High-performance blood plasma separation based on Janus membrane technique and RBC agglutination reaction

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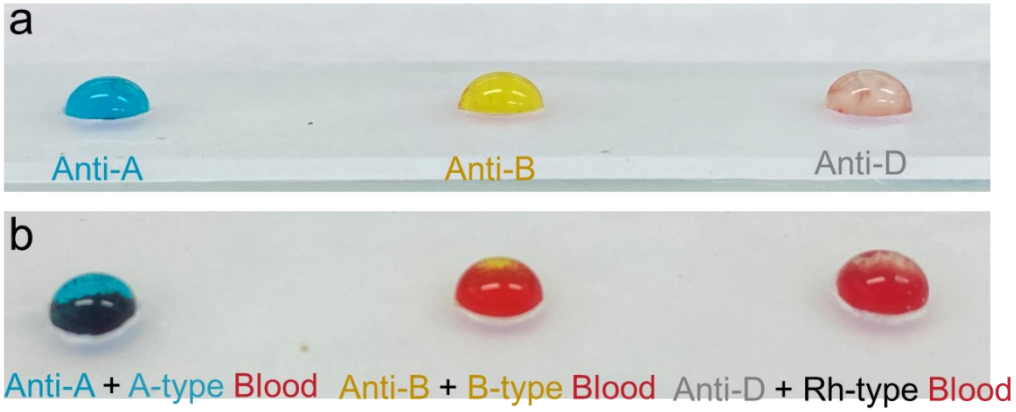

Fig. S1 RBC agglutination via blood type A with anti-A, blood type B with anti-B, blood type AB with anti-A/anti-B, and blood type RhD+ with anti-D. It produced layering phenomenon with RBCs aggregates in the bottom and liquid component on the upper layer.

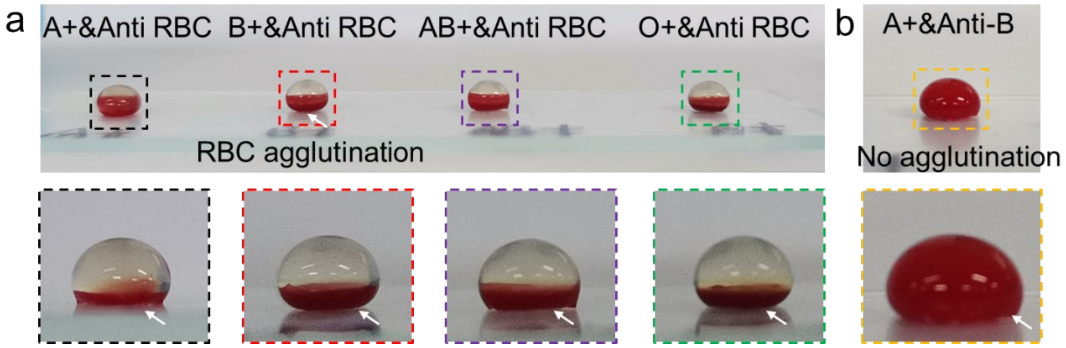

Fig. S2 RBC agglutination reaction induced via using Anti RBC antibody and Anti-B. a) Once we introduced Anti RBC antibody to the whole blood with A+, B+, AB+ or O+ type, RBC agglutination reaction happens (layering phenomenon). It indicated that Anti RBC antibody can perfectly replace anti-A/B/D and induce RBC agglutination of any blood types. b) No RBC agglutination reaction happens (no layering phenomenon) when the Anti-B antibody was introduced into the A+ type whole blood.

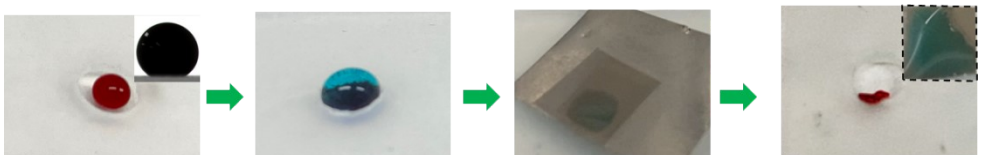

Fig. S3 Actual plasma separation process from A type whole blood. In the end, plasma was successfully separated from whole blood, leaving cell aggregates inside the well.

