Electronic Supplementary Material (ESI) for New Journal of Chemistry.

Electronic Supplementary Information

Improvement of heat transfer by promoting dropwise condensation using electrospun polytetrafluoroethylene thin films

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FT-IR spectra of electrospun PTFE thin films

FT-IR spectra of electrospun surfaces using 66 wt% and 17 wt% PTFE are shown in Fig. S1. We determined that the peaks at around 3350 cm^{-1}, 2920 cm^{-1}, 1740 cm^{-1}, 1430 cm^{-1}, and 1100 cm^{-1}, were derived from O-H stretching, C-H stretching, C=C stretching, C-H bending, C-O stretching from PVA respectively, and those around 1220 cm^{-1}, 1160 cm^{-1}, 640 cm^{-1}, 555 cm^{-1}, and 510 cm^{-1} were derived from CF_2 symmetric stretching, CF_2 symmetric stretching, CF deformation, CF_2 bending and CF_2 twisting from PTFE, respectively. Therefore, PVA nanofibers were decomposed completely after annealing.

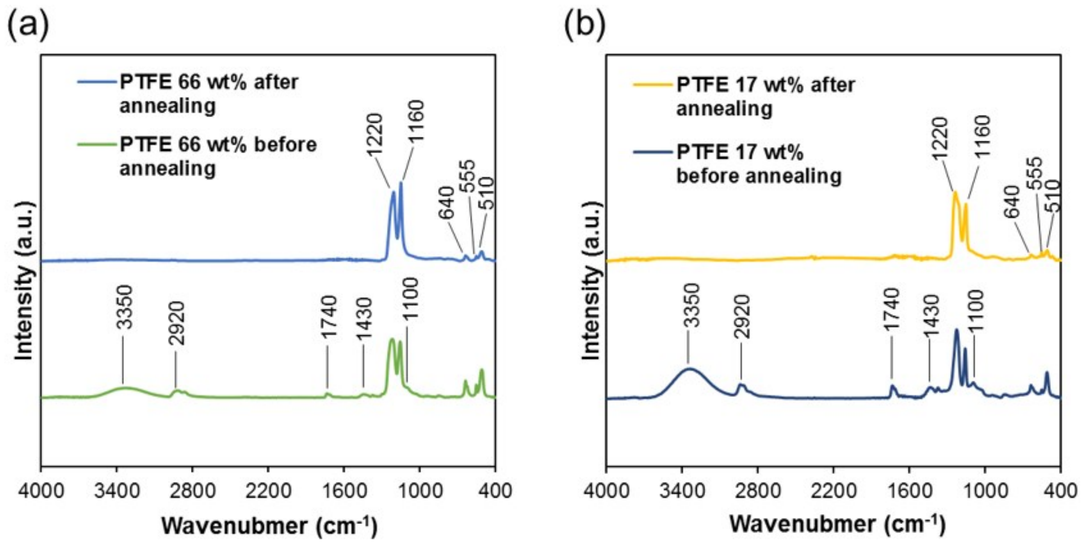

Fig. S1 FT-IR spectra of electrospun surfaces using (a) 66 wt% and (b) 17 wt% PTFE.

Raman spectra of electrospun PTFE thin films

Raman spectra of electrospun surfaces using 66 wt% PTFE are shown in Fig. S2. We determined that the peaks at around 1440 cm^{-1} were derived from C-H stretching from PVA and those around 1380 cm^{-1} and 1300 cm^{-1} were derived from CF stretching and CF_2 asymmetric stretching from PTFE, respectively. No peaks indicate carbonization were observed. Therefore, PVA nanofibers were decomposed completely after annealing, and they were not carbonized.

