Determination of ultrahigh strain rate impact hardness of metals by energy dissipation method

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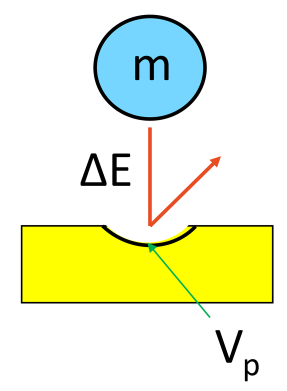
Motivation & Aim

- Study of impact dynamic material properties, material deformation and critical velocities help us in understanding the cold spray process in a better way.
- Material's properties and deformation dynamics are strain-rate-dependent.
- Studying microscopic hardness of materials under both low strain rate and high strain rate can extend our knowledge of the rate-dependent mechanisms contributing to plastic deformation processes and high strain rate strength of metals



Ultra High Strain Rate Micro-Ballistic Impacts: α-LIPIT

Advanced Laser Induced Projectile Impact Test (α-LIPIT)

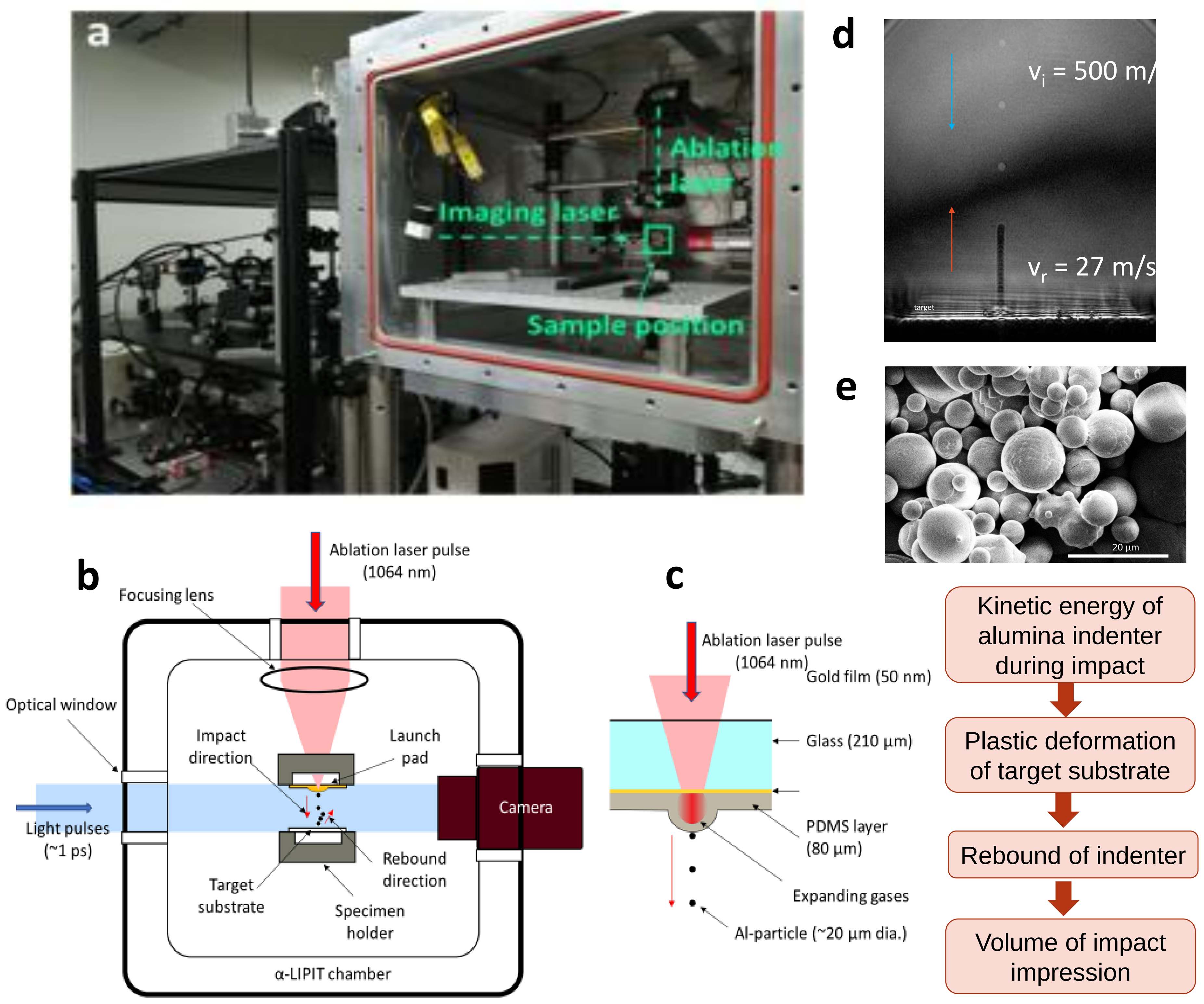
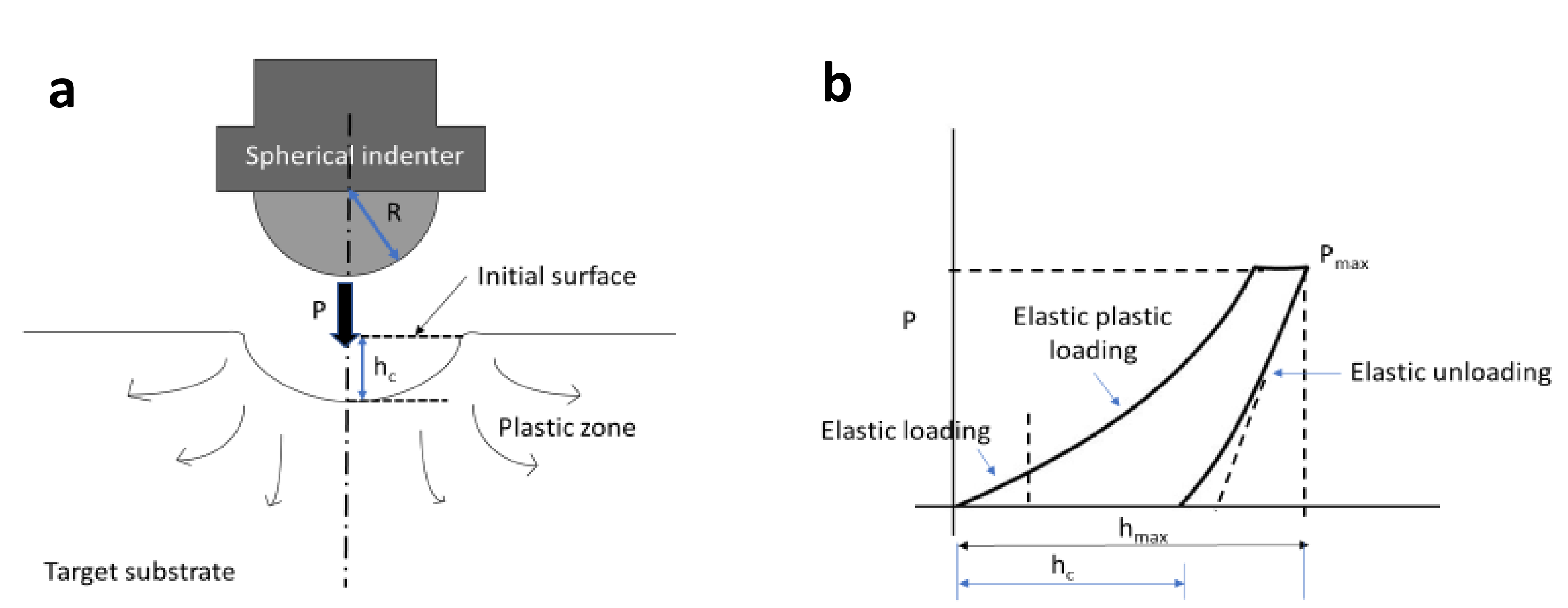


