Development of a Toroidal Diamond Anvil Cell for Multi-Megabar Equations of State

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Abstract

We present our ongoing progress in creating toroidal diamond anvils cells to achieve pressures in excess of 400 GPa, and results from recent x-ray diffraction experiments whence we formulate an equation of state for tungsten up to 390 GPa.

Diamond Anvil Cells

The diamond anvil cell is a foundational instrument of modern high-pressure research owing to its simplicity and low cost; its basic design is shown in Figure 1. Diamond anvil cells are routinely employed to reach pressures in excess of 200 GPa, and the samples contained within can be studied using x-ray diffraction or Raman signals.

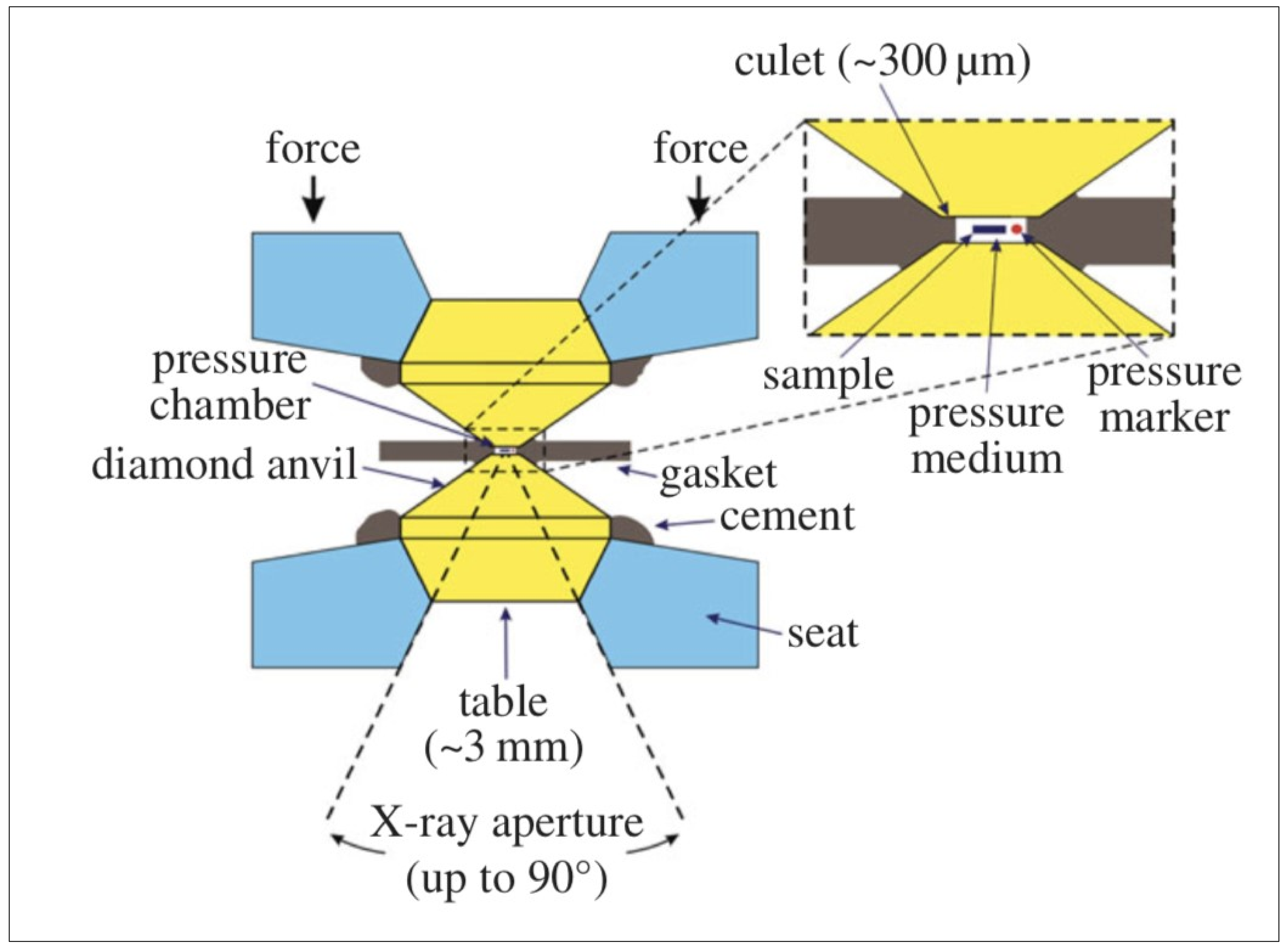

Figure 1. Typical diamond anvil cell, displaying the opposing diamonds mounted in tungsten carbide seats, with the sample and a pressure calibrant placed between them and supported radially by a gasket (generally tungsten or rhenium).