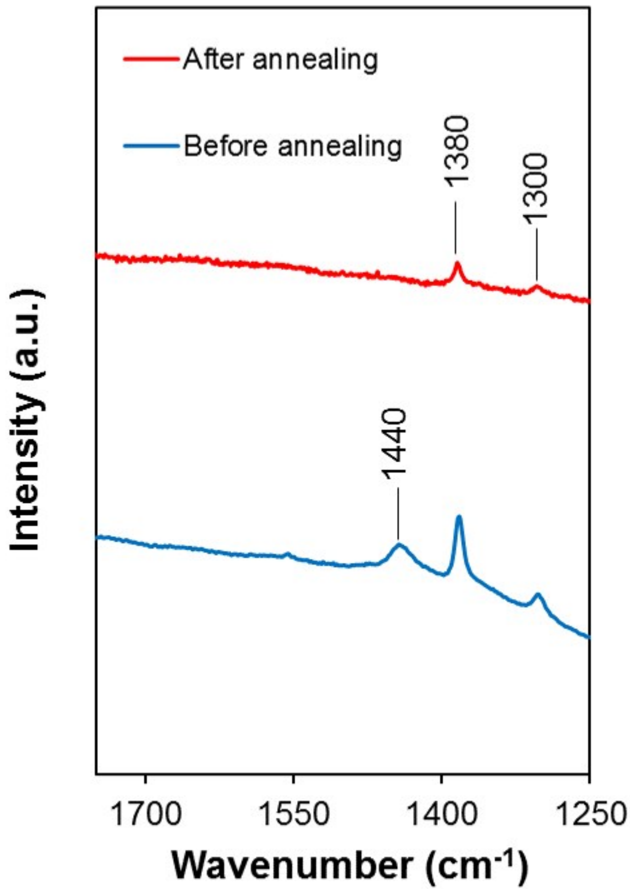

Fig. S2 Raman spectra of electrospun surfaces using 66 wt% PTFE.

Sample electrospun using solutions containing 13 wt% PTFE

The TGA curve for the sample prepared by electrospinning 13 wt% PTFE contained a large weight decrease at 280–370 °C attributed to the loss of PVA nanofibers, the same as the other samples (Fig. S3).

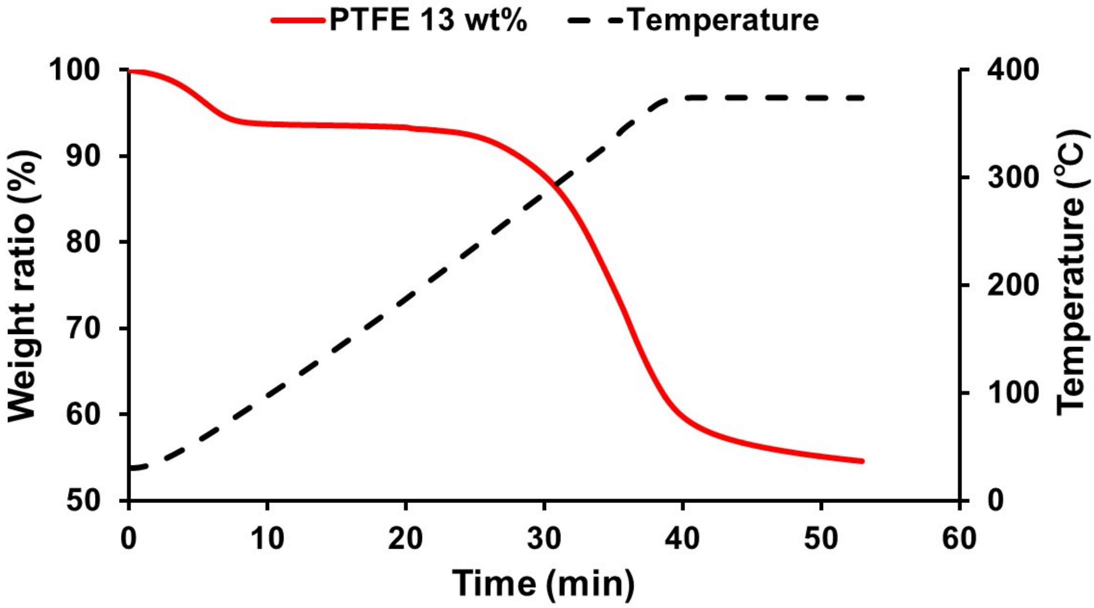

Fig. S3 TGA curves measured for electrospun thin films prepared using solutions containing 13 wt% (red line). Black dash line shows temperature.

PTFE films were not fabricated on an Al surface by electrospinning a 13 wt% PTFE solution (applied voltage = 20 kV, TCD = 20 cm) after annealing. Therefore, the water contact angle of these samples was almost the same as that of an uncoated Al surface because the PTFE: PVA ratio of the dispersion was too low, so only a few PTFE particles were observed on the Al surface (Fig. S4).

