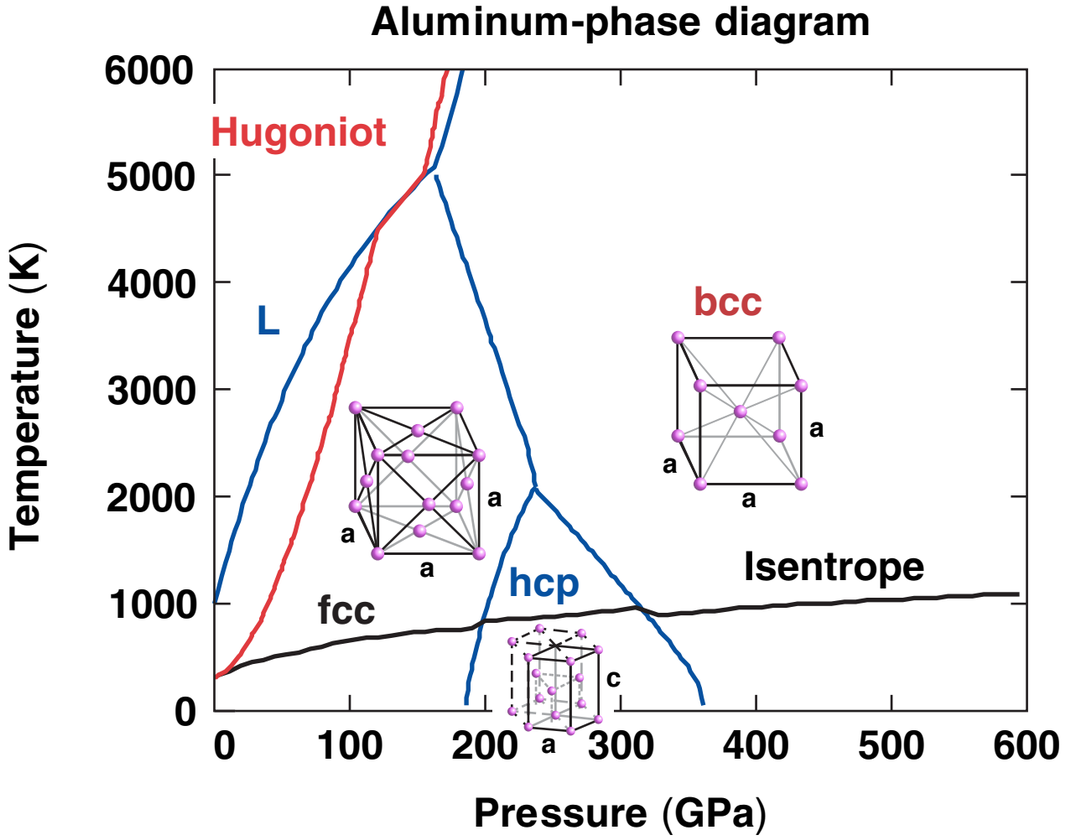
Observation of Solid–Solid Phase Transitions in Ramp-Compressed Aluminum



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Summary

We present the first observation of bcc aluminum; a high-pressure, solid-aluminum phase that exists at pressures above ~400 GPa

- Aluminum is frequently used as a standard material in high-pressure–compression experiments
- Density functional theory (DFT) calculations predict a progression of structural changes, from fcc–hcp–bcc, with increasing pressure along the isentrope
- Al was ramp-compressed and x-ray–diffraction (XRD) data measured the progression of phases fcc–hcp–bcc at pressures of 80 to 540 GPa