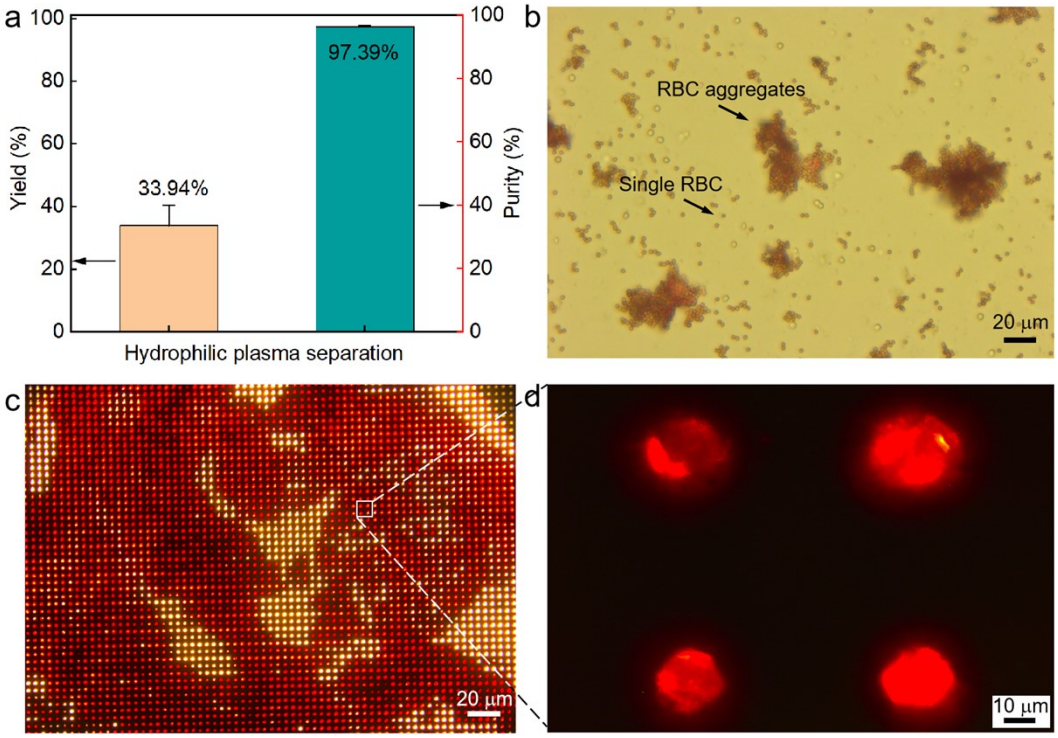

Fig. S4 The plasma separation result through using a hydrophilic Titanium membrane (Blood hematocrit level: 35%). a) The hydrophilic plasma separation can separate ~33.94% plasma yield and 97.39% plasma purity. b) Several RBC aggregates and single RBCs situated inside the extracted plasma. c) The hydrophilic plasma membrane with clogged micropores. Red area showed the clogged micropores induced by large RBC aggregates. The bright yellow area showed the unclogged micropores. d) Enlarged image of the clogged micropores.

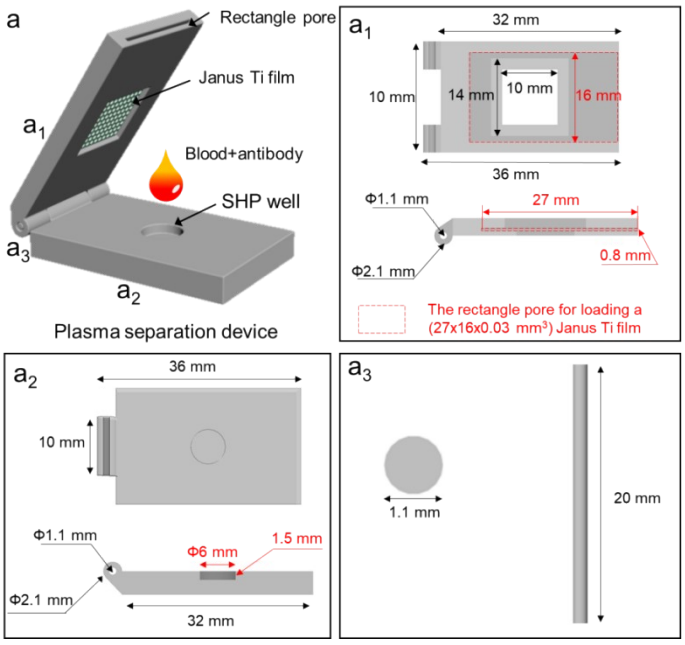

Fig. S5 The clamshell-style plasma separation device and its design. The rectangle pore was used for loading of the Janus membrane. And the whole blood and antibody were introduced inside the superhydrophobic (SHP) well.