Fig. 1 HSR Experimental setup (a) α-LIPIT setup (b)Schematic illustration of α-LIPIT (c) schematic of acceleration of microparticle(impactor) from surface of launch pad (d)Multi-exposure image of the impact and rebound of impactor(c) micrograph showing the impactors (alumina microparticles ˜20μm diameter)

$$H_{DH} = \frac{\text{Energy dissipated}}{\text{Volume of impression}} = \frac{E_i - E_r}{V_p}$$

$$V_p = \frac{\pi h_{max}^2}{3}(3R - h_{max})$$

Low Strain Rate Spherical Nanoindentation



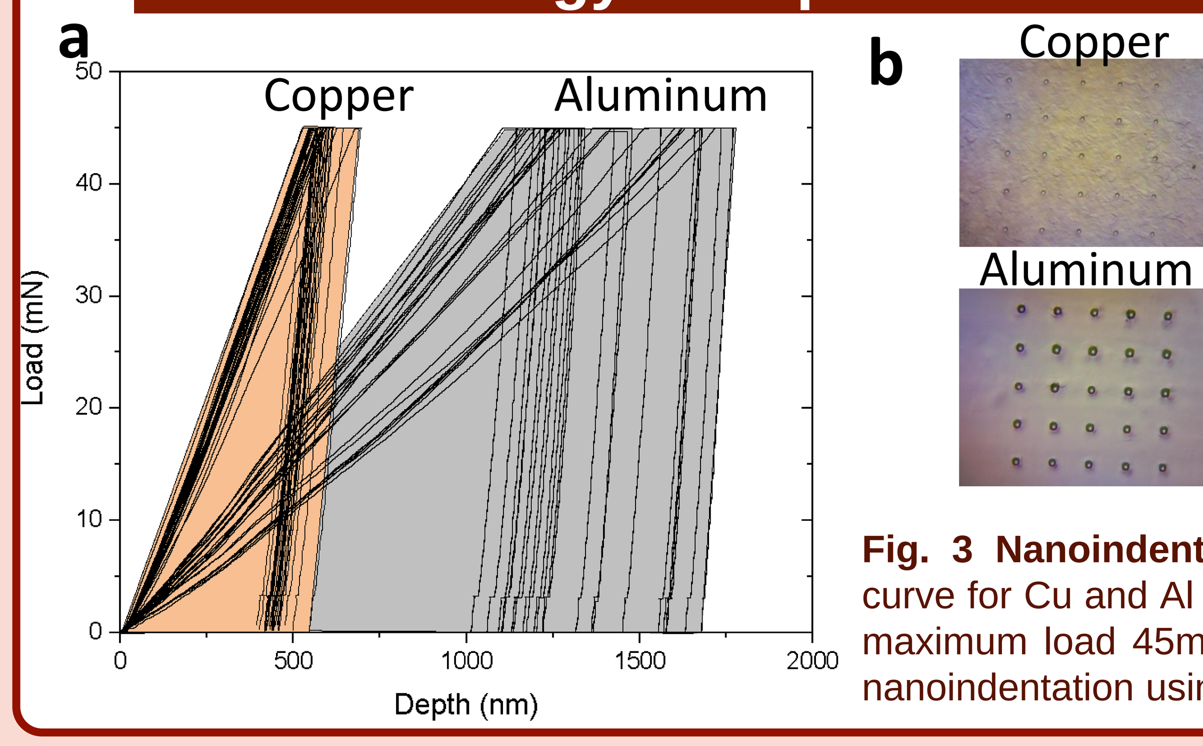
$$H_{DL} = \frac{\text{Energy dissipated}}{\text{Volume of impression}} = \frac{\Delta E}{V_p}$$

ΔE= ∫area under load-unload curve

$$V_p = \frac{\pi h_c^2}{3}(3R - h_c)$$

Fig. 2 Nanoindentation (a) Illustration of a spherical nano-indenter (b) Load vs displacement curve for an elastic-plastic sample loaded with spherical indenter with maximum load P_{max} applied. After complete unloading, the graph shows a residual impression of height h_c.

