Self-folding shape memory bilayer structures formed by irradiating anisotropically stressed polycarbonate films

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The poster will describe a method for fabricating 3-D shape memory structures (SMS), shown in figure 1, made by irradiating anisotropically stressed, 2-D polycarbonate substrates with a high dose ($> \ 360 \ \mu C/cm^2$) of He ions or neutral atoms. The SMS fold in various shapes on their own upon release of the constraints, have short recovery time (< 1 sec), are ultra-thin ($\leq 2 \ \mu m$) and very resilient. They can be gently unrolled, metallized by quasi-planar processing techniques and recover their 3-D form when the constraints are removed. The SMS substrates are ideal for extra-neural cuffs for peripheral nerves since they address many disadvantages of the state-of-the-art which are limited by a small electrode count [1,2], large size [1-3] and/or suturing requirements [3-5].

The fabrication method is briefly described by the schematic in figure 2. The irradiation leads to chain scissioning, crosslinking and partial carbonization [4-6] which forms a stiff and brittle layer at the surface. This layer is as thick as the penetration depth of the He ions or atoms (~600 nm thick at 50 KeV), thus, a bilayer of crosslinked and un-crosslinked regions is formed as shown in figure 3. The preliminary results indicate that the phenomenon of curling is similar to the previously reported effect of photonic curing-induced, non-uniform volume shrinkage [7]. Our technique has two advantages: first, the stress gradient can be much larger for ions than for photons. The second advantage is that the use of an anisotropic pre-stress provides greater control over the direction of the curl.

The diameter of the curling hinge of the cuff can be changed by varying the thickness ratio of irradiated and un-irradiated regions (T_i/T_{ui}) as shown in figure 4. The resilience of these structures was tested by making them flat more than 50 times. The structures reverted to their 3-D shape every time without failure. Quantitative data for resilience, mechanical properties of the bilayer and in-vitro data for metallized cuff electrodes will be presented at the conference.

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1. Self-closing nerve cuffs for peripheral nerves by Micro-Leads, Somerville, MA.
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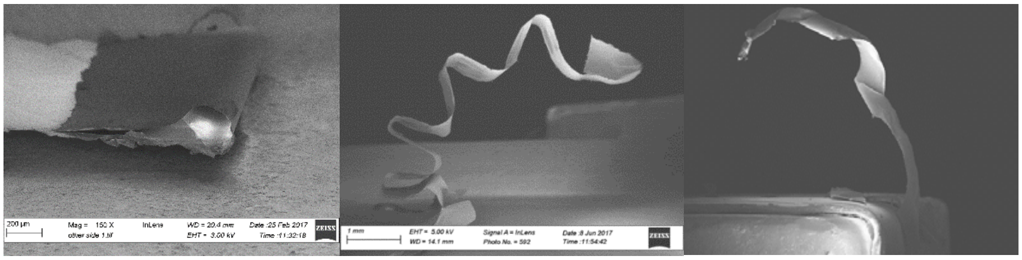

Figure 1: SEM images of a cylindrical cuff (left), a Zig-zag (middle) and a helical coil (right) shape memory structures. The structures can be made flat by using mechanical force but quickly revert to their 3-D shape upon release.

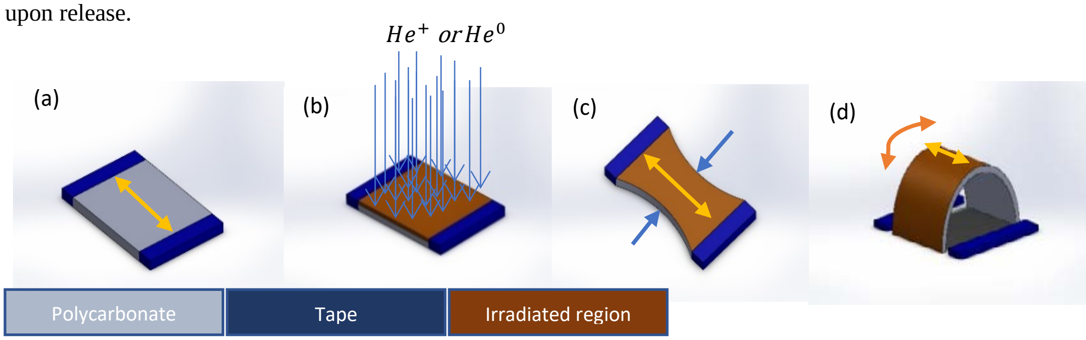

Figure 2: (a) Polycarbonate sheet is constrained unidirectionally in the direction of yellow arrow with a tape. (b) Irradiation with 50 KeV He^{+} or He^{0} at high dose ($> 360\ \mu C/cm^{2}$) forms a stiff layer at the surface (c) Polycarbonate sheet shrinks in the direction of blue arrows, but not the yellow arrow due to constraints, leading to anisotropic stress in the direction of the yellow arrow (d) Upon release from the constraint (by cutting the edges with a blade) the stiff region acts as a hinge and the polymer curls (orange arrow) about the axis of induced stress (yellow arrow) towards the direction away from the irradiated surface.

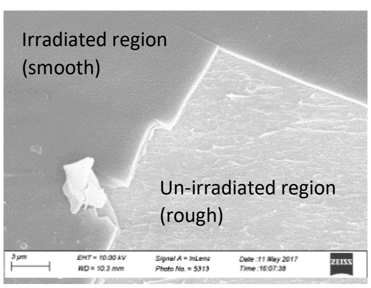

Figure 3: SEM image showing irradiated and un-irradiated bilayer on the surface in a region where irradiated layer has peeled off partially. The irradiated region appears smooth and breaks like glass implying that it is stiff and brittle due to high degree of crosslinking.

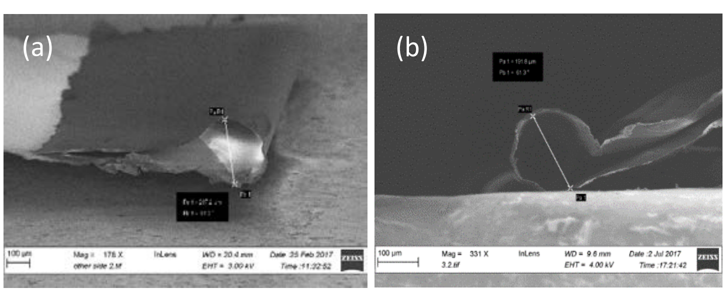

Figure 4: SEM images of (a) a cuff with 280μm diameter and thickness ratio (T_i/T_{ui}) ~ 0.3 (b) a cuff with 190μm diameter and thickness ratio (T_i/T_{ui}) ~ 0.4. The thickness ratio (T_i/T_{ui}) was changed by making the polycarbonate sheet thinner (~1.5 μm thick) with the help of oxygen plasma etching.