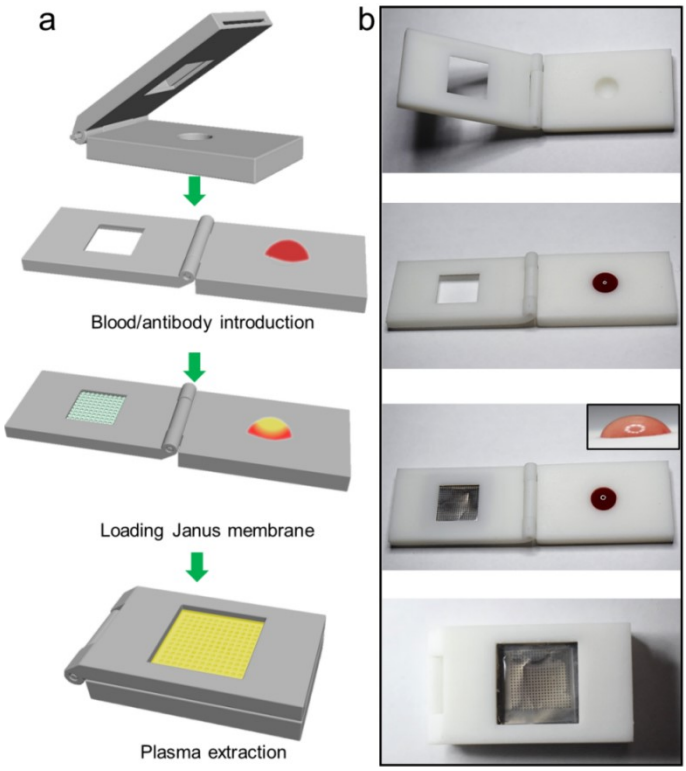

Fig. S6 The plasma separation process based on the device. 20-30 μl whole blood and same volume of corresponding antibody were firstly introduced into the well. Then, the mixed sample was allowed to react for ~60 s (RBC agglutination). Meanwhile, the Janus film was inserted into the rectangle pore. After that, the plasma separation device was closed. Within 20 s, the plasma completely transported to the top surface. Finally, the plasma can be transferred or extracted by a pipette.

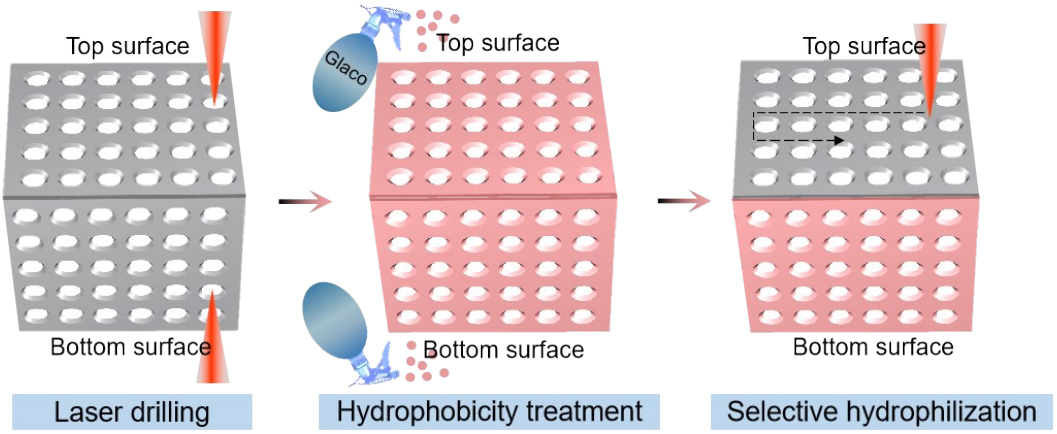

Fig. S7 Fabrication of the Janus film. The process contained three steps. Firstly, laser micro-drilling was used to fabricate the microholes. Then, hydrophobicity coating (Glaco spraying) was chosen to form the hydrophobic-to-hydrophobic surfaces. Finally, laser ablation on the top surface achieved selective hydrophilization (top surface: hydrophilic, bottom surface: hydrophobic). The gray images showed the hydrophilic Ti surface and the red images showed the hydrophobic surface. The arrow showed the scanning path of the laser.