Toroidal Diamond Anvil Cells

The Toroidal Diamond Anvil Cell is a variation of the standard diamond anvil cell but uses diamonds with a circular groove which has been milled with a focussed ion beam (Figures 2 & 3). The modified geometry serves to mitigate diamond failure at ultra-high pressures, and recent experiments using toroidal diamond anvil cells have achieved pressures in excess of 500 GPa [1, 2].

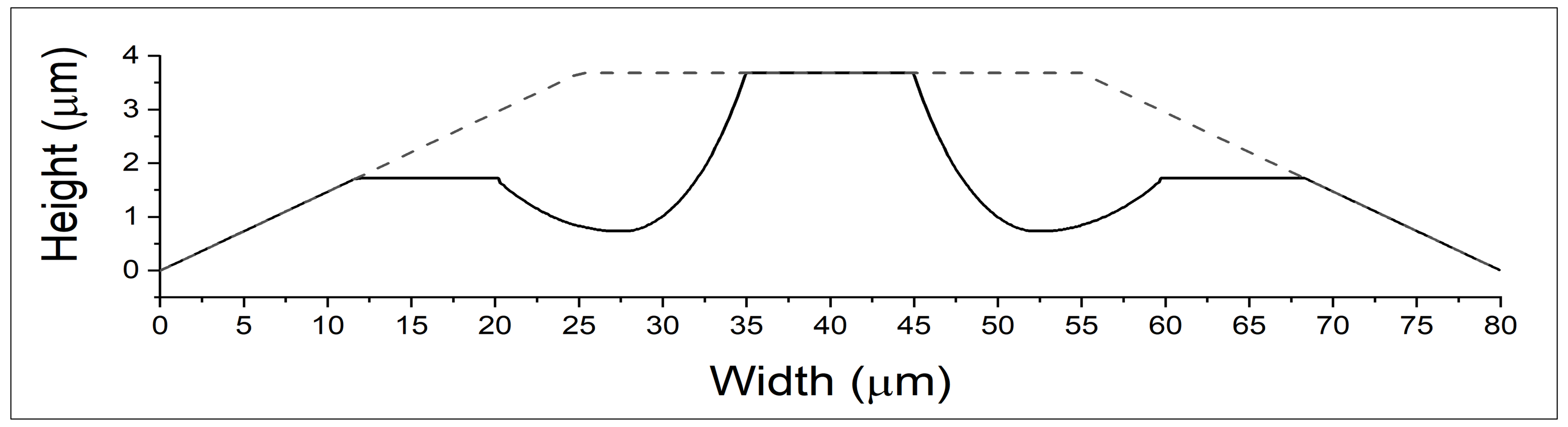

Figure 2. The cross-section of a toroidal diamond anvil cell, showing the original diamond shape (dashed) and the final toroidal shape (solid).