fcc = face-centered cubic
bcc = body-centered cubic
hcp = hexagonal close packed

Collaborators

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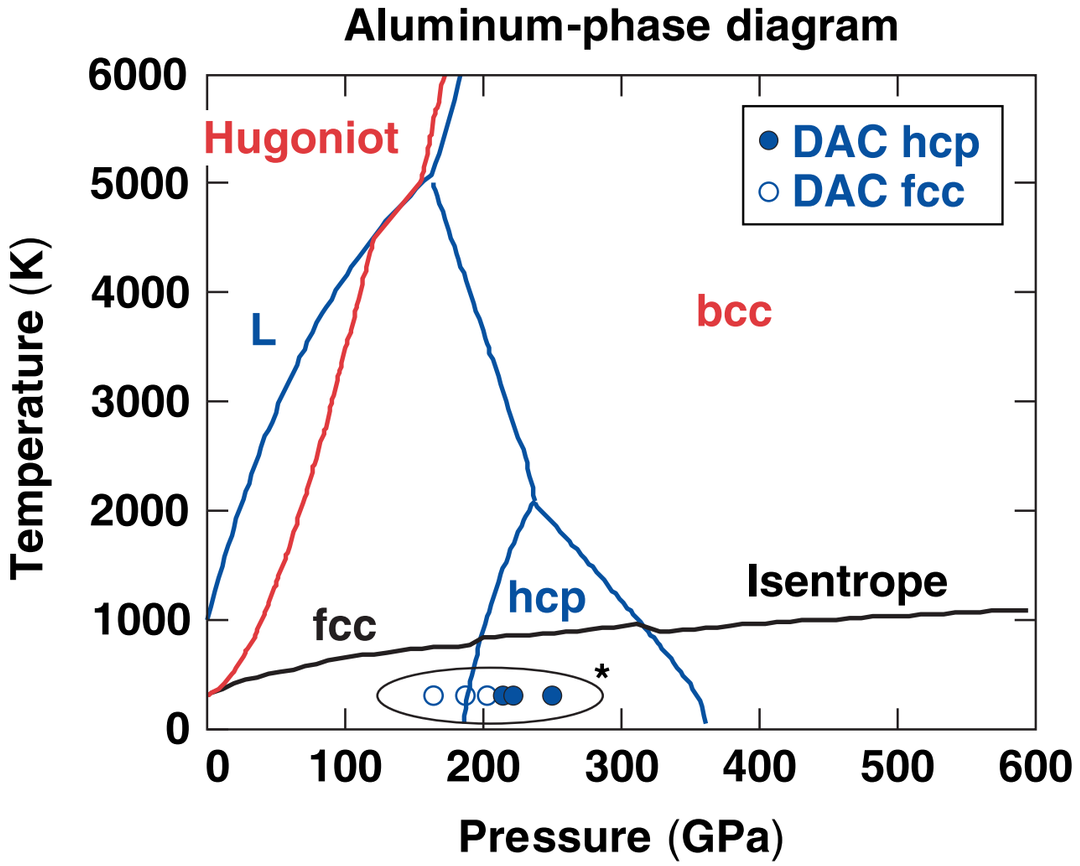
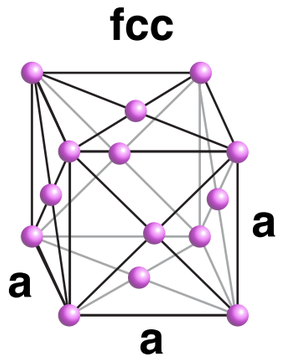
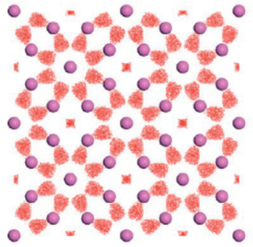
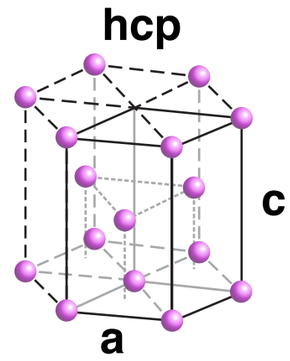
Aluminum is predicted to undergo fcc–hcp and hcp–bcc solid–solid phase transitions as it is compressed at low temperatures



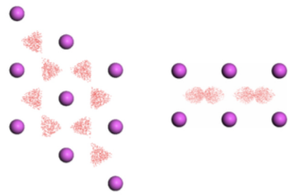


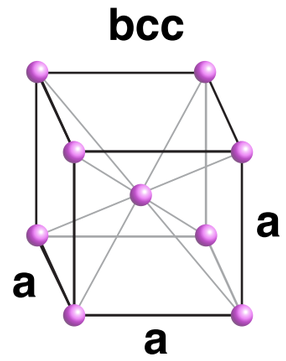
Host–Guest structure



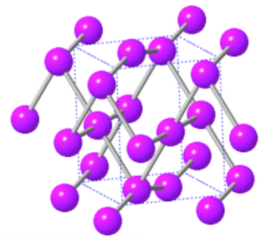


Simple Hexagonal Electride





CMMA Electride



DAC: diamond-anvil cell

*Y. Akahama *et al.*, Phys. Rev. Lett. 96, 045505 (2006).

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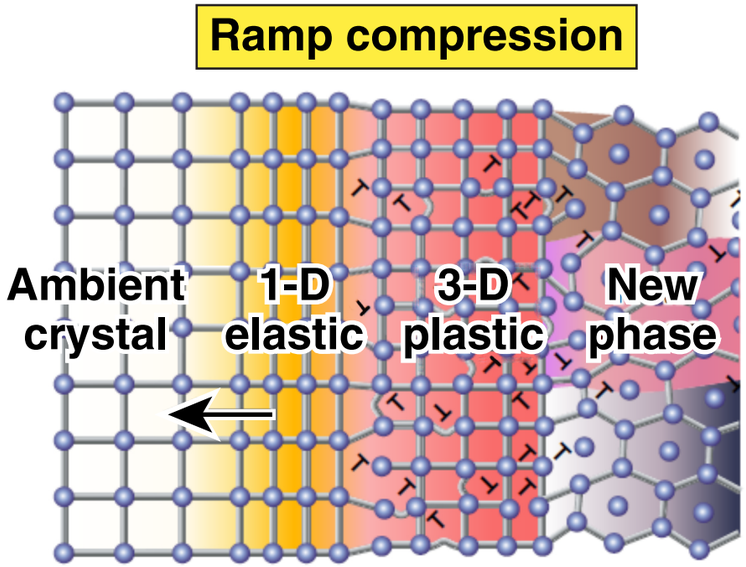
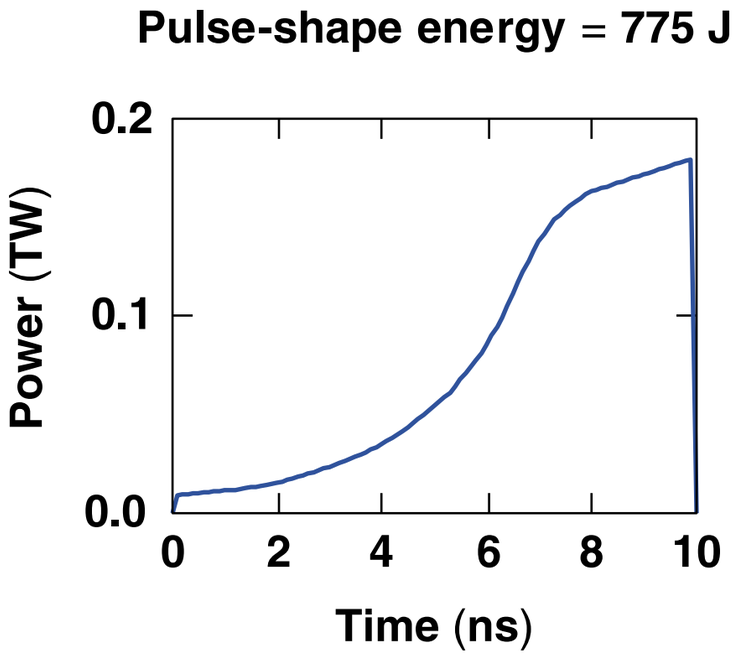
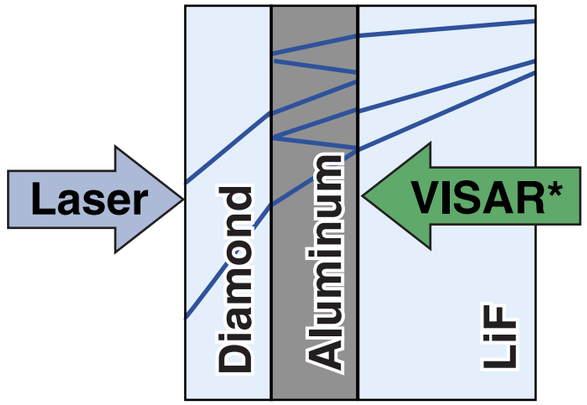
The OMEGA EP laser ramp-compressed aluminum to various constant-pressure states







