Additive Manufacturing of NbMoTaW Refractory High Entropy Alloy

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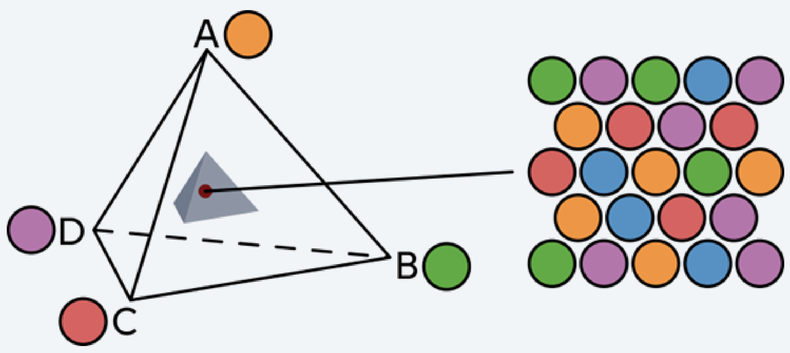
Background

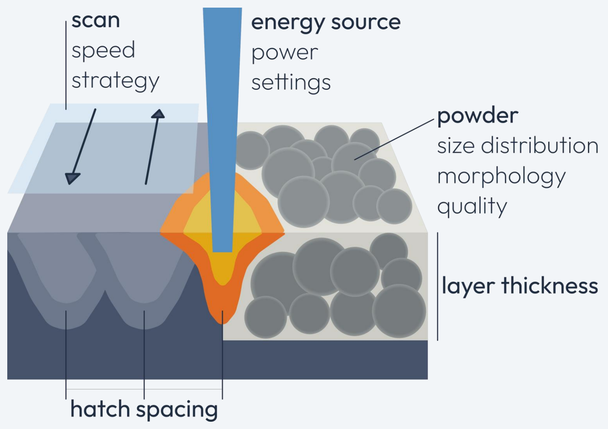
Laser powder bed fusion of refractory high entropy alloys are relatively underexplored, especially pre-alloyed NbMoTaW, due to challenges in producing the feedstock and identifying process conditions for defect-lean microstructures.

High entropy alloys (HEAs)



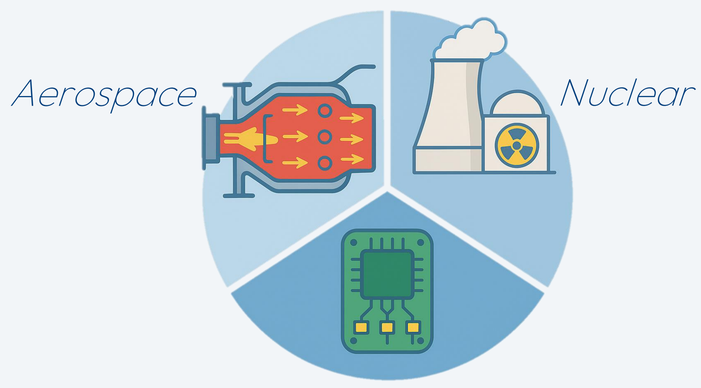
Multi-principal element alloys with exceptional properties, often attributed to high entropy effects. They typically have simple, stable phase constitution, suitable for extreme applications.

Laser powder bed fusion (L-PBF)



Metal AM technique that selectively melts powder layers with a high-energy laser, enabling precise fabrication of complex geometries with microstructure control.