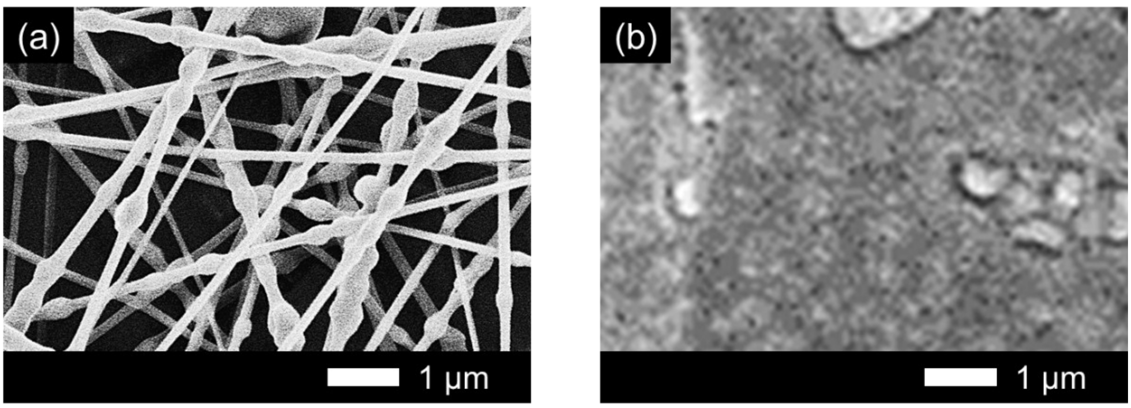

Fig. S4 FE-SEM images of the Al surfaces prepared using 13 wt% PTFE: (a) before annealing and (b) after annealing. All white scale bars are 1 μm.

Influences of TCD and applied voltage on contact angle

The influences of TCD and applied voltage on the contact angles of the surfaces were determined using an electrospinning solution containing 23 wt% PTFE (Fig. S5). A longer TCD led to a decrease of contact angle because the content of PTFE particles decreased during flight from the tip to the collector. Meanwhile, the change of contact angle caused by applied voltage modification was unclear. Therefore, we decided to use a fixed applied voltage to fabricate PTFE films on Al and Cu tubes.

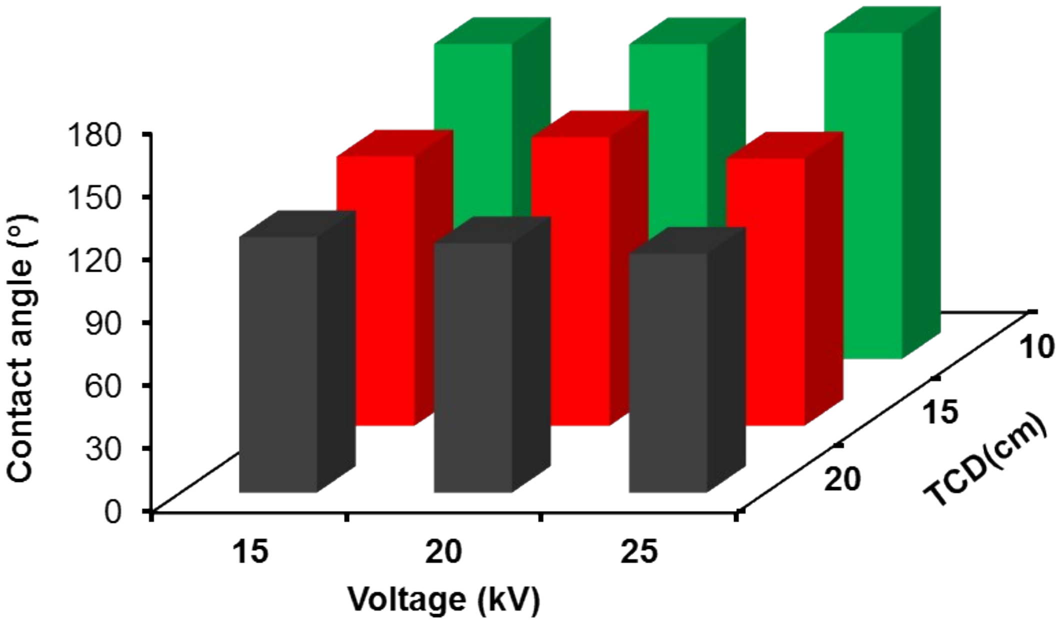

Fig. S5 Water contact angles of PTFE thin films on Al plates for each applied voltage and TCD (PTFE weight ratio = 23 wt%).