*VISAR: velocity interferometer system for any reflector

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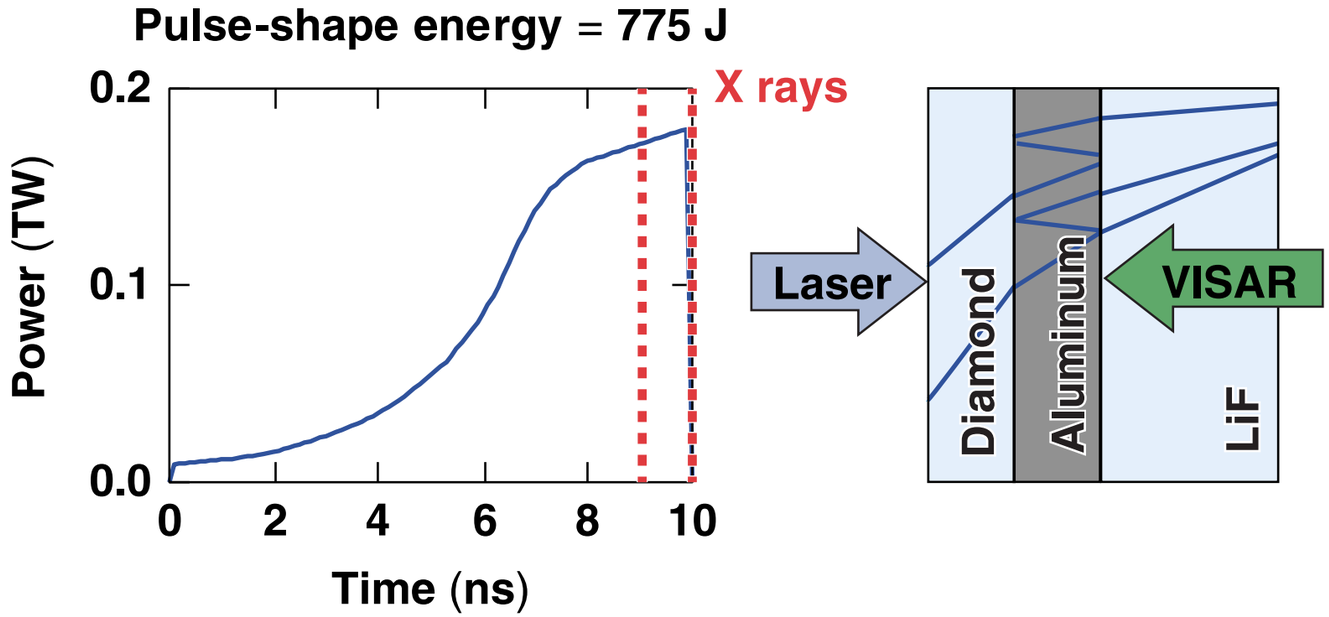
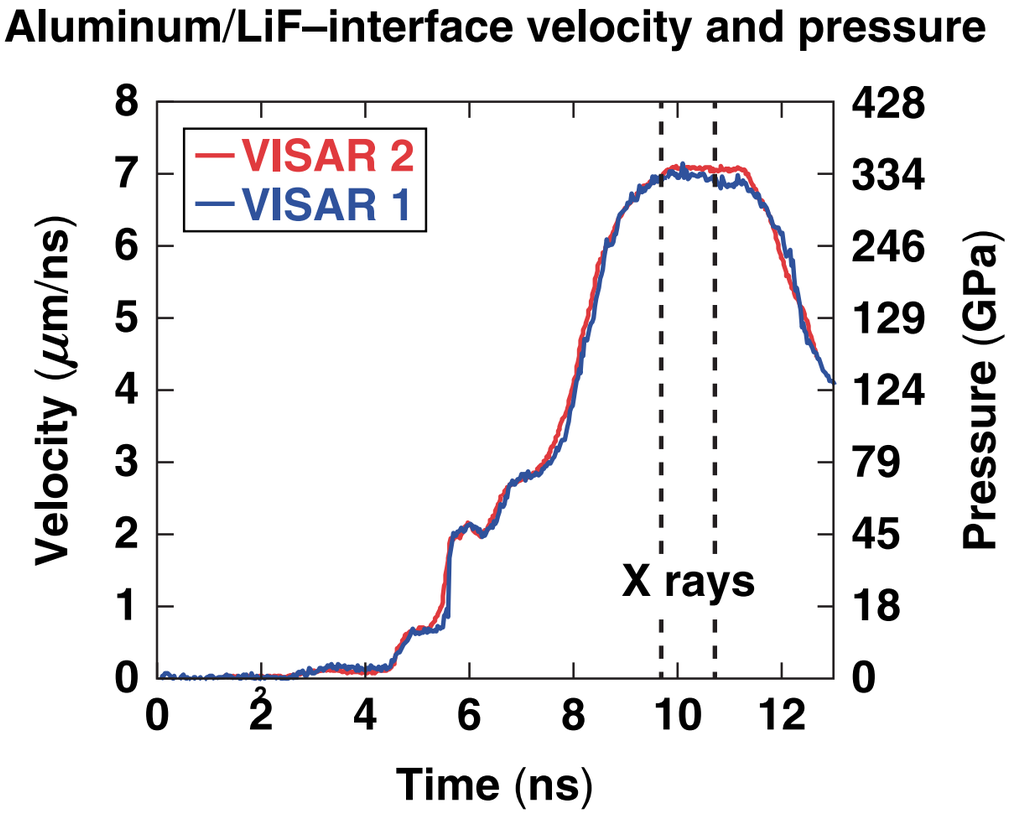
The samples were probed with 8.4-keV x rays with 1-ns duration, and pressure was determined from VISAR–interface velocities