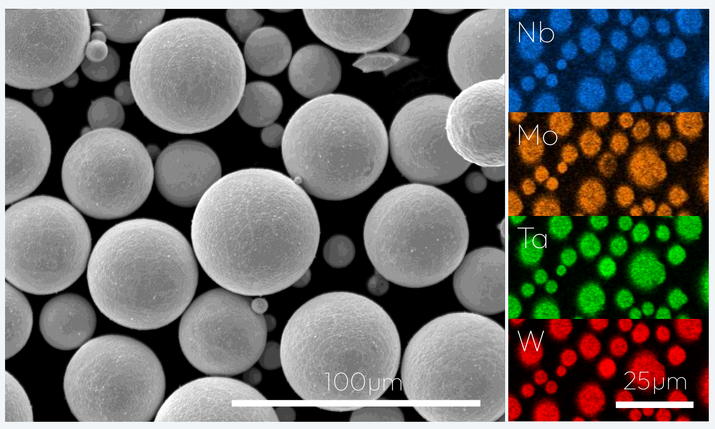
Refractory metals



High melting point metals that withstand applications in high-temperature environments. They are very difficult to process conventionally.

Materials

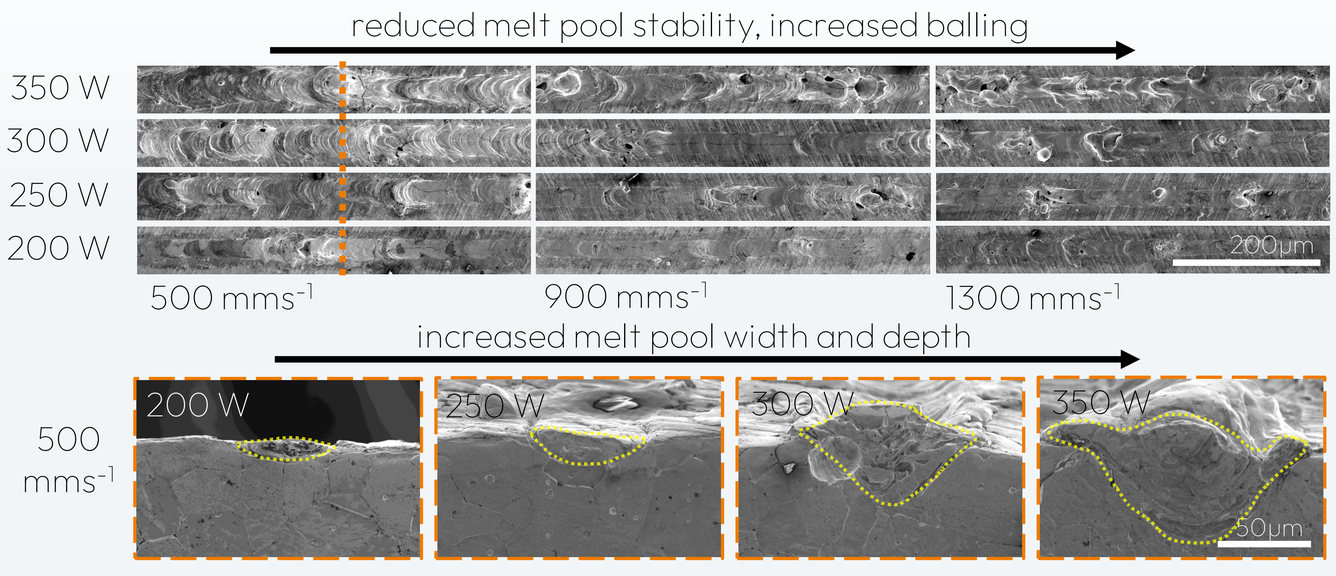
A pre-alloyed AM grade spherical NbMoTaW powder was used.