Surface structures of PTFE thin films on Al and Cu tubes after annealing

FE-SEM images of Al and Cu tube surfaces are shown in Fig. S6 and S7, respectively. The content of PTFE particles decreased, and the spherical shape of PTFE particle was lost with lower PTFE weight ratio and longer TCD. A lower PTFE weight ratio led to a decrease of surface roughness, and thus lower contact angle. The difference of surface structures on Al and Cu is mainly derived from the annealing procedure. During annealing, rough thin CuO films formed on the Cu substrates.

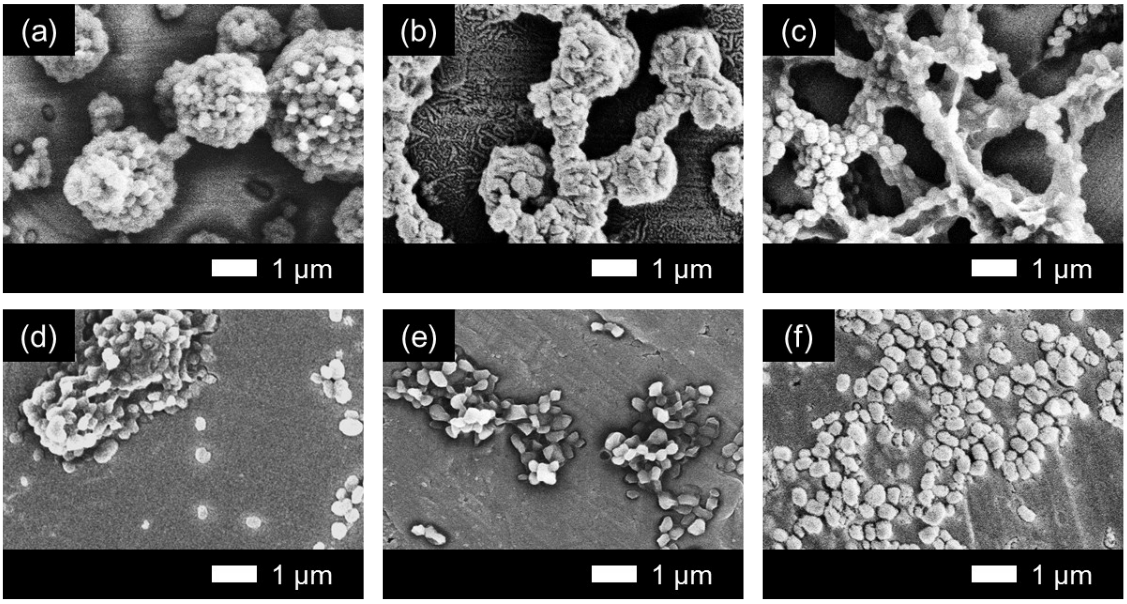

Fig. S6 FE-SEM images of coated Al tube surfaces prepared using (a) 100 wt%, (b) 66 wt%, (c) 33 wt%, (d) 23 wt%, (e) 17 wt% (TCD = 15 cm), (f) 17 wt% (TCD = 20 cm) PTFE. All white scale bars are 1 µm.