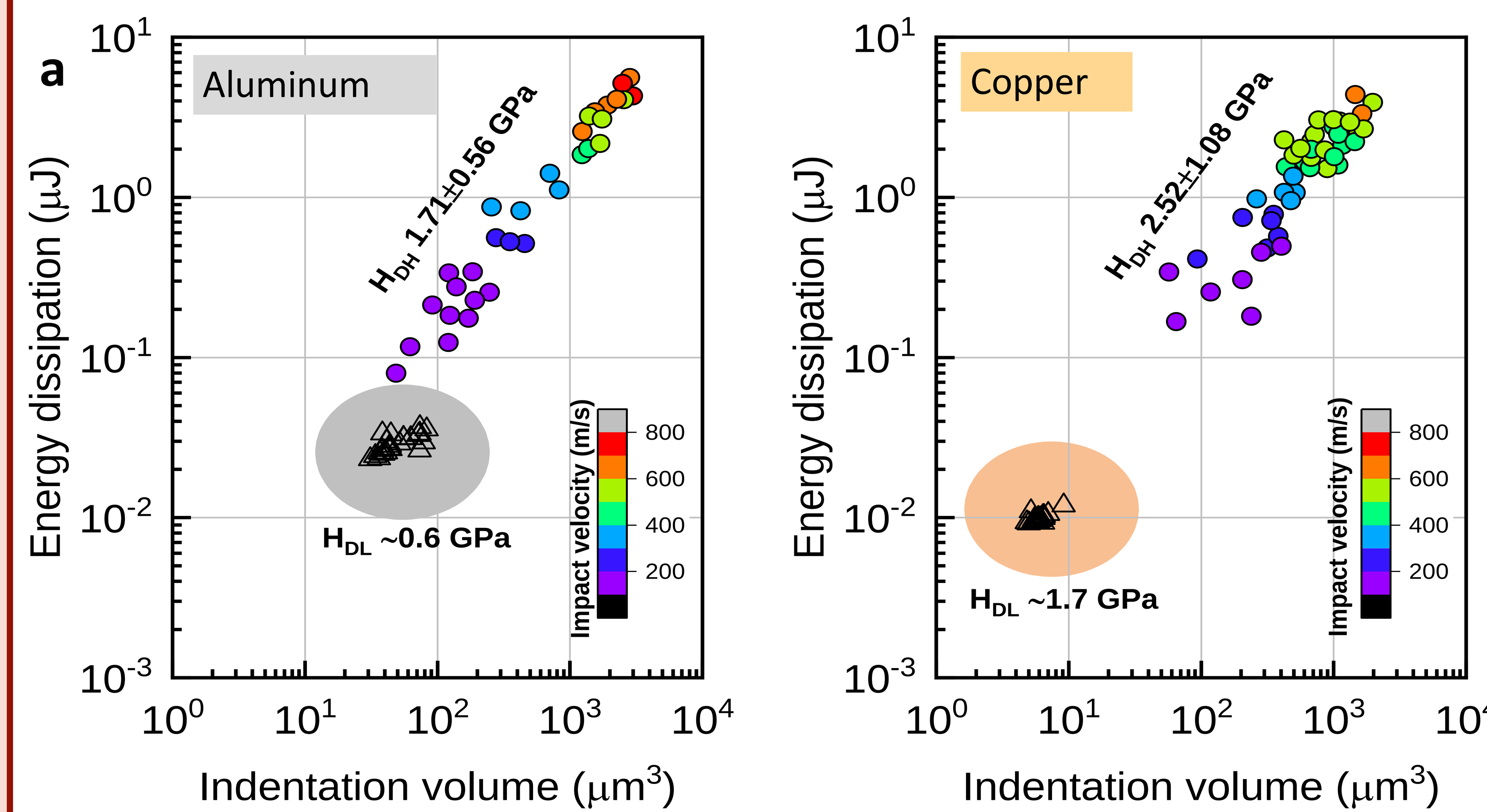
Energy Dissipation At Low Strain Rates



- Less elastic recovery of copper as compared to aluminum.
- Maximum residual depth of indent larger for Aluminum than Copper, indicating Al to be a softer material than Cu.