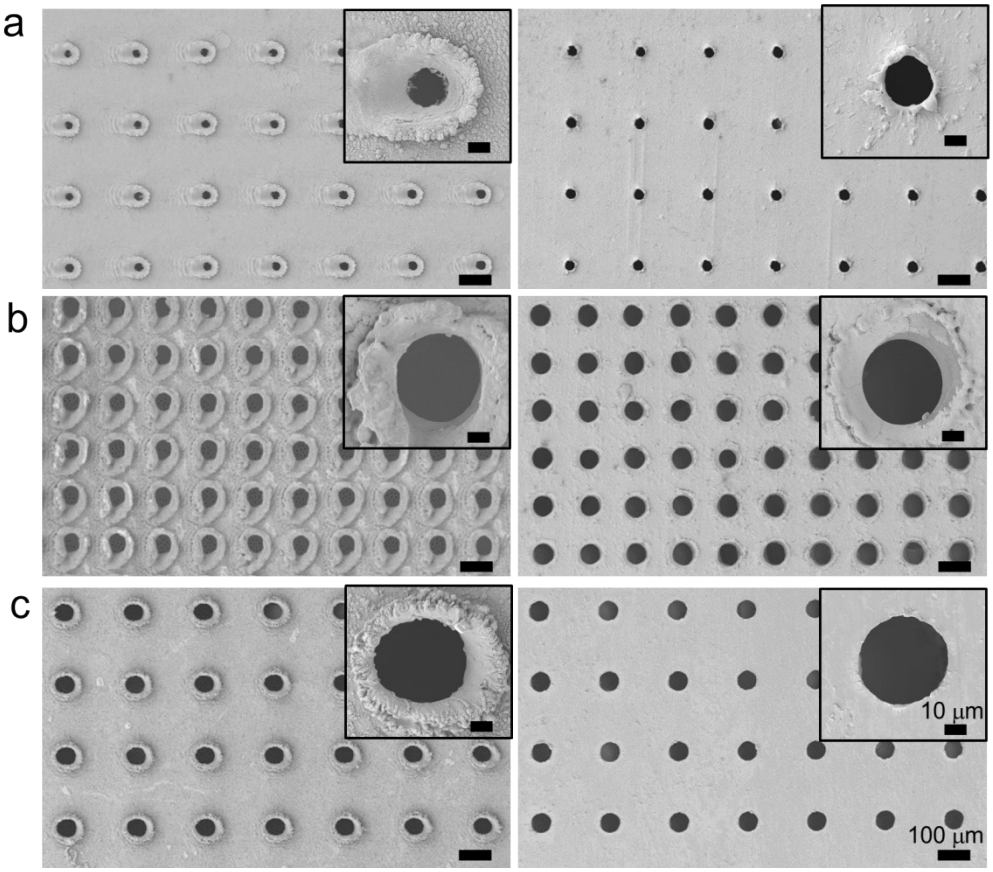

Fig. S8 A series of films with different pore sizes obtained via adjusting the laser power (a-c: 100, 300 to 500 mW).

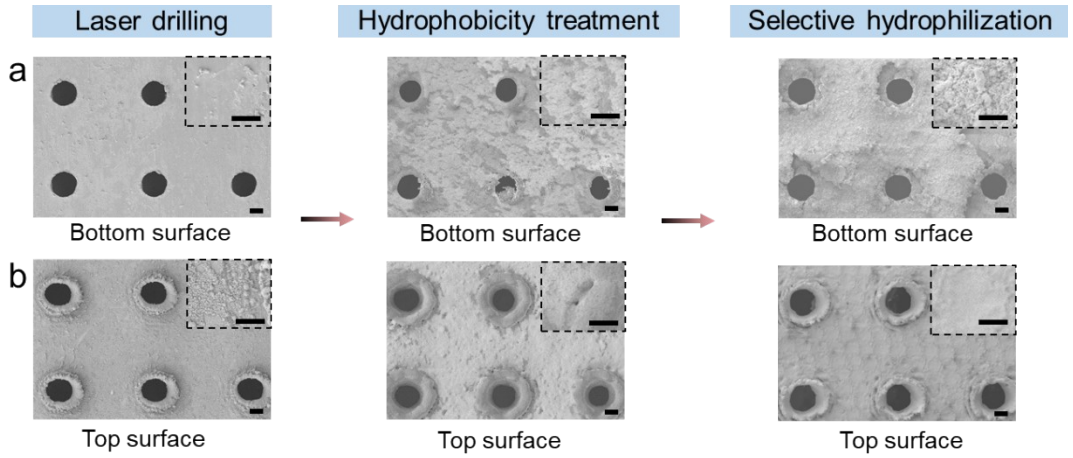

Fig. S9 SEM images of the fabricated films in each steps. The scale bars in a) and b) were 20 μm. The scale bars in the inset images were 5 μm.

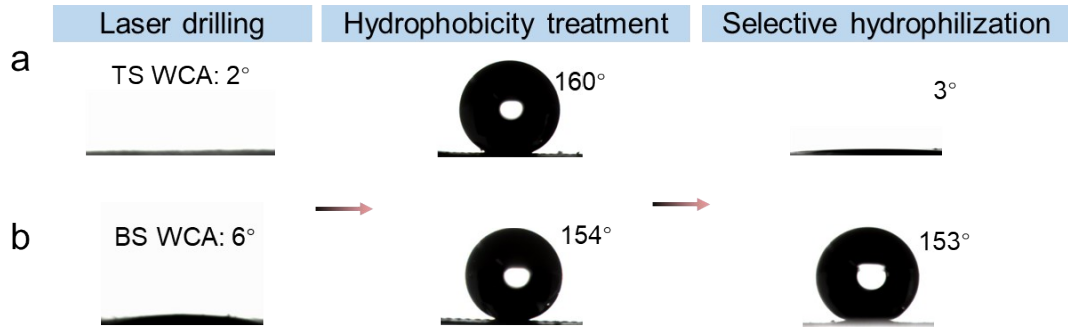

Fig. S10 Contact angles of the fabricated film in each steps. BS and TS were short for bottom surface and top surface, respectively.

