Accurate assembly process of shape memory alloy tubular micro manipulator
with a coaxial bias mechanism

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This paper describes a batch fabrication and accurate assembly processes of shape memory alloy (SMA) tubular micro manipulator with a coaxial bias mechanism. Tubular micro manipulators with a function of bending motion have been developed for minimally invasive medical applications such as active catheters. In particular, SMA micro actuators have been used for the manipulators due to the significant deformation and force generation [1-2]. In previous work, SMA tubular actuators having multiple meandering springs have been successfully batch-fabricated from an SMA tube with a non-planer photolithography and etching processes [3, 4]. The SMA actuators needed additional bias mechanism such as a coaxial cylindrical spring for repeated bending motion [4]. However, it was difficult to insert and assemble the bias mechanism with the small tubular actuator. In this paper, we propose a novel accurate assembly process of a tubular SMA manipulator with a cylindrical bias spring. The SMA actuator consists of meandering shaped springs with connection rings which have an expandable structure so that the tubular bias spring can be easily inserted into them.

An SMA tube (Ti-44at%Ni-6at%Cu, O.D.: 1.0 mm, wall thickness: 85µm) which had been heat-treated for shape memorization was used. Figure 1 shows the photo mask pattern for etching of the SMA tube. After a positive photoresist was dip-coated, meandering patterns and connecting ring patterns with slits were transferred from the planar photo mask onto the SMA tube surface by a rotational step-and-repeat proximity exposure [4]. With the photoresist pattern, the SMA tube was electrochemically half-etched, as shown in Figure 2 (a). The tube wall was thinned from inside by a chemical polishing with hydrofluoric acid and nitric acid mixture until 30 µm thick meandering springs remained (Figure 2 (b)). By using a small diameter needle, the connecting rings was easily extended to 1.1 mm in diameter due to the flexibility provided by the slits in the rings. The meandering SMA actuators were elongated (50 %) in the longitudinal direction previously to obtain a shrinking shape recovery.

Figure 3 shows a tubular bias spring fabricated from a TiNi super elastic alloy tube (O.D.: 900 µm) with the similar etching processes. The bias spring consisted of ladder-shaped alternating beams to obtain the flexibility for bending. The wide rings in the bias spring were formed for mounting the SMA actuator. The tubular bias spring was inserted through the extended SMA rings, and then the mounting bases were aligned to the SMA rings under a microscope (Figure 4 (a)). The each extended SMA ring was locally heated by a needle-type micro heater one-by-one so that the ring was contracted to clamp the mounting base (Figure 4 (b)). By the expansion and contraction of the SMA rings, the tubular actuator was accurately assembled with the coaxial bias spring. Finally, the cramped SAM rings were further fixed with a conductive resin (Figure 4 (c)), followed by a final coating with an insulative resin. Lead wires were attached on the bonding pads of the SMA actuators with the conductive resin.

When one of the meandering SMA actuator was electrically heated (23 mW, about 50 °C) to generate the tensile force of about 50 mN, the assembled manipulator was successfully bent to an angle of 30 °. The proposed assembly method with mechanical cramp enables us to obtain sufficient assembly strength without fracture during the operation of the bending motion.

References:

Figure 1. Photo mask pattern for SMA tube etching.
Figure 2. Fabrication of the SMA tubular actuator
(a) Patterning by electrochemical etching
(b) Chemical polishing from tube inside
Figure 3. Bias spring fabricated from a super elastic alloy tube.
(a) dia. 1.0 mm
(b) dia. 1.1 mm
(c)
Figure 4. Assembly of the tubular SMA actuator with the bias spring
(a) Bias spring insertion through the extended ring
(b) Ring contraction
(c) Conductive resin addition