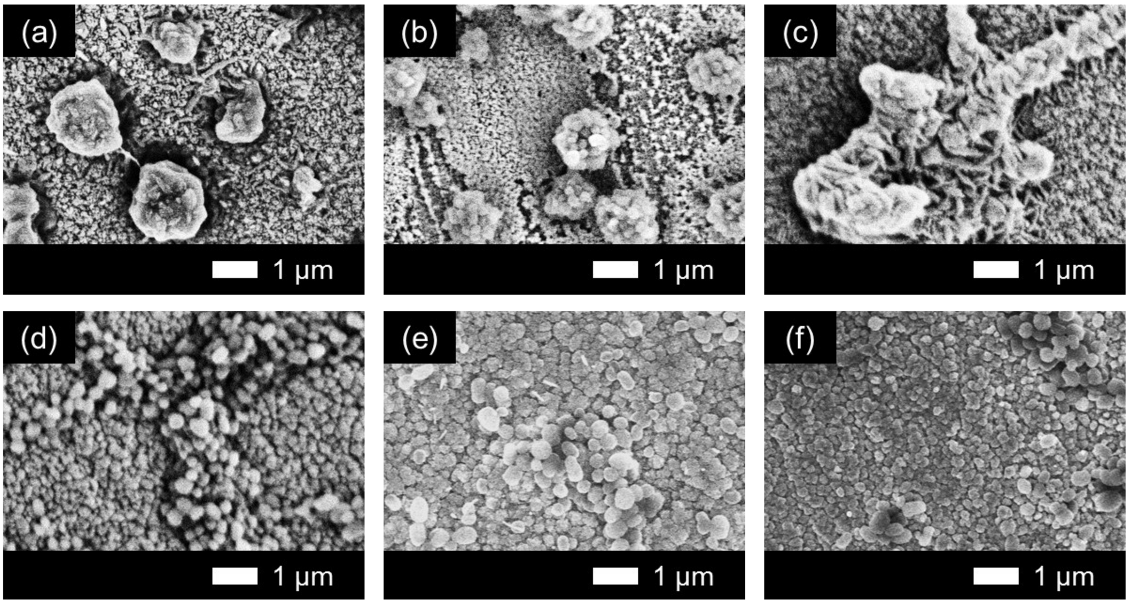

Fig. S7 FE-SEM images of coated Cu tube surfaces prepared using (a) 100 wt%, (b) 66 wt%, (c) 33 wt%, (d) 23 wt%, (e) 17 wt% (TCD = 15 cm), (f) 17 wt% (TCD = 20 cm) PTFE. All white scale bars are 1 μm.

Laser scanning microscope images of Al and Cu surfaces are provided in Fig. S8 and S9, respectively. The PTFE film prepared on an Al surface using 66 wt% PTFE possessed the roughest structure. Few rough structures were observed on the coated Al surfaces produced using 23 wt% and 17 wt% PTFE. The situation was similar for the PTFE films on Cu surfaces.