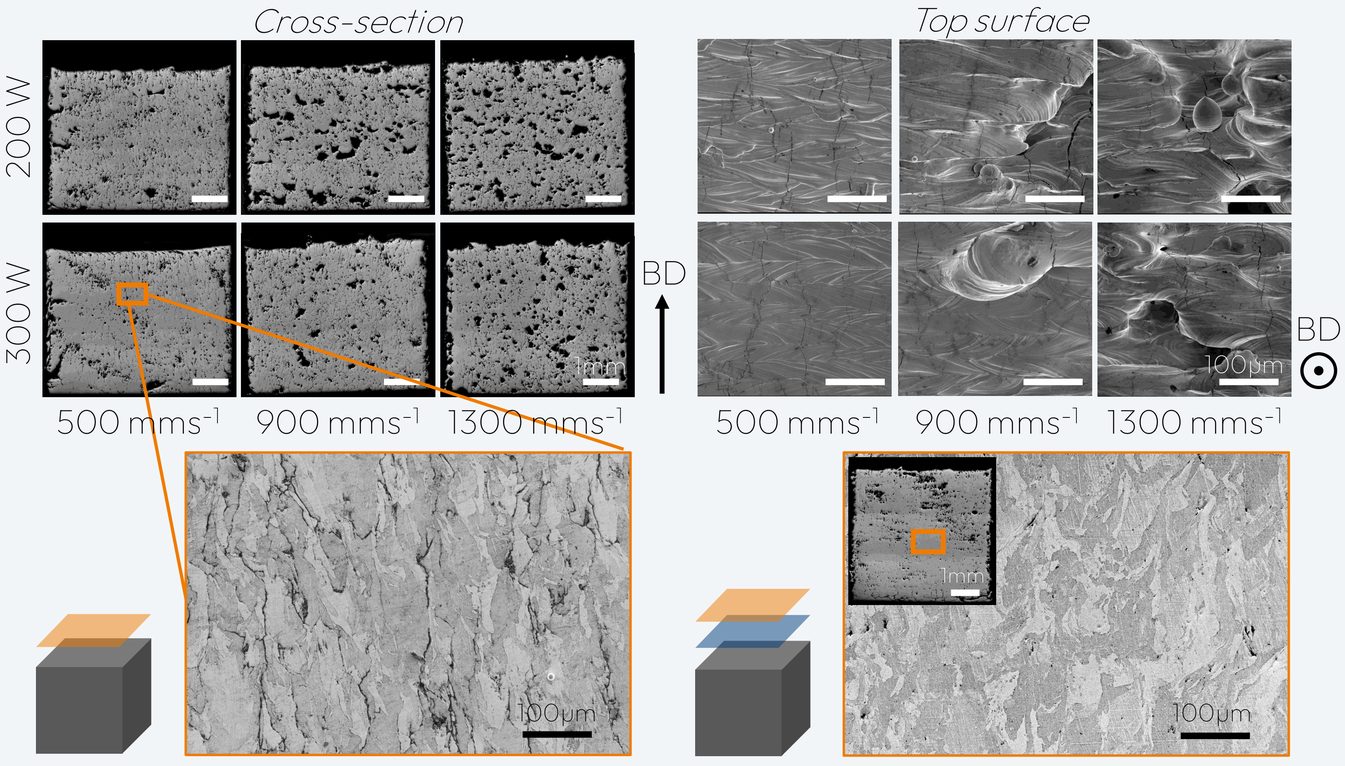
Composition	NbMoTaW
Morphology	Spherical
Size	15-53 µm
Density	8.33 g/cm^3 (tap) 7.81 g/cm^3 (app.)
Impurities	O: ~200 ppm Ni: ~0.3 wt%
Crystallography	BCC (single-phase)