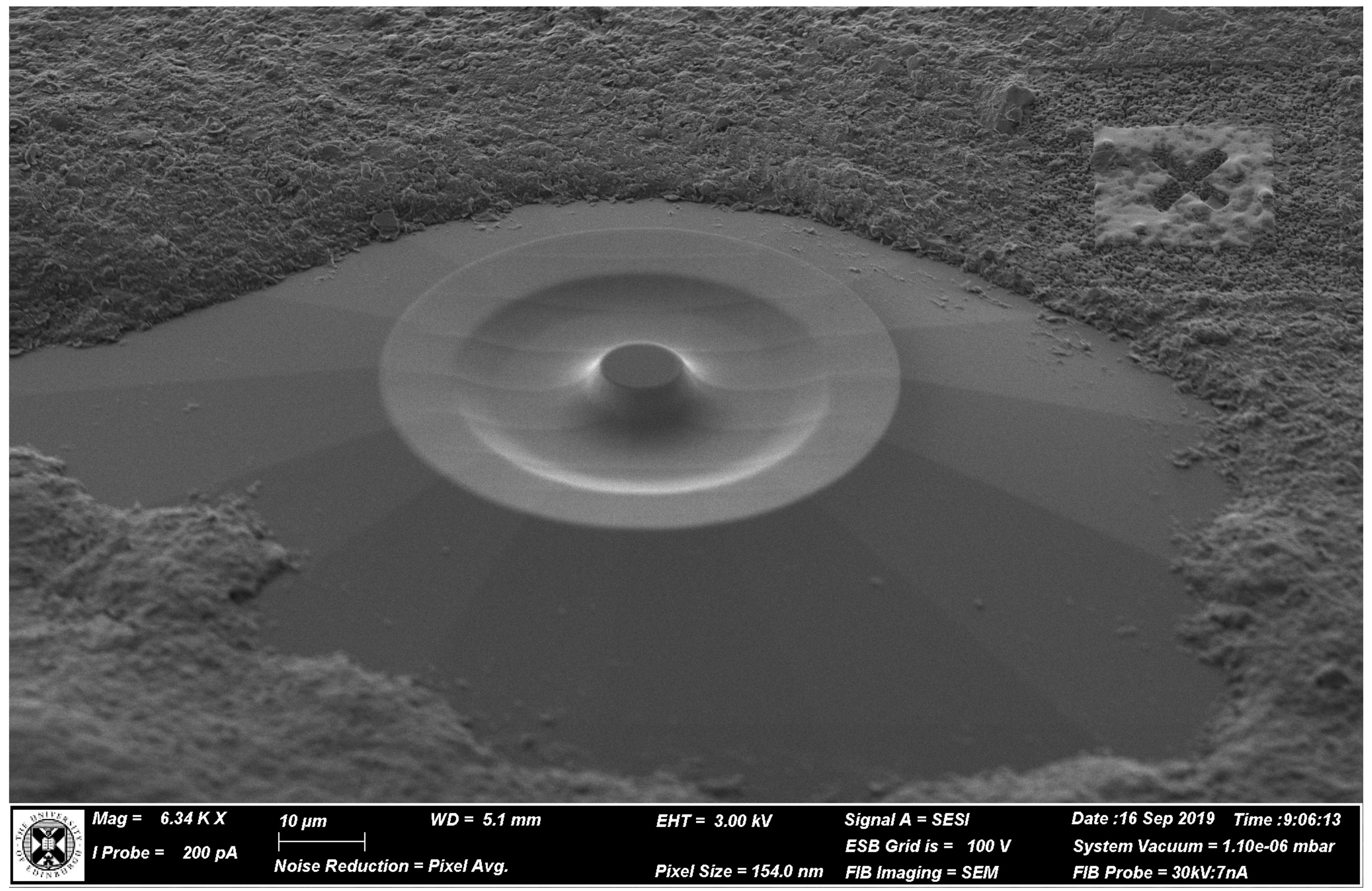

Figure 3. SEM imagine of a toroidal diamond anvil after milling at the newly installed focussed ion beam machine at the University of Edinburgh. The central culet is 10 microns in diameter, with the overall feature being 60 microns wide.

Tungsten Equation of State

Tungsten is widely used in industrial settings due to its mechanical strength and stable phase diagram [3]. Indeed, it is frequently used to create gaskets for diamond anvil cells, or as a pressure calibrant for high pressure experiments. It is therefore critical to formulate an accurate equation of state for this transition metal.

Two experiments were conducted with toroidal diamond anvil cells: one using a Cu calibrant and the other an Au calibrant, and the self-consistent equations of state for the two metals published in Ref. 4 were used to obtain the sample pressure.