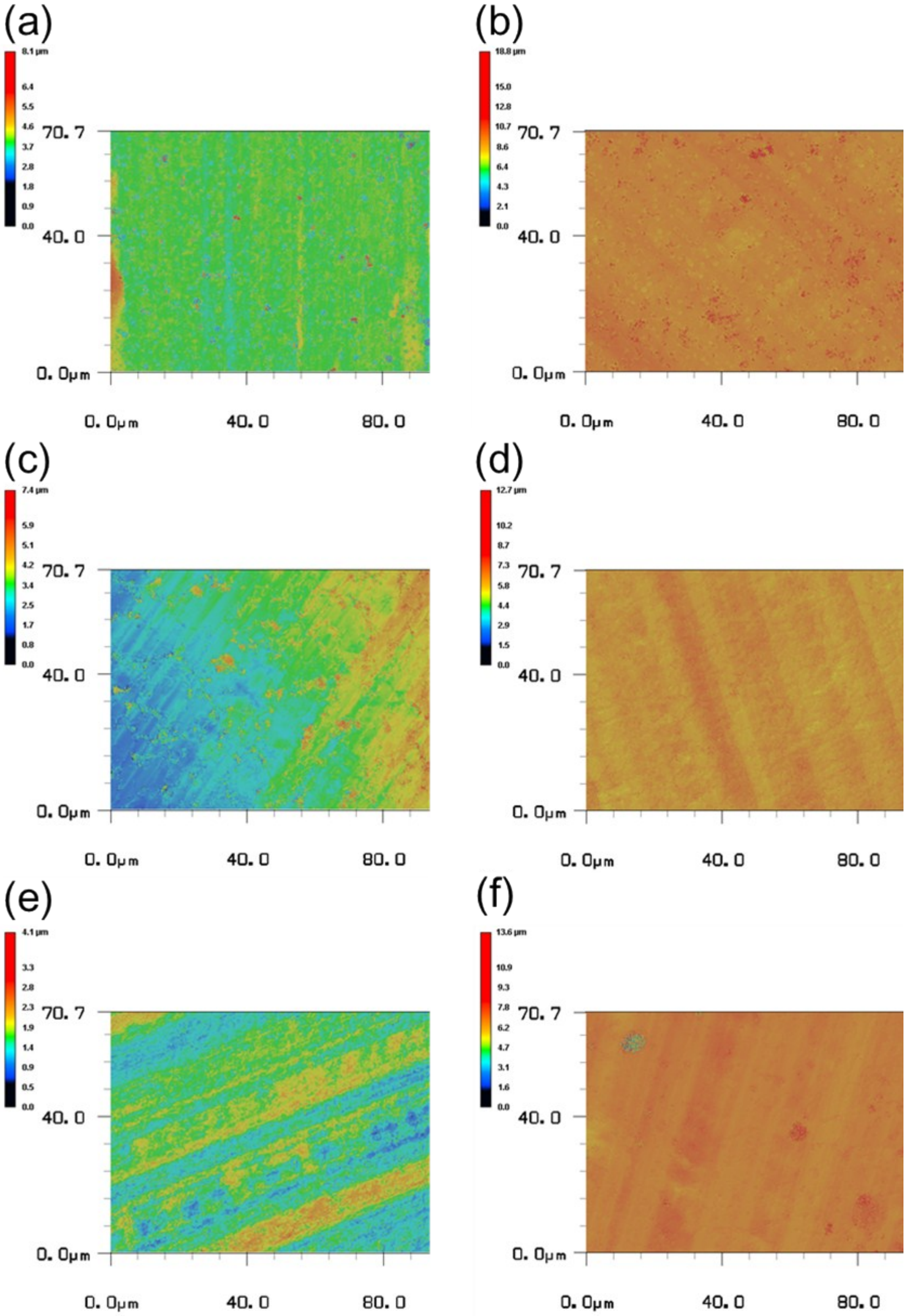

Fig. S8 Laser scanning microscope images of coated Al tube surfaces prepared using (a) 100 wt%, (b) 66 wt%, (c) 33 wt%, (d) 23 wt%, (e) 17 wt% (TCD = 15 cm), (f) 17 wt% (TCD = 20 cm) PTFE.