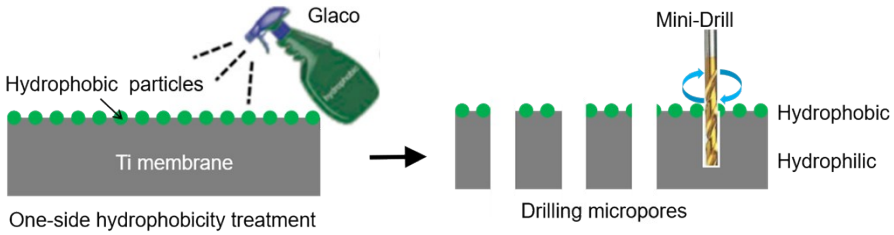

Fig. S11 Potential commercial method for creating mass production of Janus Ti films. Generally, the original Titanium membrane is hydrophilic. Thus, the process of a Janus Titanium membrane can be simplified to two steps: one-side hydrophobic Glaco treatment and microdrilling process. The former treatment can create hydrophobicity on the top surface and the latter drilling can form micropores on the membrane.

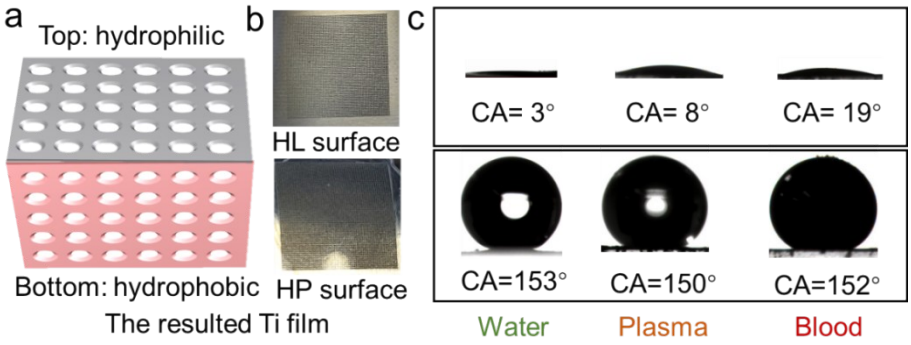

Fig. S12 Wetting property of the Janus film to water, plasma and blood. Water/plasma/blood were all nonwetted on the superhydrophobic side and all wetted on the superhydrophilic side.

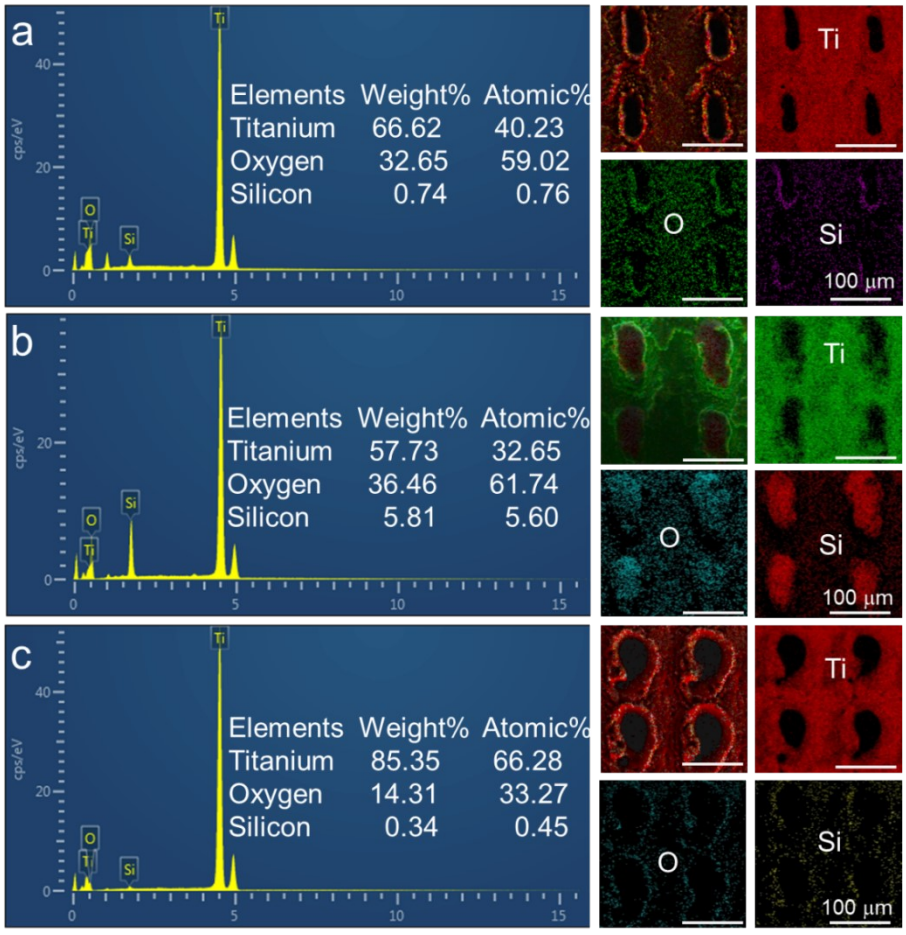

Fig. S13 EDS analysis of the fabrication process. After laser microdrilling, there was less Si elements on the Titanium membrane surface. After Glaco spaying, the atomic content of silicon element increased to 5.60%. It meant that silicon dioxide nanoparticles were covered on the Titanium surface, inducing a superhydrophobic surface. After laser scanning, the atomic content of silicon element decreased to 0.45%. It meant that silicon dioxide nanoparticles were removed on the Titanium surface, inducing a superhydrophilic surface.

