Electronic Supplementary Material (ESI) for Nanoscale Advances.

Supplementary Information

Cutting depth of different processes

In the process of consolidated abrasive lapping, the material removal mechanism is determined by the maximum cutting depth of a single abrasive grain, which is determined by the undeformed chip thickness h_m. The equation is as follows,[1]

$$h_{max} = \left[\frac{P_0}{2\left(1 + \sqrt{\frac{\pi\sigma_s}{2E^*}}\right)\lambda\eta H} \right]^{\frac{1}{3}} D_L \tag{1}$$

where P_0 is lapping pressure, H is hardness of the sample, E^* is equivalent elastic modulus of lapping pad, λ is lapping pad bump ratio factor, D_L is abrasive diameter, η is particle volume concentration and σ_s is yield strength.

Based on experimental parameters and existing literature,[2] the performance parameters of the lapping pad can be determined, as illustrated in Table 1.

Tab. 1 Performance parameters of grinding pad

Abrasive diameter D_L (μm)	Particle volume concentration η	Equivalent elastic modulus of lapping pad E^* (GPa)	Lapping pad bump ratio factor λ
4.42	0.12	0.87466	0.44

Based on equation (1), the maximum cutting depth of a single abrasive grain is determined to be 206 nm.

In the process of CMP, The load F_p on a single abrasive grain and the indentation depth δ_w should satisfy the following equation,[3]

$$\delta_w = \frac{F_p}{\pi R_p H} \tag{2}$$

where F_p is load of single abrasive and R_p is abrasive radius. F_p can be calculated using the Hertz contact theory. Assuming that during the polishing process, the abrasive grain size is consistent, the representation of the number of effective abrasive grains per unit area during the polishing process is denoted as η_p,

$$\eta_{\mathrm{p}} = \frac{3C_{\mathrm{a}}\rho_{\mathrm{s}}}{2\pi R_{\mathrm{p}}^{2}\rho_{\mathrm{p}}} \tag{3}$$

Where C_a is mass fraction of the abrasive, ρ_s is density of polishing slurry and ρ_p is density of abrasive.

Based on experimental parameters and abrasive information in the manuscript, polishing slurry parameter information could be determined. There are as follows,

Tab. 2 Polishing slurry parameter information

Name	Abrasive radius R_p (nm)	Mass fraction of the abrasive C_a (wt.%)	Density of polishing slurry ρ_s (g/cm^3)	Density of abrasive ρ_p (g/cm^3)
Parameter	74.3	1.0	1.1	7.1

On the basis of information in Tab. 2 regarding polishing slurry parameters and equation (3), the effective abrasive particle count η_p within a unit area can be calculated,

$$\eta_{\mathrm{p}} = 1.34 \times 10^{5} (1/\mathrm{mm}^{2}) \tag{4}$$

When the polishing pressure is set at 0.20 MPa, the corresponding calculations of δ_w from equations (3) and (4) is 6.5 nm.

References

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2. T. Kvackaj, A. Kovacova, R. Kocisko, J. Bidulska, L. Lityńska–Dobrzyńska, P. Jenei and J. Gubicza, *Mater. Charact.*, 2017, **134**, 246-252.
3. H. S. Lee, H. D. Jeong and D. A. Dornfeld, *Precis. Eng.*, 2013, **37**, 483-490.