The diamond pusher and LiF tamper confine the sample; reverberations create a uniform pressure.

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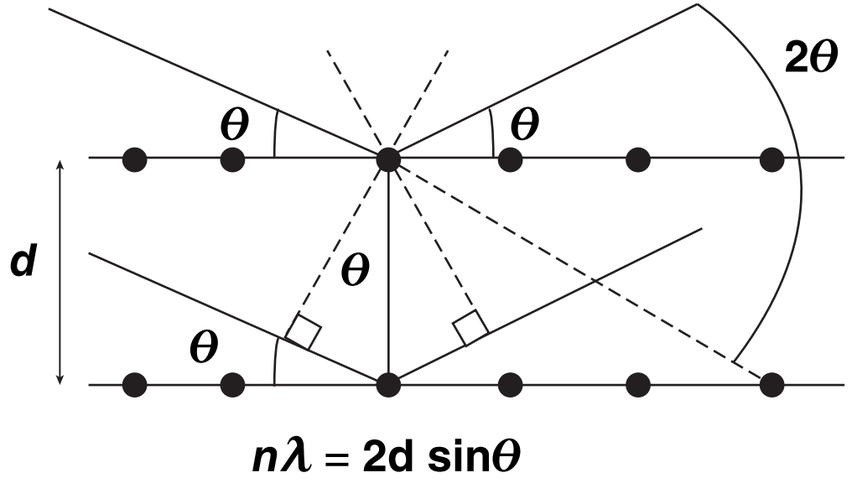
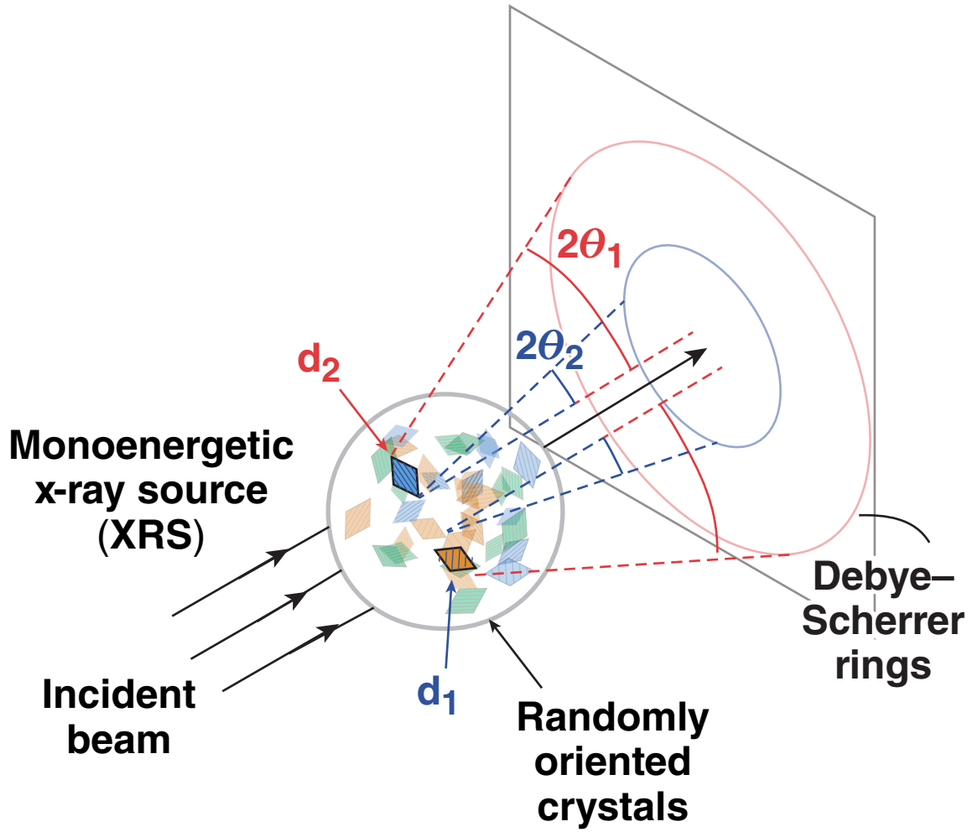
X-Ray Diffraction