Fig. 3 Nanoindentation results (a) Load vs displacement curve for Cu and Al samples loaded with spherical indenter with maximum load 45mN applied.). (b) Cu and Al substrates after nanoindentation using a diamond spherical indenter of 20 μm.

α-LIPIT Ultra High Strain Rate Hardness



Hardness (GPa)	Aluminum	Copper	Strain rate (s^{-1})
α-LIPIT	1.7	2.5	10^7-10^8
Nanoindentation	0.6	1.7	10^{-1}

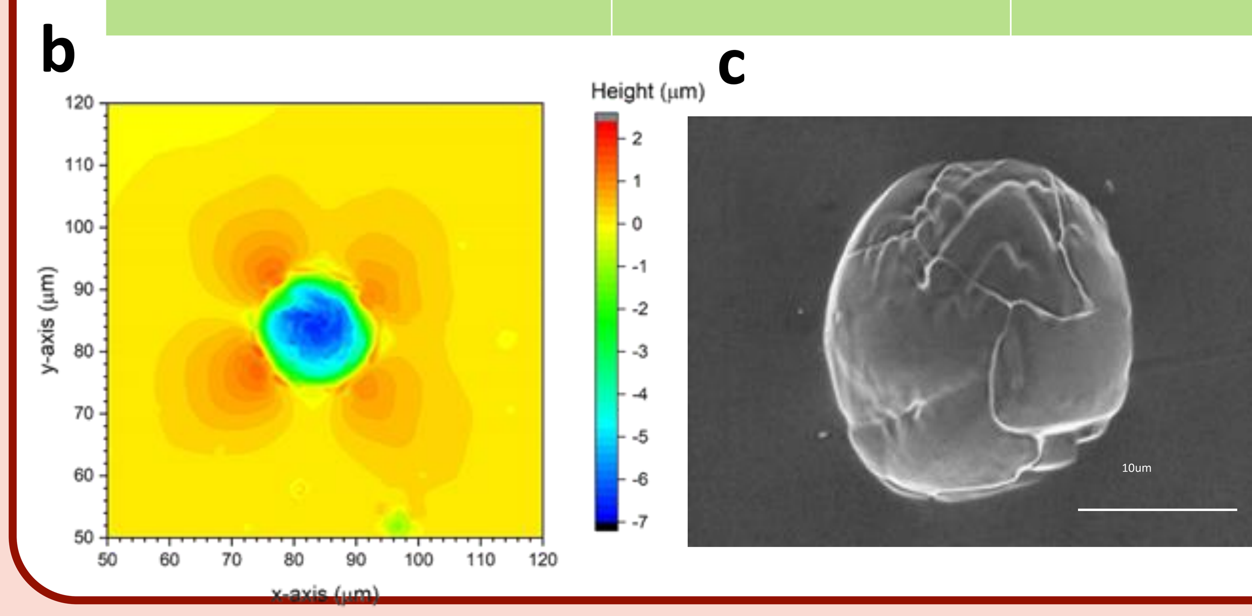


Fig. 4 Energy dissipation as a function of indentation volume and impact velocity
(a) Results showing microscopic impact hardness of aluminum and copper at uHSR (b) Profile map of residual impression after AO impactor impact on Cu substrate with hmax=6.7μm (c) SEM micrograph showing the residual impression on Cu target substrate after AO impactor's impact