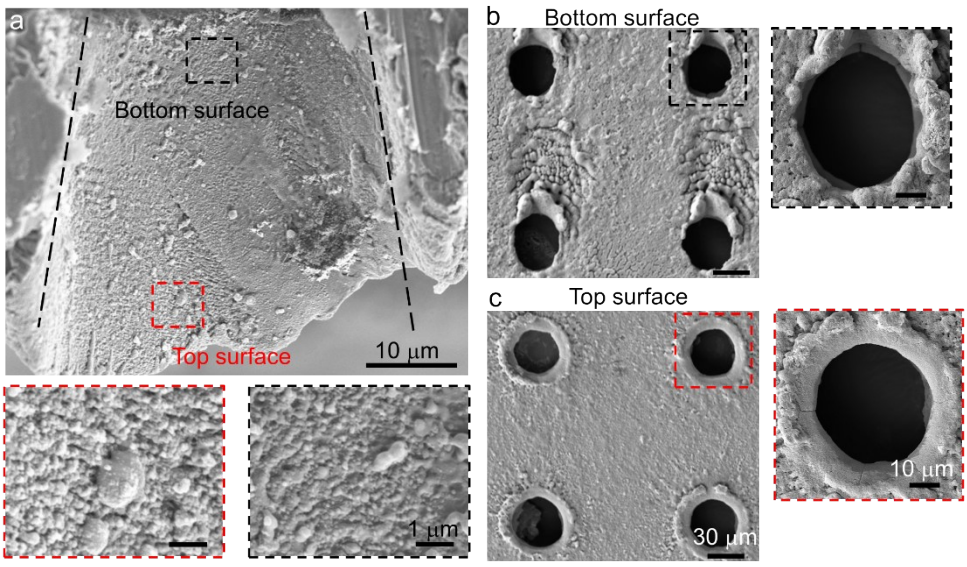

Fig. S14 SEM images of the tapered micropores.

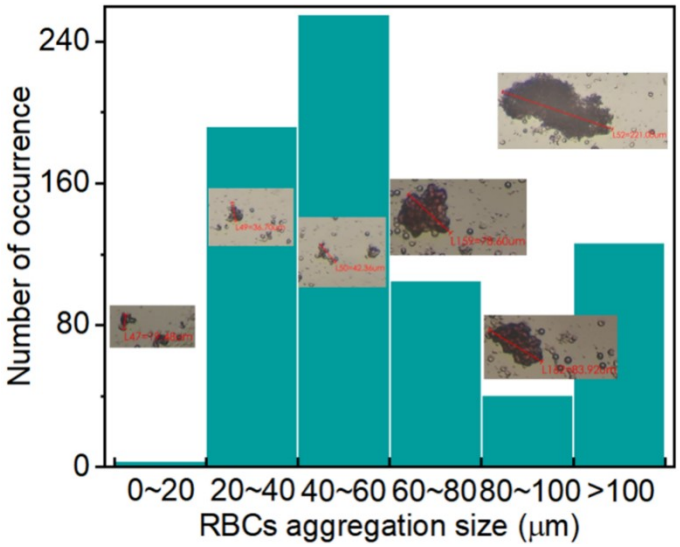

Fig. S15 Size distribution of RBCs aggregates.

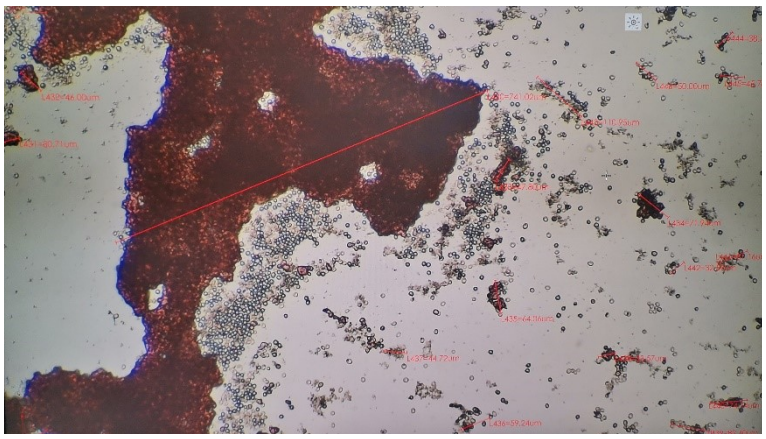

Fig. S16 Large RBC agglutination.