Results

1) Parametric study - single line deposition

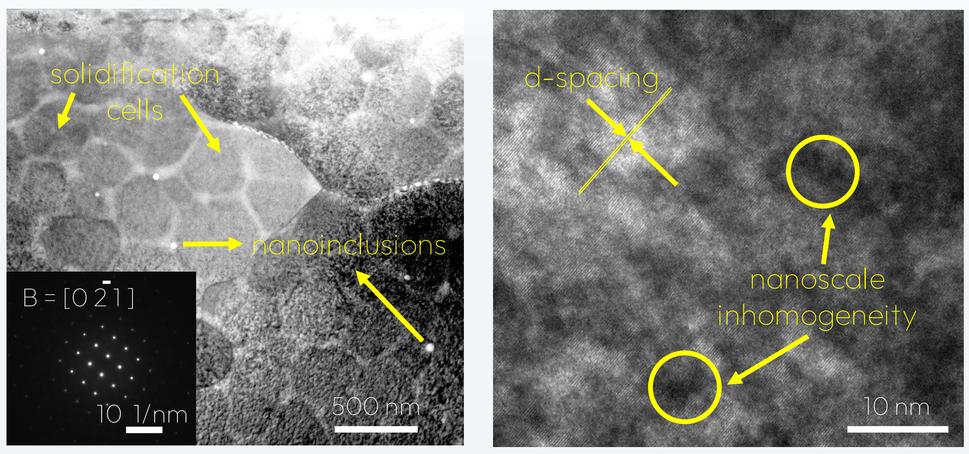


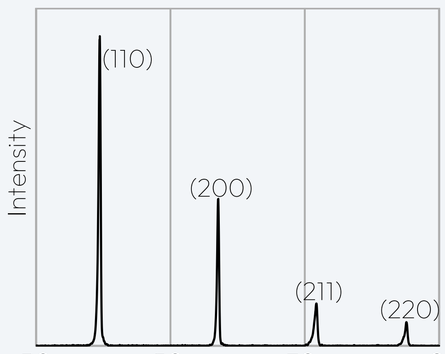
2) Parametric study - single cube deposition



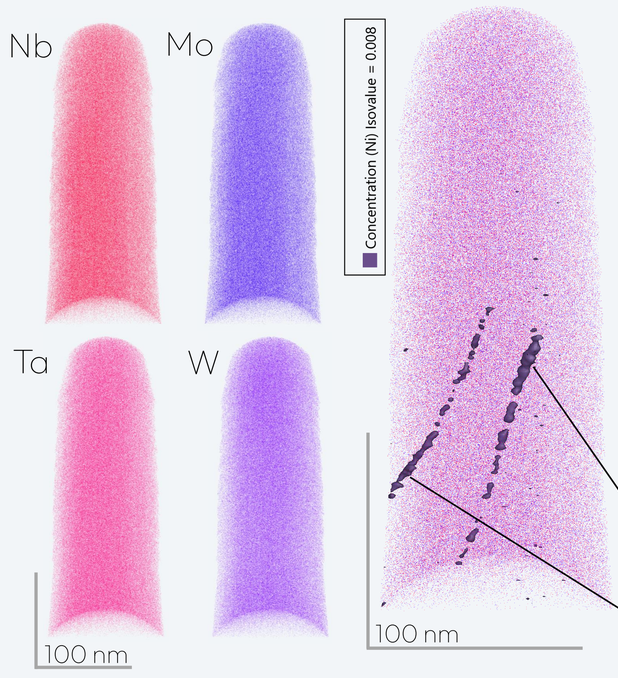
Low energy density scan (blue) as a preheating method was applied before the melting high energy scan (orange), suppressing crack formation.

3) Materials characterization





Lattice parameter	0.3222 nm
Phase	disordered BCC
Peak positions (XRD)	(110), (200), (211), (220)
d-spacing (HRTEM)	0.116 nm
Cellular dimension	~500 nm



Relatively homogenous solid solution with possible nanoscale inhomogeneity.

z	at.%
Nb	25.57%
Mo	25.13%
Ta	24.96%
W	23.76%
O	0.53%
Ni	0.05%

**Data obtained with CAMECA Invizo 6000.*

Conclusions

- Pre-alloyed equiatomic NbMoTaW powder was processed with high energy density L-PBF.
- Characteristic features across multiple length scales were investigated from macro- (surface profile), meso- (melt pool geometry), micro- (porosity, cracks, solidification cellular structures), nano- (dislocations, nanoinclusions), and near atomic (crystallographic parameters) scales.
- A crack-mitigation strategy by laser pre-heating was developed, yielding crack-free samples with the record highest relative density of >99.2%.