Solid state nanopore-based sensing has emerged as a promising candidate for the detection and characterization of biomolecules. To date, most of the fabricated nanopores in various materials including SiO₂, Si₃N₄, Al₂O₃, etc., are circular with no obvious facets, as a result of the isotropic property in amorphous materials. While faceted nanopores can be potentially employed in rapid electrical detection and analysis of biomacromolecule with various shapes, the relevant investigation has been rarely reported. Herein, we show the successful fabrication of faceted nanopores in magnesium via focused e-beam inside transmission electron microscope (TEM). By manipulating the e-beam irradiation direction, the as-fabricated nanopores exhibit different shapes as observed along different typical orientations, e.g., [0001], [11-20], etc (Fig. 1).

Surprisingly, when the e-beam is spread out, the nanopores would continuously shrink and finally disappear. Such atomic-scale healing dynamics are directly recorded by the in situ high-resolution transmission electron microscopy (HRTEM) techniques, as evidenced by the layer-by-layer growth of atomic planes at the nanopore periphery (Fig. 2). Meanwhile, it is noted that the proposed healing process was attributed to the e-beam-induced anisotropic diffusion of Mg atoms at the nanopore edges. When the e-beam was turned off, the nanopore would retain its shape. Hence, using TEM images, which provide real-time feedback during the healing process, allows for the precise control of pores with sub-nanometer sizes along different directions. The size-controllable synthesis of faceted nanopore does not only broaden its potential applications but provide an important insight into the nanopore patterning in metallic materials. The direct observation of atomic diffusion process indicates that TEM may serve as an alternative to other techniques, such as scanning tunneling microscopy, in the race towards comprehensive investigations of surface science.


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Fig. 1: Fabrication of faceted nanopores in Mg. (a-c) A schematic illustration and (d-f) HRTEM images of nanopores along the (a) [0001], (b) [11-20], and (c) [11-23] zone axes, correspondingly. The insets in (d-f) show the SAED patterns of the corresponding regions, respectively.

Fig. 2: E-beam assisted healing of faceted nanopores in Mg along the [0001] zone axis. (a-c) A schematic illustration and (d-f) time-lapsed experimental images showing the healing of an individual nanopore under wide-field e-beam irradiation.