Computational Analysis Of Hardness At Low And Ultra High Strain Rates

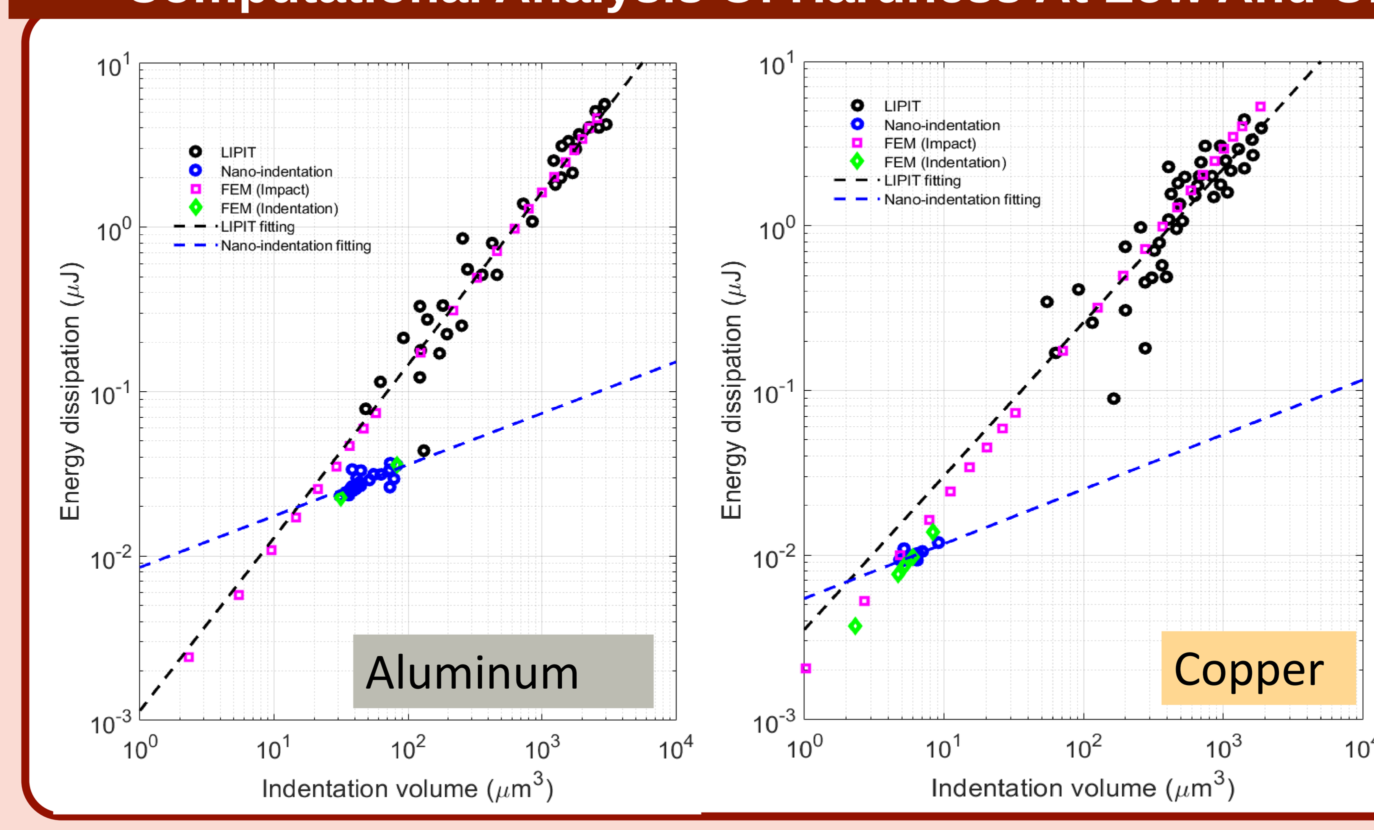


Fig. 5 Computational modeling and comparison of LSR and HSR data.

- The difference in energy values in quasi static and dynamic indentation can be attributed to the strain rate effect during impact.

Summary

- **The dynamic and quasi-static behavior of aluminum and copper is quantified using the micro-ballistic characterization and spherical nanoindentation.**
- **Micro impact hardness is strain rate dependent.**
- **Aluminum shows greater strain rate sensitivity than that of copper.**

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