

Supporting Information

Extrusion printing of designed three-dimensional $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ superconductor with milled precursor powder

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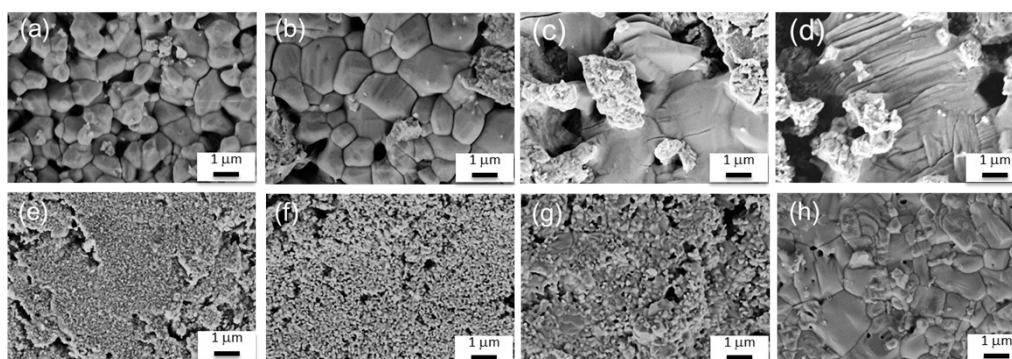


Fig. S1 SEM images of bulk YBCO of unmilled powder after sintering at different temperatures: (a) 750 °C, (b) 800 °C, (c) 850 °C, (d) 900 °C. SEM images of bulk YBCO of milled powder after sintering at different temperatures: (e) 750 °C, (f) 800 °C, (g) 850 °C, (h) 900 °C. The scaling bar is 1 μm .

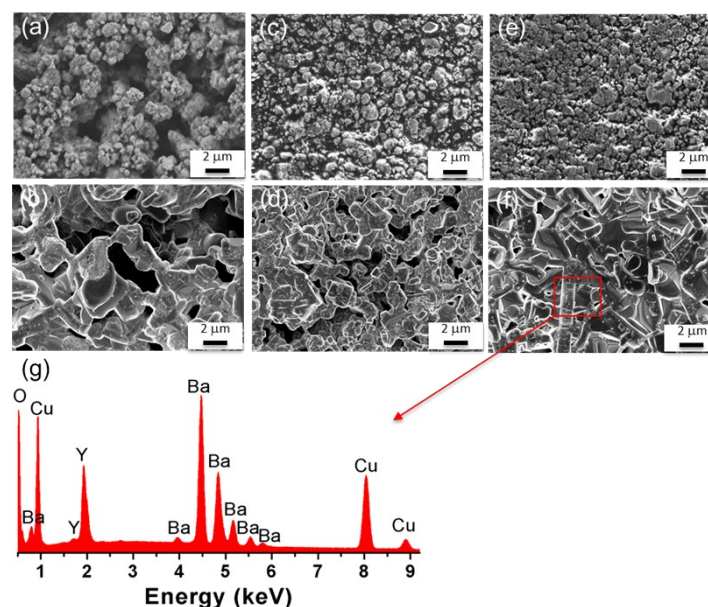


Fig. S2 SEM images of (a) as-printed and (b) sintered YBCO for sample A. SEM images of (c) as-printed and (d) sintered YBCO for sample B. SEM images of (e) as-

printed and (f) sintered YBCO for sample C. Sintering was carried out at 940 °C for 10 h in air with annealing at 500 °C for 20 h. The scaling bar is 2 μ m. (g) EDXS spectrum taken from the selected area.

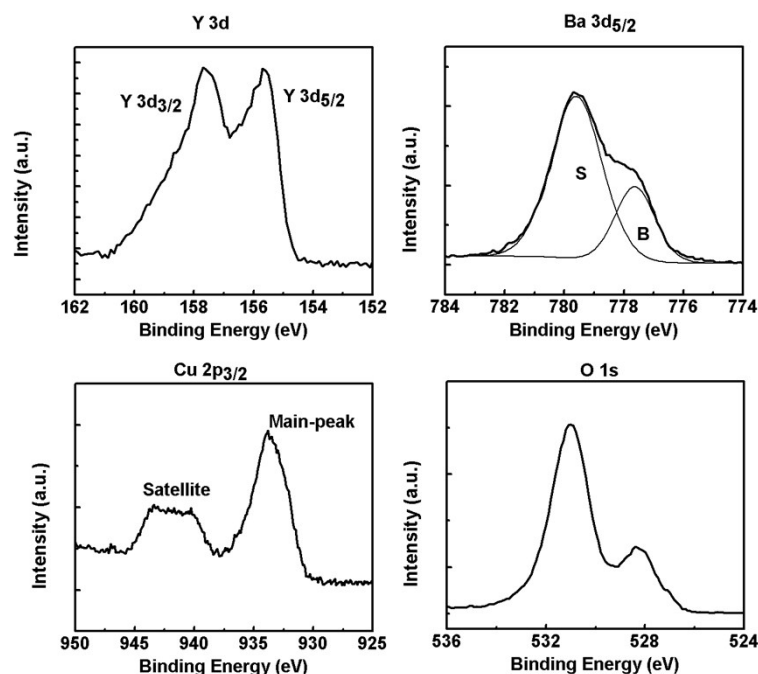


Fig. S3 X-ray photoelectron spectra of sample C after sintering at 940 °C for 10 h

XPS analysis of annealed sample C demonstrates the presence of four elements yttrium (Y 3d peak), barium (Ba 3d peak), copper (Cu 2p peak) and oxygen on the surface. These peak positions are in good agreement with results reported by several groups.¹ For yttrium, the most intensive core-level emission is Y 3d with almost identical spin-orbit splitting.² While the Ba 3d_{5/2} peak at 779.5 eV and 777.6 eV can be clearly distinguished. The higher binding energy is associated with a surface Ba-O component whereas the lower binding energy is ascribed to the bulk.³ The Cu 2p_{3/2} structure consists of a main peak and a related broad satellite peak. The intensity ratio of the satellite and main peaks ($I_{\text{sat}}/I_{\text{main}}$) was calculated to be about 0.43. This value is also the evidence of copper existing in a mixture of Cu²⁺ and Cu³⁺. A binding energy of the O 1s peak appearing in the range of 528-528.5 eV is assigned to the bulk.⁴

Reference:

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- 2 C. S. Lim, L. Wang, C. K. Chua, Z. Sofer, O. Jankovský and M. Pumera, *J. Mater. Chem. A*, 2015, **3**, 8346-8352.
- 3 C. Ziegler, G. Frank and W. Göpel, *Z. Phys. B: Condens. Matter*, 1990, **81**, 349-353.
- 4 P. Srivastava, B. R. Sekhar, N. L. Saini, S. K. Sharma, K. B. Garg, B. Mercey, P. Lecoeur and H. Murray, *Solid State Commun.*, 1993, **88**, 105-110.