low CMC addition catacitance is more important than resistance. In the case of random-CMC sensors, the CMC addition amount is larger than in the case of array-CMC sensors. Thus, in Fig.3, more attention should be paid to R change, while in Fig.5, more attention should be paid to LC change.

3.3 Comparison of different stimuli

Fig.6 shows the change of L parameter of the CMC sensor elements under approximating a hand and a heated solder tong, as well as under applying static load of 200mgf. Strong signal changes are observed when a hand or heated solder tong is approximated to the sensor elements. An IR ray is emitted from a hand. Furthermore, it was observed that L and R signal changes was observed when cellular phone or sound was approximated. That is, the CMC tactile sensors can be detected various stresses, temperature, IR, EM waves, etc. with very high detection sensitivity and high discrimination ability. Accordingly, the CMC sensor elements has high potential applications as tactile sensors for endoscopes, catheters, manipulation sheet, etc., or as artificial skin of a humanoid robot, detection sensors of humans buried in debris by earthquake, and various industrial sensors. It is considered that these properties may be affected by the formation of hybrid LCR oscillation circuit between CMC and dielectric elastic matrix.

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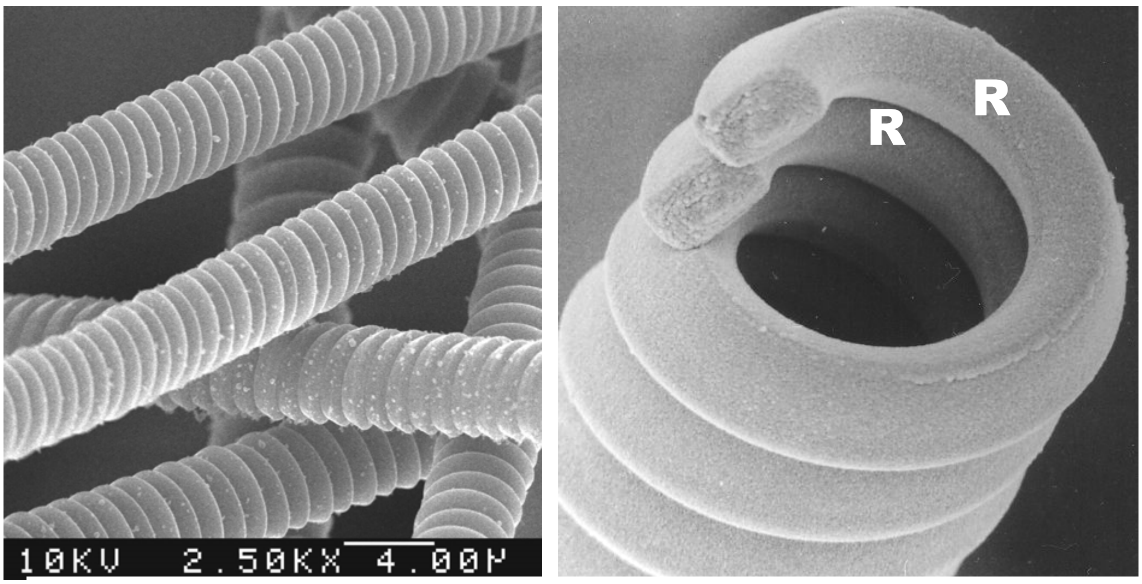

Fig.1 Regular double-helix carbon microcoils:coil diameter, 4μm

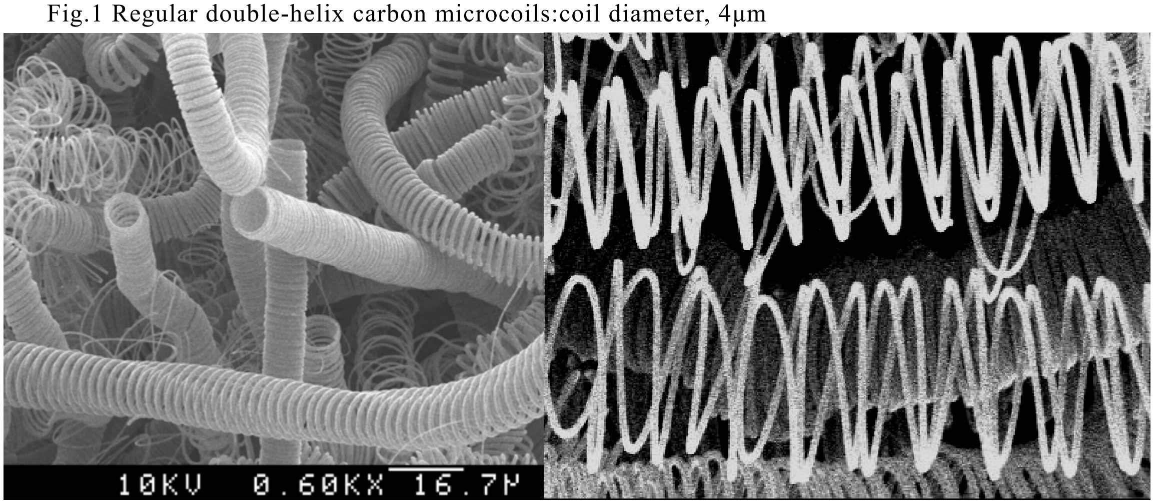

Fig.2 Irregular double-helix carbon microcoils with a super-elastic property (SECMC), coil diameter: 10-15μm.