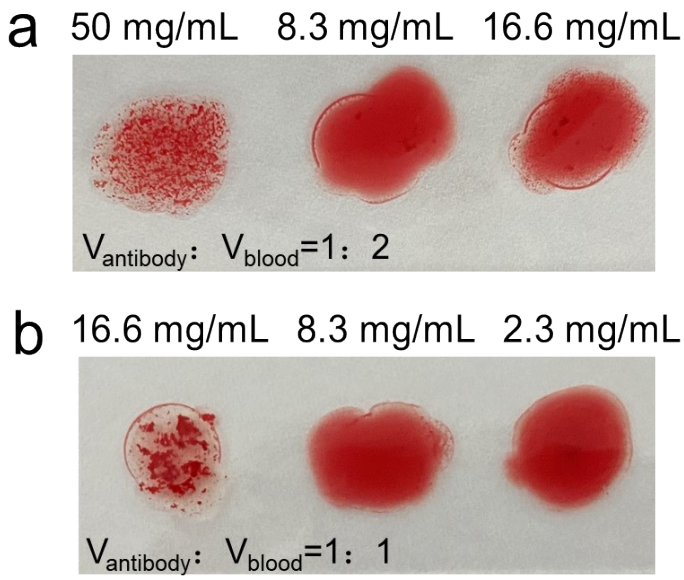

Fig. S17 The dependence of volume ratio and antibody concentration on RBC agglutination results.

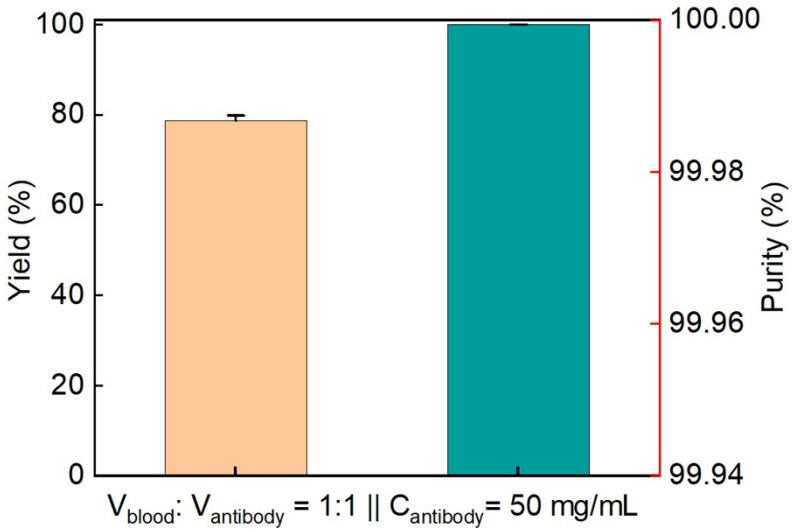

Fig. S18 The plasma separation yield and purity via using the new Anti RBC antibody. The new antibody can get a high yield (~78.69%) and purity (99.99%).

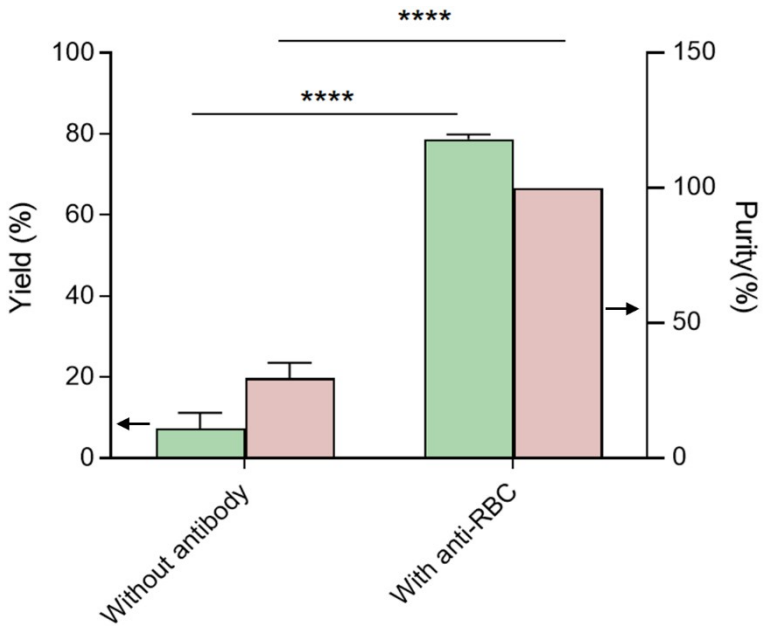

Fig. S19 Plasma yield/purity obtained through a Janus membrane without antibody and with anti-RBC, respectively. Results in all histograms were plotted as the mean ±s.d. (n = 3), ****$p < 0.0001$.