“Powder” x-ray diffraction (XRD) uses a powdered sample, where a sufficiently large number of crystalline planes are randomly oriented to satisfy the Bragg condition





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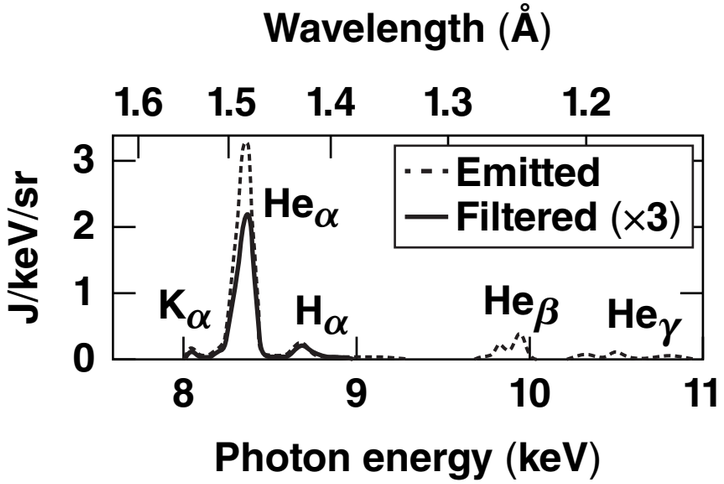
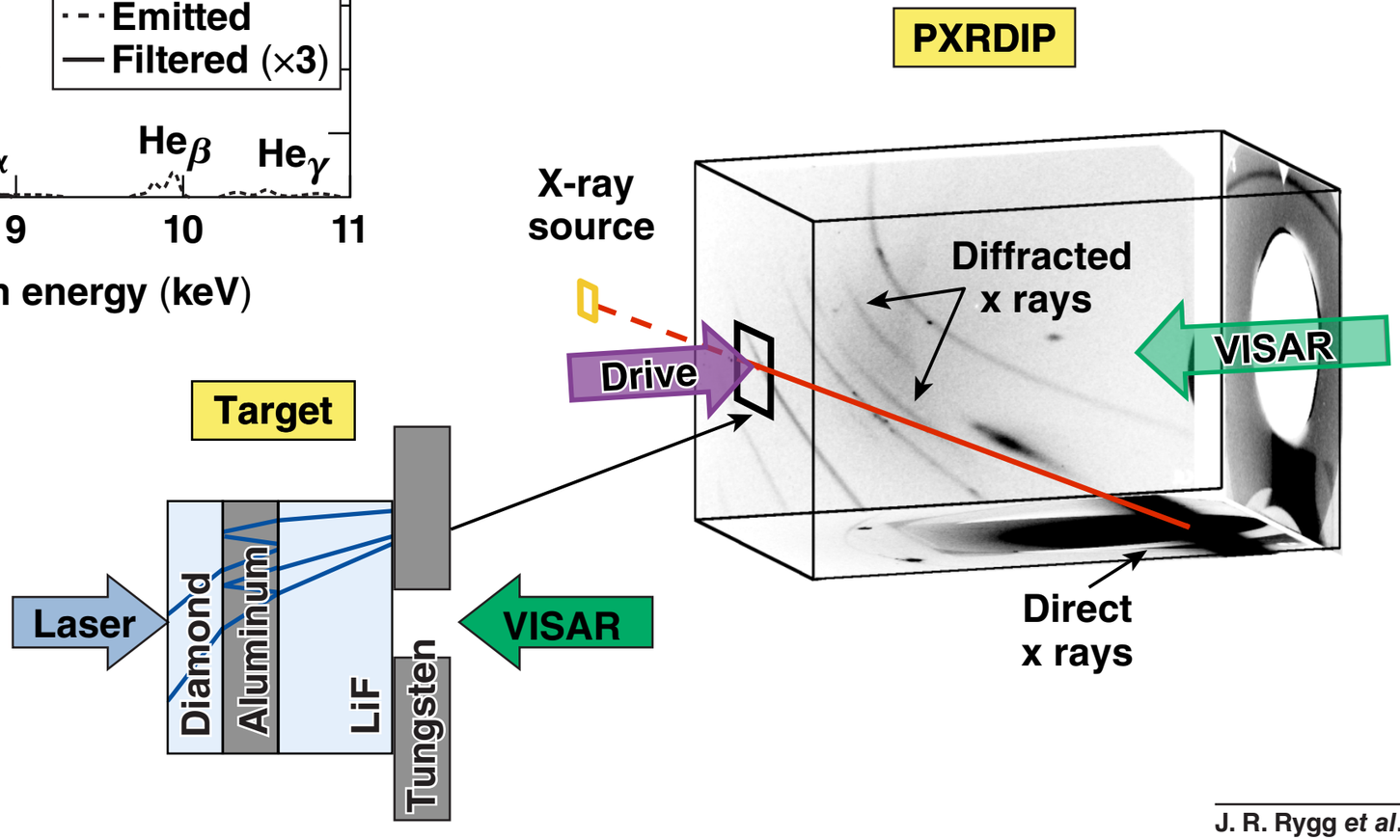
X-ray Diffraction

Powder XRD patterns are recorded using the powder x-ray diffraction image plates (PXRDIP) diagnostic on OMEGA EP





VISAR measured interface velocities to infer the pressure state of the sample.