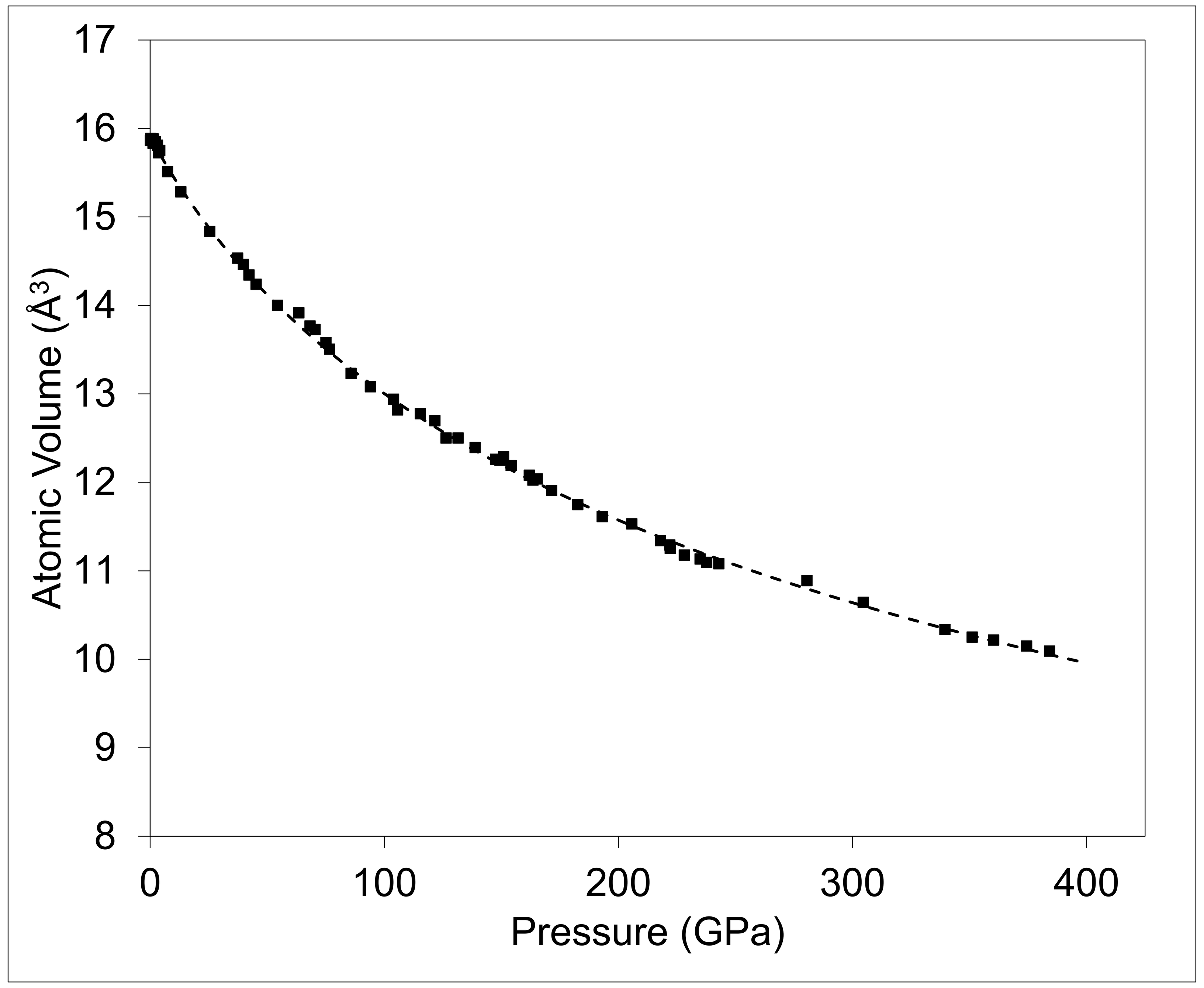

Figure 4. The compression curve of tungsten calibrated against gold and copper, with a Vinet equation of state fitted for tungsten, with $K_0 = 332.0$ GPa and $K' = 4.02$.

References

1. Dewaele *et al Nat. Comm.* **9**, 2913 (2018)
2. Jenei *et al., Nat. Comm.* **9**, 3563 (2018)
3. Lassner & Shubert, *The Element Tungsten*, Springer (1999)
4. Sokolova *et al*., *Comput. Geosci.* **94**, 162–169 (2016).

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