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In Situ TEM Visualization on the Super Flexibility of Multi-layered Hydroxyapatite Nanobelts with Antibacterial Property

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Hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$, HA) has been the most extensively used bone implant material for the reconstruction and substitution of hard tissues[1]. However, the success and long-term survival of the implants are dependent on the prevention of bacterial infection after implant placement. On the other hand, there is a growing interest in flexible HA nanostructures, since being brittle with a poor fatigue resistance is the major limitation to use HA-based biomaterials as load-bearing bioceramics.

Here, multi-layered HA nanobelts with silver doping (Ag-HA) was successfully synthesized by a hydrothermal homogeneous precipitation method. In vitro studies showed that the Ag-HA nanobelts had good antibacterial property as well as enhanced bioactivity. Most importantly, cyclic compression-bending behavior of Ag-HA nanobelts with multi-layered structures was observed via *in situ* TEM technique, showing the superior flexibility of the nanobelts. *In situ* TEM enables us to visualize the deformation behavior of an individual Ag-HA nanobelt under an external force in real time. As illustrated in Fig. 1[2], the Ag-HA nanobelt was subjected to eight continuous compression-bending cycles without any morphological change. The nanobelt can return to its original state after each of the compression-bending trials, even with extreme bending angles (180°). No crack formation was found inside the structure. To the best of our knowledge, we for the first time observed the unique flexibility of an individual Ag-HA nanobelt. Multi-layered nanobelts can endure more stress than single-layered nanobelts during the deformation process, due to the fact that multi-layered structures can slide next to each other easily to avoid stress concentration. The compression-bending behavior in Ag-HA nanobelts is in a plate-like manner wherein layer sliding occurs and releases the in-plane strains efficiently on the neutral surface, just like bending a stack of paper[3]. Such a multi-layered structure plays an important role in contributing to the superior flexibility of the Ag-HA nanobelts.

This work provides new insight into the design of HA nanobelts with antibacterial properties and opens new opportunities for their load-supporting applications. It is also instructive to reveal the mechanical behavior of other ceramic materials in nanoscale.[4]

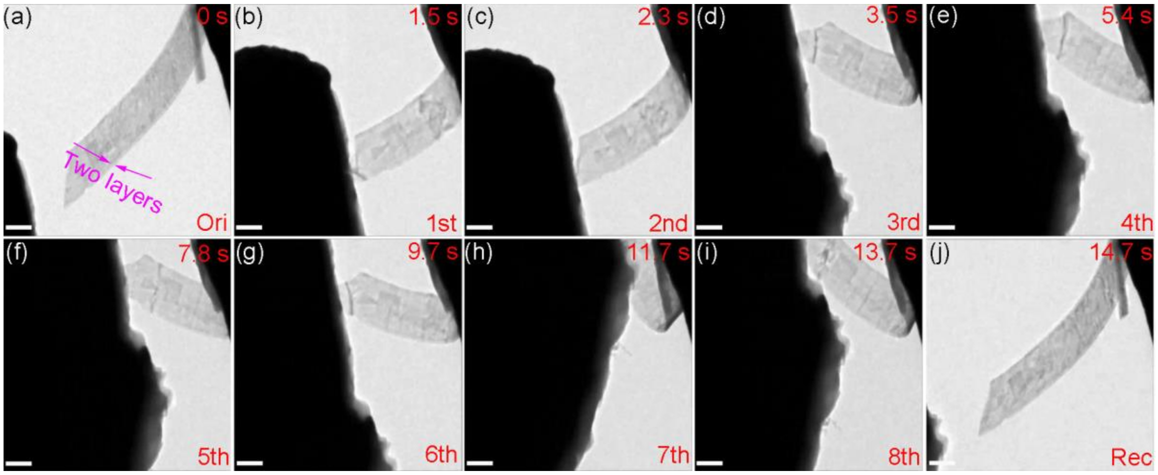

Figure 1. In situ TEM snapshot progress of an individual Ag-HA nanobelt in the eight compression-bending-recovery cycles. (a) an original nanobelt with two layers, (b-i) the nanobelt during the first to the eight bending cycles, (j) the nanobelt after recovery. Scale bars in the images are 200 nm[2].

References

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