E25411a

J. R. Rygg *et al.*, Rev. Sci. Instrum. 83, 113904 (2012).

fcc–hcp Aluminum

When pressure was increased from 118 GPa to 333 GPa, two diffraction lines were newly observed, consistent with hcp aluminum and distinct from fcc

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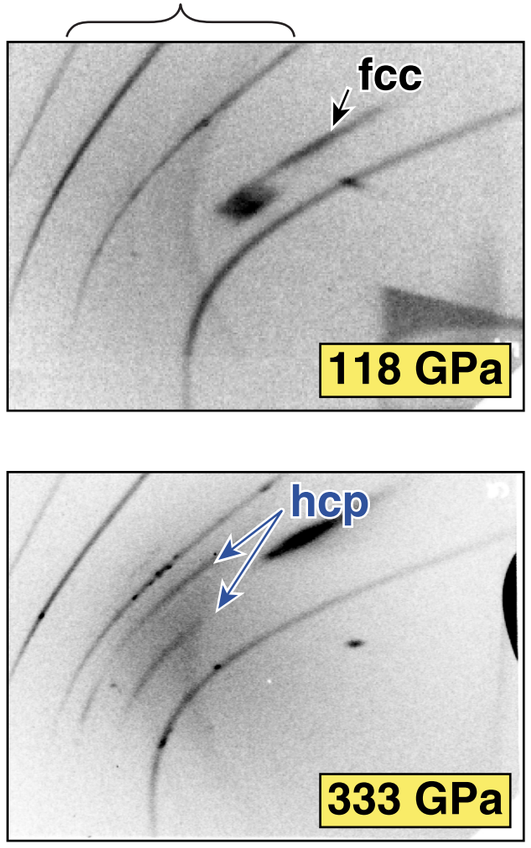
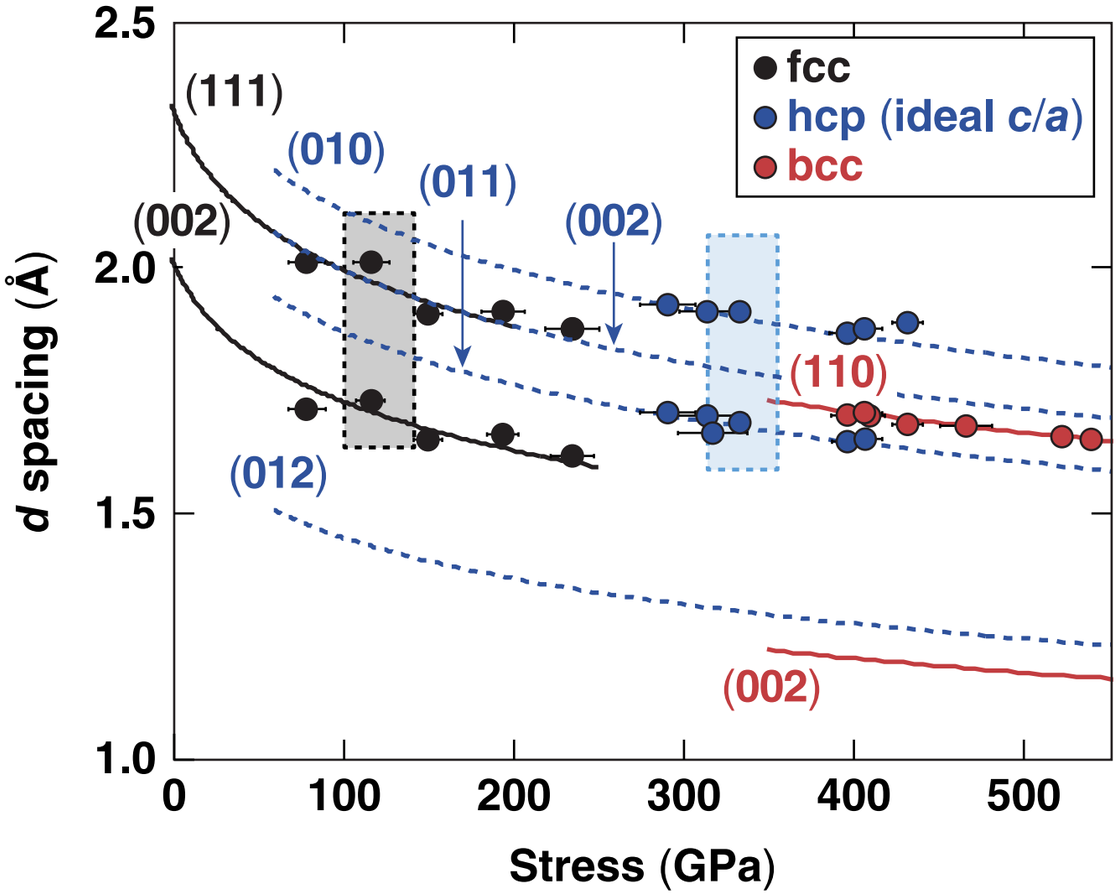
Calibration lines



