**Carbon nano-particle composite actuators**
**— for printable electronics and mechatronics systems —**

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Light, flexible actuators are required for advanced robots and medical devices. Electroactive polymers (EAPs) are promising materials for one of the most advanced actuators because they are light weight and flexible and allow for ease of processing. We have developed electroactive-polymer actuators using a carbon nano-particles (CNP) composite, which consists of CNP and organic polymer.

The CNP composite actuators have several variations depending on the CNP and polymer species. We elaborated two typical CNP composite actuators by adjusting the ingredients of the composites; one operates in the electrolyte solution, and the other can operate in air. Both of them are linear actuators. Although the compositions of the materials of both actuators are the same, the actuation principles are completely different. The former works by a charge that accumulates in the electric double layer formed on minute particle surfaces. The latter utilizes thermal expansion induced by Joule heating. The typical properties of the two types of CNP composite actuators, consisting of Ketjenblack and Nafion®, are shown in Table 1. Their properties are similar because they depend on the mechanical properties of the actuator film.

The former actuators operating in solution are superior in energy consumption. The actuator can keep the deformation as long as the charge is stored, which means that little energy is needed to maintain the deformation if the system is in an ideal situation where current leakage is negligible.

One of the latter actuators operating in air is unique in that it can be fabricated using only the printing process such as screen printing. This means the actuator modules can be produced at low cost and at large scale. Furthermore, actuators with complicated structures, such as an actuator matrix, can be easily fabricated. The unimorph bending actuators were easily fabricated by printing actuator patterns on a polyimide film using a screen-printing process, as shown in Figure 1.

Table 1. Properties of two types of CNP composite actuators.

| **Properties** | **Operating in solution** | **Operating in air** |
|---|---|---|
| Strain (%) | Maximum 4<br>Typical 2 | Maximum 4<br>Typical 2 |
| Driving voltage (V) | < 10<br>Typical 3 | < 100<br>Typical 10–40 |
| Max. Response (Hz) | > 30 | > 30 |
| Max. Stress (MPa) | ~ 4 | ~ 4 |
| Life (cycles) | > 100,000 | > 10,000 |

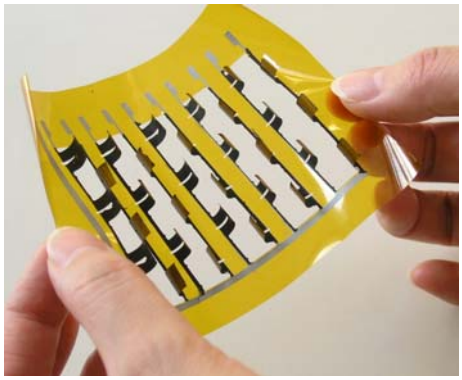

Fig. 1 CNP composite actuators
that were fabricated by printing process.