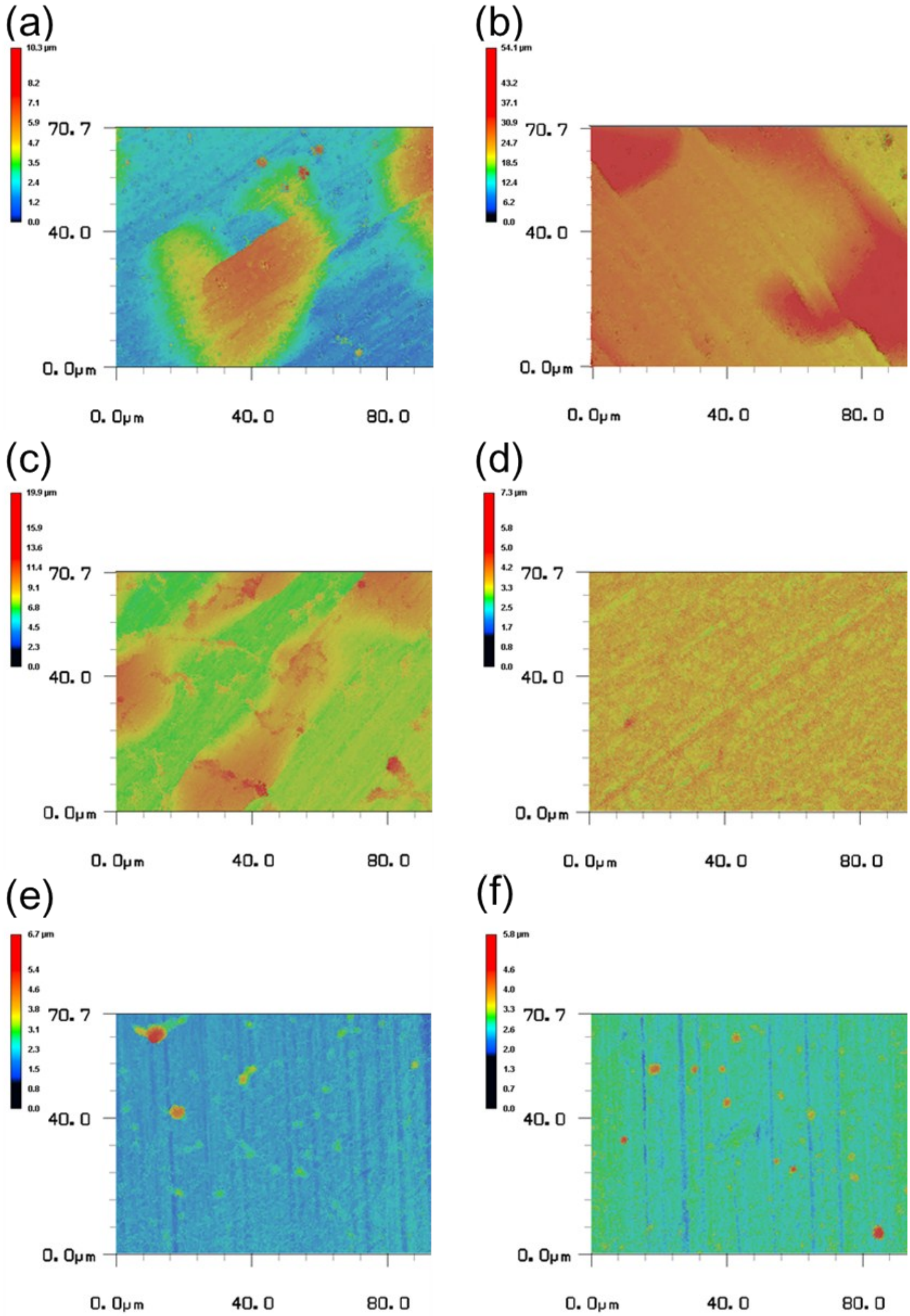

Fig. S9 Laser scanning microscope images of coated Cu tube surfaces prepared using (a) 100 wt%, (b) 66 wt%, (c) 33 wt%, (d) 23 wt%, (e) 17 wt% (TCD = 15 cm), (f) 17 wt% (TCD = 20 cm) PTFE.

The influence of TCD on the wettability and condensation heat transfer on PTFE-coated Al and Cu tubes

Water contact angle, sliding angle and contact angle hysteresis of the PTFE-coated Al and Cu tube surfaces obtained using 17 wt% PTFE for TCD = 15 and 20 cm are shown in Fig. S10. Surfaces produced using TCD = 15 cm showed higher contact angles than those formed with TCD = 20 cm, consistent with the results in Fig. S3. Water did not slide on any of these surfaces.