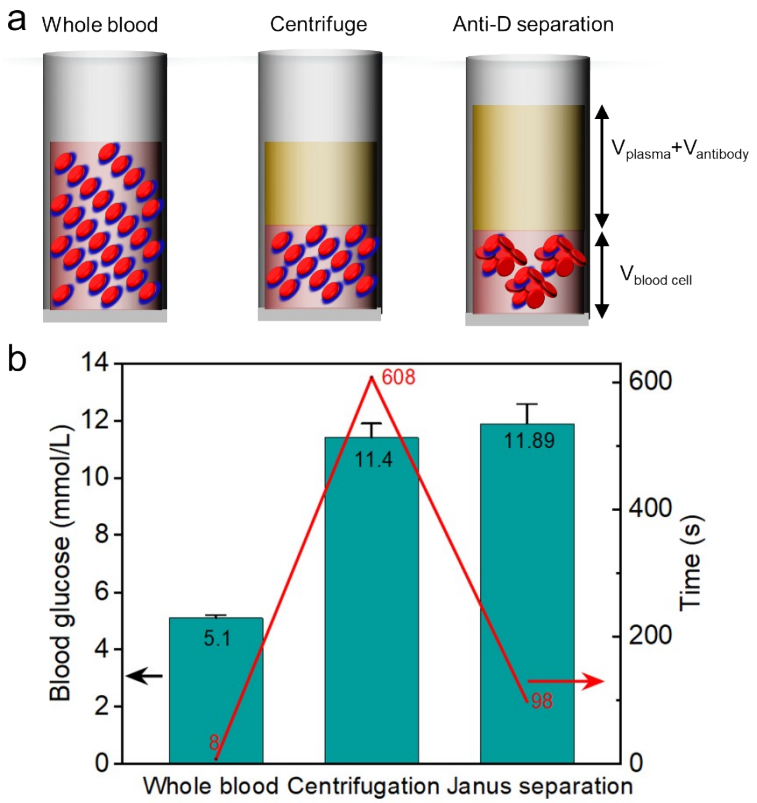

Fig. S20 a) After RBC agglutination reaction induced by anti-D, the mixed sample contained plasma, liquid in antibody and RBCs aggregates. b) Blood glucose level measuring via whole blood (~5.1 mmol/L), after centrifugation (11.4 mmol/L) and after antibody induced RBC agglutination (3.9 mmol/L). The time for testing glucose concentration of whole blood, blood after centrifugation and blood after RBC agglutination were 8 s, 608 s (600 s for plasma separation and 8 s for glucose test) and 98 s (90 s for plasma separation and 8 s for glucose test), respectively.

Fig. S21 Blood glucose level measuring via using a blood glucose meter.

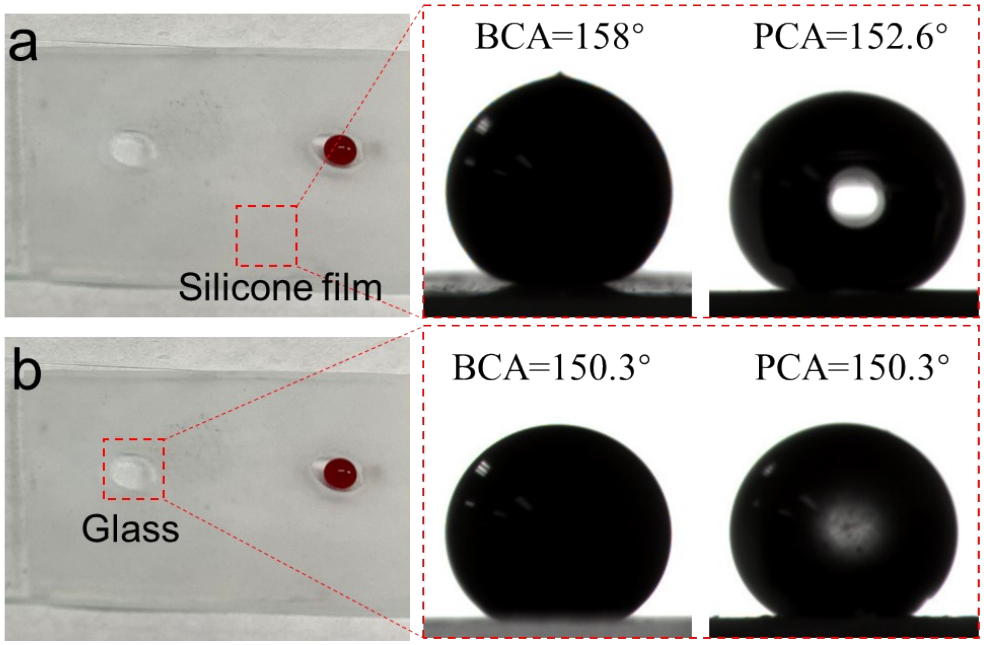

Fig. S22 a) Contact angles of blood and plasma on the silicone film. b) Contact angles of blood and plasma on the well. The silicone film and the well were all nonwetting to blood and plasma which was beneficial to ultra-high purity/yield plasma extraction.