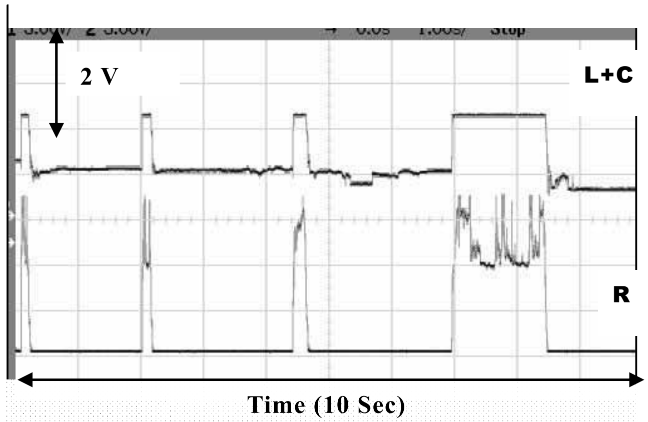

Fig.3 Change in LCR parameters of the SECMC (composite sheet) tactile sensors to a needle with a load of 5 g, the output of L+C and R respectively.

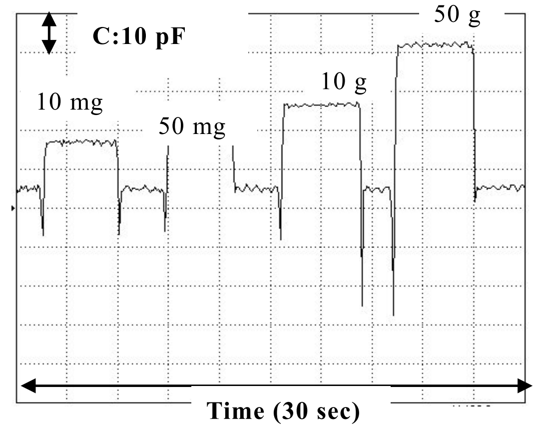

Fig.4 Capacitance change of SECMC sensor when applied different loads.

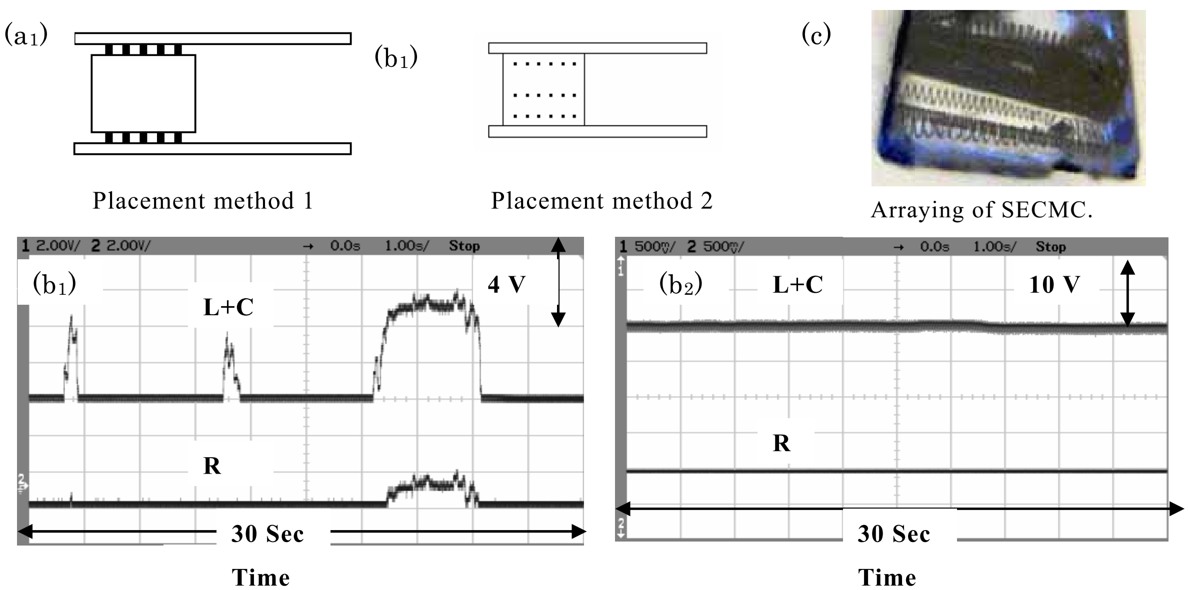

Fig.5 Change in LCR parameters of the SECMC (composite films) tactile sensor with CMC arraying. (a_2): when the setup of the sensor and electrodes was done as in a_1. (b_2): when the setup of the sensor and electrodes was done as in b_1. (c): arraying of SECMC in the film sensor element.

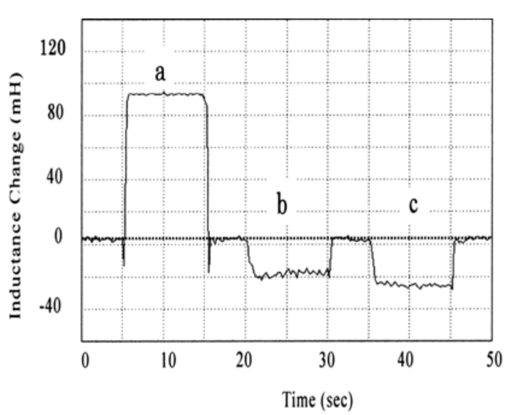

Fig. 6 Inductance changes under applying small loads and approximating of a hand and heated solder tong.
Dotted line indicates without applying load.
(a) applying of a load 200mgf, (b) approximating of a hand, (c) approximating of a heated solder tong.