Observed diffraction peaks



$n\lambda = 2d \sin\theta$

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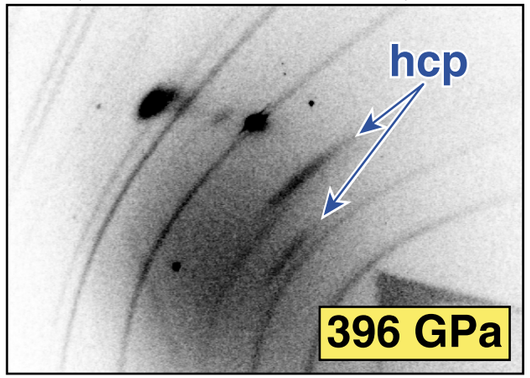
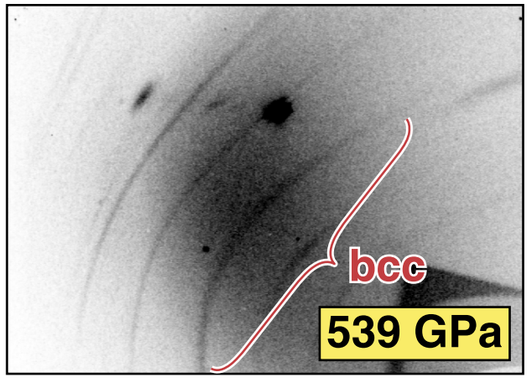
hcp–bcc Aluminum

Above 465 GPa, the two hcp lines disappear, replaced by a single intense line consistent with (110) bcc aluminum that exhibits significantly less texture

UR LLE

Calibration lines





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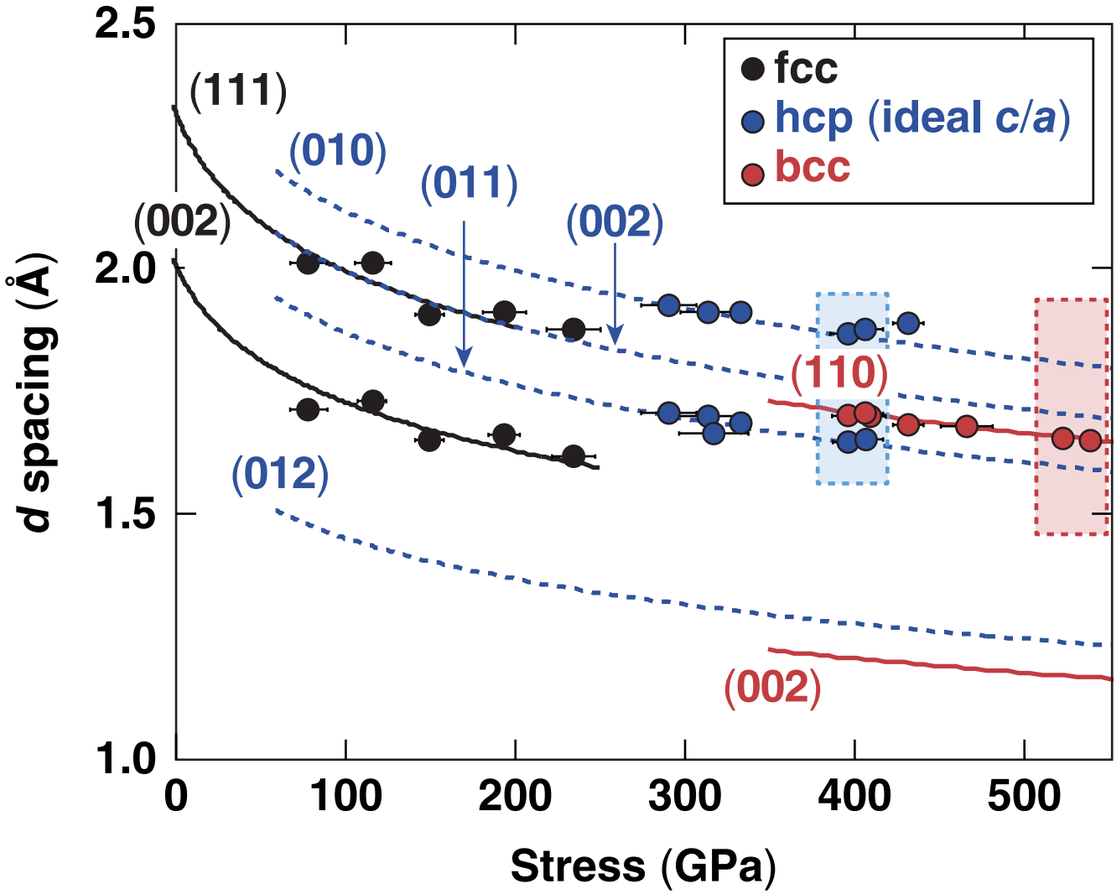
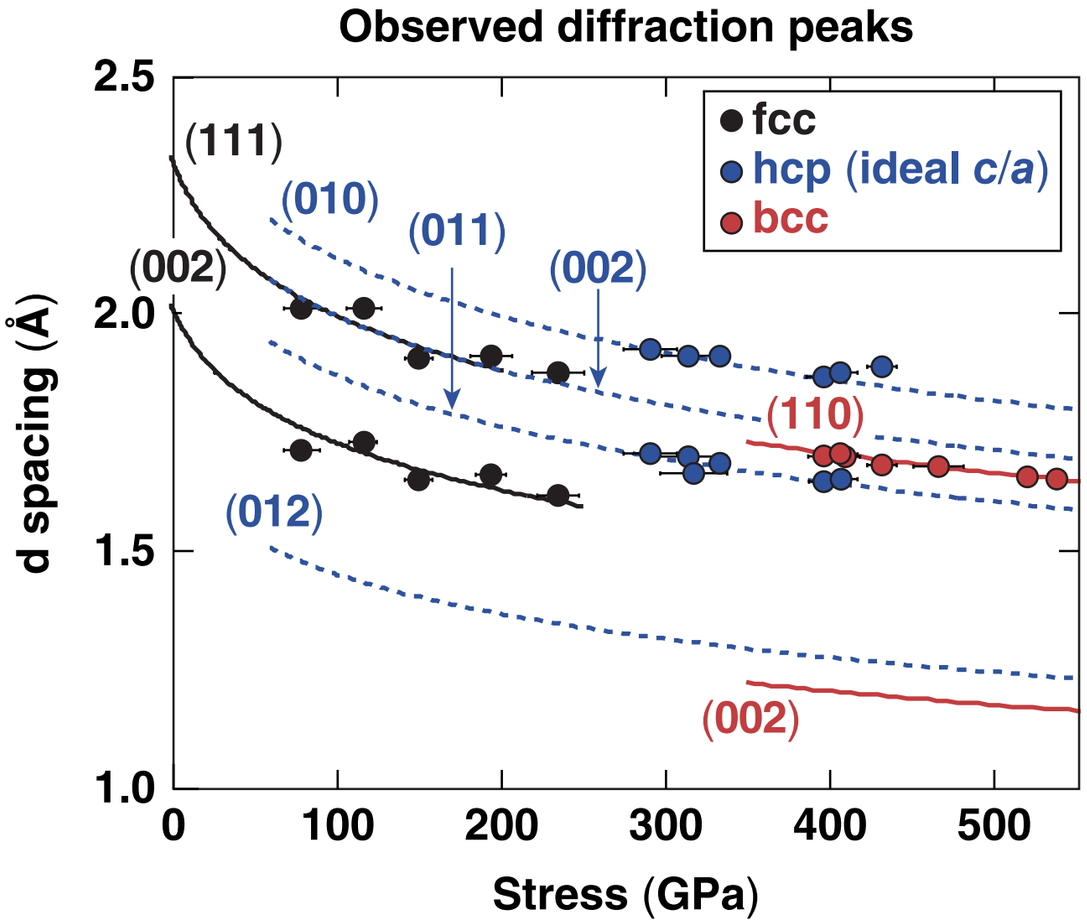


