

MEMS-Based Flexible NiTi Shape Memory Alloy Micro Actuator for Cochlear Electrode Applications

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Summary:

This work presents a MEMS-based flexible NiTi micro actuator using co-sputtered thin films for cochlear electrode applications. Film composition was tuned to Ni_{51.3}Ti_{48.7} by adjusting Ti sputtering power, followed by vacuum annealing at 400°C for 2 hours. Crystallization was confirmed by XRD, and EDX verified composition. The films exhibit a two-way shape memory effect with reversible actuation around 65 °C, demonstrating potential for integration into biomedical MEMS systems.

Keywords: Co-sputtering, MEMS actuators, NiTi thin films, shape memory alloys, thermal actuation

1. Background and Motivation

Shape memory alloys are widely used due to their unique ability to recover predefined shapes upon thermal stimulation, making them highly attractive for micro-actuation applications. This functionality enables their use in biomedical microsystems, where controlled deformation and recovery are critical [1]. Cochlear electrode systems represent a demanding application, as they must conform precisely to the spiral geometry of the cochlea to ensure effective neural interfacing, while simultaneously providing controlled mechanical compliance and actuation to enable smooth insertion and minimize trauma to delicate cochlear tissues [2]. For such biomedical applications, the phase transformation temperature must also be compatible with body temperature to ensure safe and effective operation.

This work aims to fabricate and characterize NiTi thin films via co-sputtering on a flexible substrate and evaluate their functional behavior for potential use in cochlear implant applications.

2. Materials and Methods

NiTi shape memory alloys were selected in this work because their phase transformation temperature can be tuned close to body temperature by controlling composition, which is critical for cochlear implant applications. Achieving this precise tuning requires strict compositional control, since even ~1% variation in Ni content can shift the transformation temperature by nearly 100 °C [3]. To enable this level of control, co-sputtering from separate Ni and Ti targets was employed, allowing independent adjustment of elemental contributions despite their different

sputtering yields [4,5]. The as-deposited amorphous films were crystallized by high-temperature post-deposition annealing to activate shape memory behavior [6].

2.1. Fabrication Process

Fig.1 illustrates the fabrication process flow of the NiTi-based actuator. PI-2610 was used as a flexible substrate due to its high temperature resistance and mechanical flexibility, making it suitable to withstand the post-deposition annealing required for NiTi crystallization while enabling safe deformation during cochlear electrode insertion and operation. A 1 µm NiTi thin film is deposited by co-sputtering. Top and bottom PI layer thicknesses are intentionally made different so that the neutral axis does not lie within the NiTi layer, resulting in a predefined curvature upon release, thereby forming a permanently bent electrode structure that conforms to the shape of the cochlea. Upon heating, the structure straightens, enabling atraumatic insertion into the cochlea with no damage.

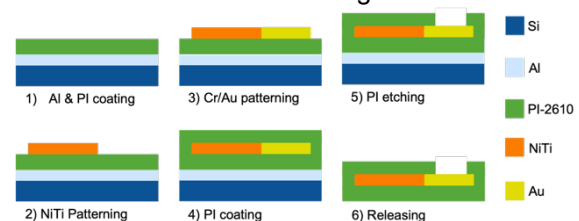


Fig. 1. Fabrication flow of the flexible SMA actuator

2.2. Characterization Methods

The chemical composition of the co-sputtered NiTi thin films was analyzed using EDX to evaluate the effectiveness of the compositional

optimization. The crystalline structure and phase formation were investigated using XRD measurements. Thermal behavior and shape memory response of the fabricated devices were evaluated through a heating test, where the actuation behavior of the NiTi thin films were observed.

3. Results

To enable actuation near body temperature, a slightly Ni-rich composition (~51 at. % Ni) was targeted as a higher Ni content would significantly shift the phase transformation temperature beyond the desired range. The Ni sputtering power was kept constant while the Ti sputtering power was varied to tune the film composition. Table 1 shows the dependence of the film composition on the applied powers.

Tab.1: EDX results for NiTi co-sputtering optimization

Process	Target Power (W)		Composition (at %)
	Ni	Ti	
1	42	200	Ni _{57.8} Ti _{42.2}
2	42	225	Ni _{54.5} Ti _{45.5}
3	42	250	Ni _{51.3} Ti _{48.7}

Ni_{51.3}Ti_{48.7} film annealed at 400 °C for 2 h under vacuum conditions. Fig.2 presents the XRD patterns of the as-deposited amorphous film and the annealed film, highlighting crystallization after annealing. The diffraction peaks observed at 41.41°, 43.40°, and 46.19° are attributed to the martensitic phase of NiTi [3], indicating that the film is predominantly in this phase at room temperature. This suggests that the phase transformation to austenite occurs at higher temperatures.

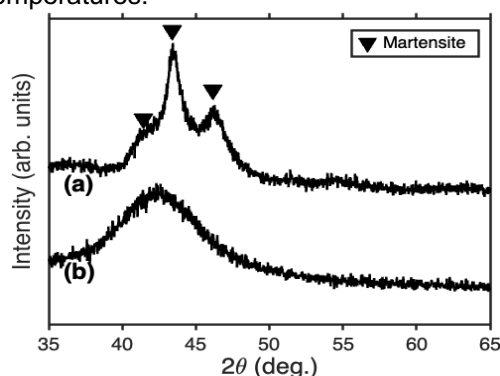


Fig. 2. XRD profiles of Ni_{51.3}Ti_{48.7} (a) annealed at 400 °C for 2h (b) as deposited

Fig.3 shows the released die and the die heated on a hot plate at 65 °C for 3 minutes. As expected, the heated dies straighten, recovering the flat shape defined during annealing. Moreover, once removed from the hot plate, the samples return to its original shape at around 25 °C within approximately one minute, indicating a two-way shape memory effect. The shape

memory alloy can also be actuated electrically by applying a voltage, for example by attaching the die to a PCB using epoxy, as shown in Fig. 3(c).

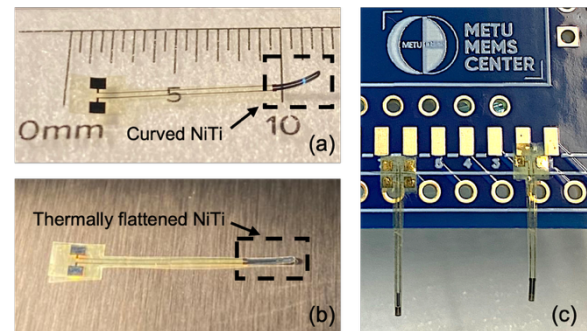


Fig.3. (a) Released die, (b) die heated on a hot plate at 65 °C for 3 min, and (c) die attached to a PCB

The results demonstrate promising potential for shape memory alloys in cochlear electrode applications, with rapid shape recovery observed at around 65 °C. The phase transformation temperature can be further tuned closer to body temperature by optimizing annealing parameters such as temperature and duration. This approach enables an actively reconfigurable electrode architecture compared to conventional passive designs, offering reduced insertion trauma and improved conformity to the cochlear spiral, and highlights the feasibility of integrating MEMS-fabricated shape memory alloys into next-generation cochlear interfaces. As a future work insertion tests can be performed using a cochlear model for further validation.

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