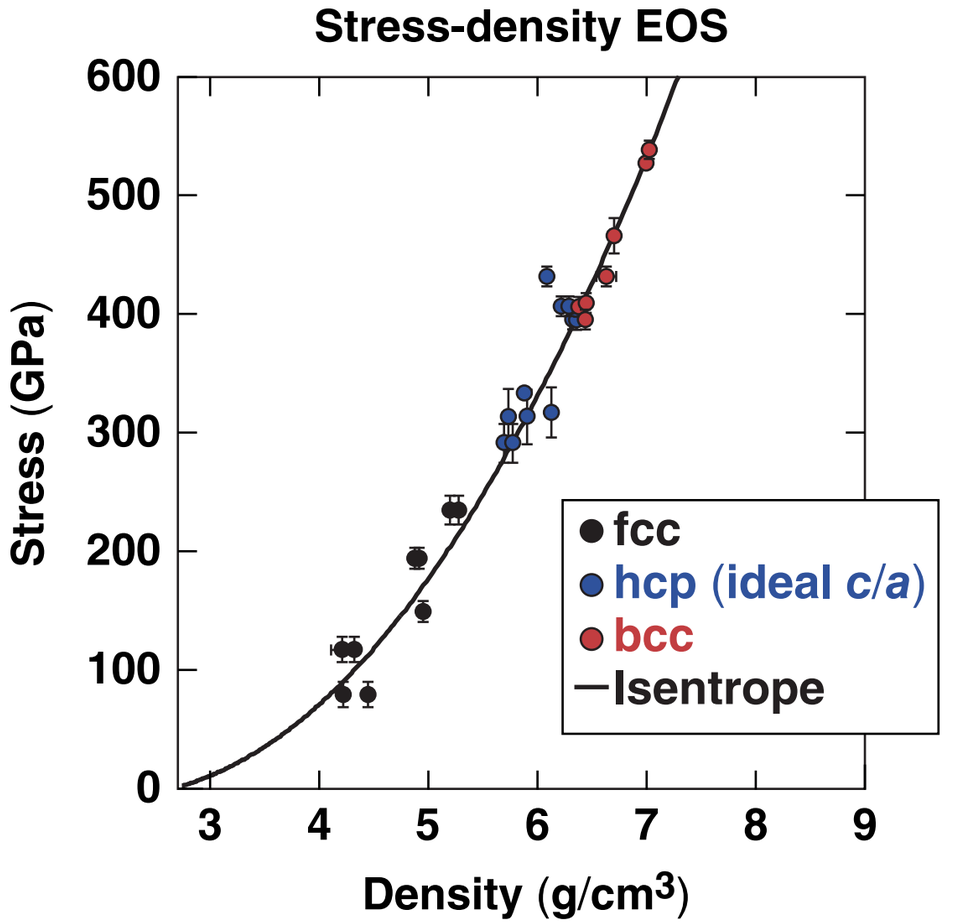
This is the first experimental observation of the predicted bcc phase of aluminum.

E25412d

Results

Aluminum stress-density equation of state (EOS) is constructed using the measured interatomic spacing





E25545

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