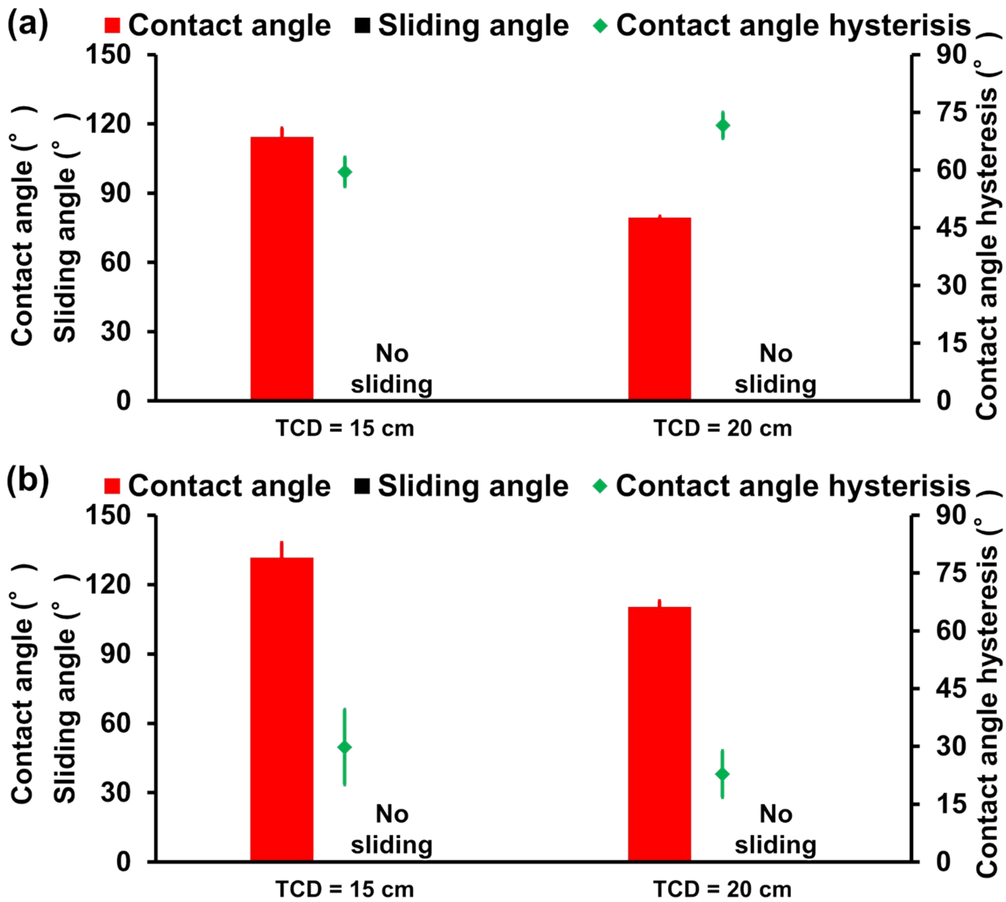

Fig. S10 Water contact angle (red bars), sliding angle (black bars) and contact angle hysteresis (green diamonds) of surfaces prepared using 17 wt% PTFE in the case of TCD = 15 cm and 20 cm on (a) Al and (b) Cu tubes.

All Al and Cu surfaces produced using 17 wt% PTFE with TCD = 15 and 20 cm displayed dropwise condensation, the same as the other PTFE-coated surfaces (Fig. S11). The heat transfer coefficients and departure frequencies of condensed water droplets were similar on Al and Cu tubes in the case of the 17 wt% PTFE electrospinning solution (Fig. S12). The difference of heat transfer coefficient was small because the departure frequencies of condensed water droplets were almost the same on Al and Cu. Therefore, the mixing ratio of PTFE and PVA was changed to evaluate the best conditions to maximize condensation heat transfer.

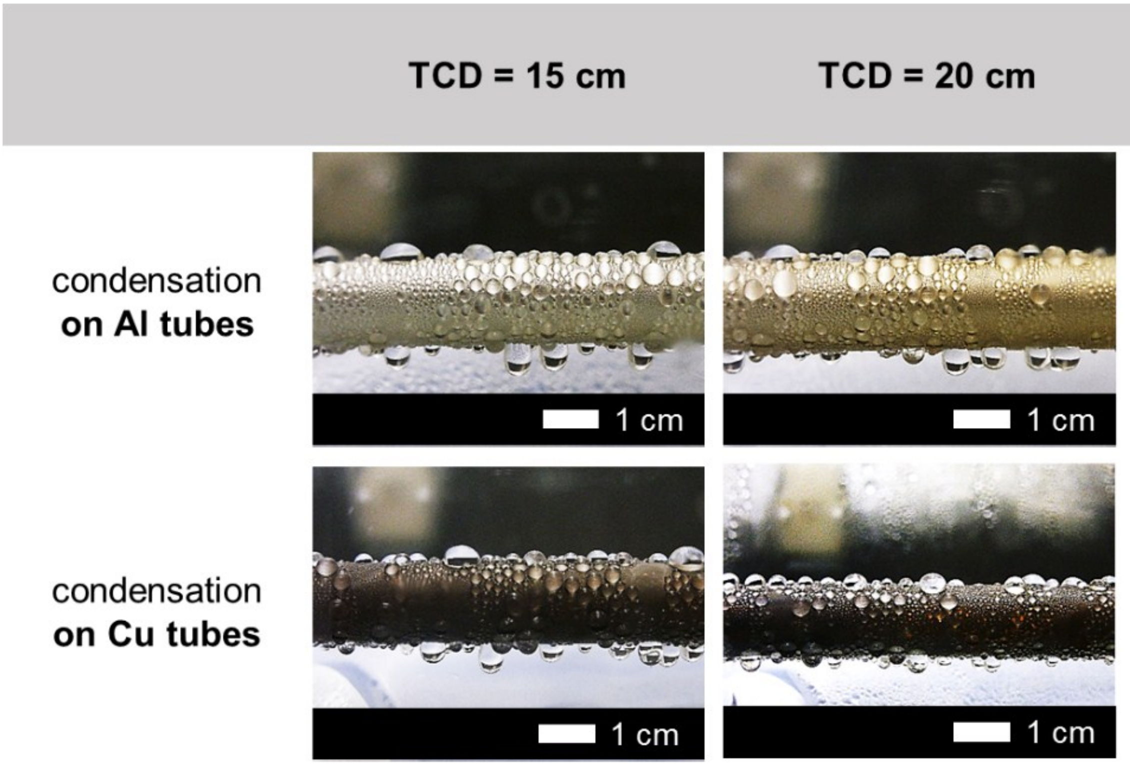

Fig. S11 Photographs of condensation states on PTFE coatings prepared using 17 wt% PTFE in the case of TCD = 15 cm and 20 cm on Al and Cu tubes. All white scale bars are 1 cm.

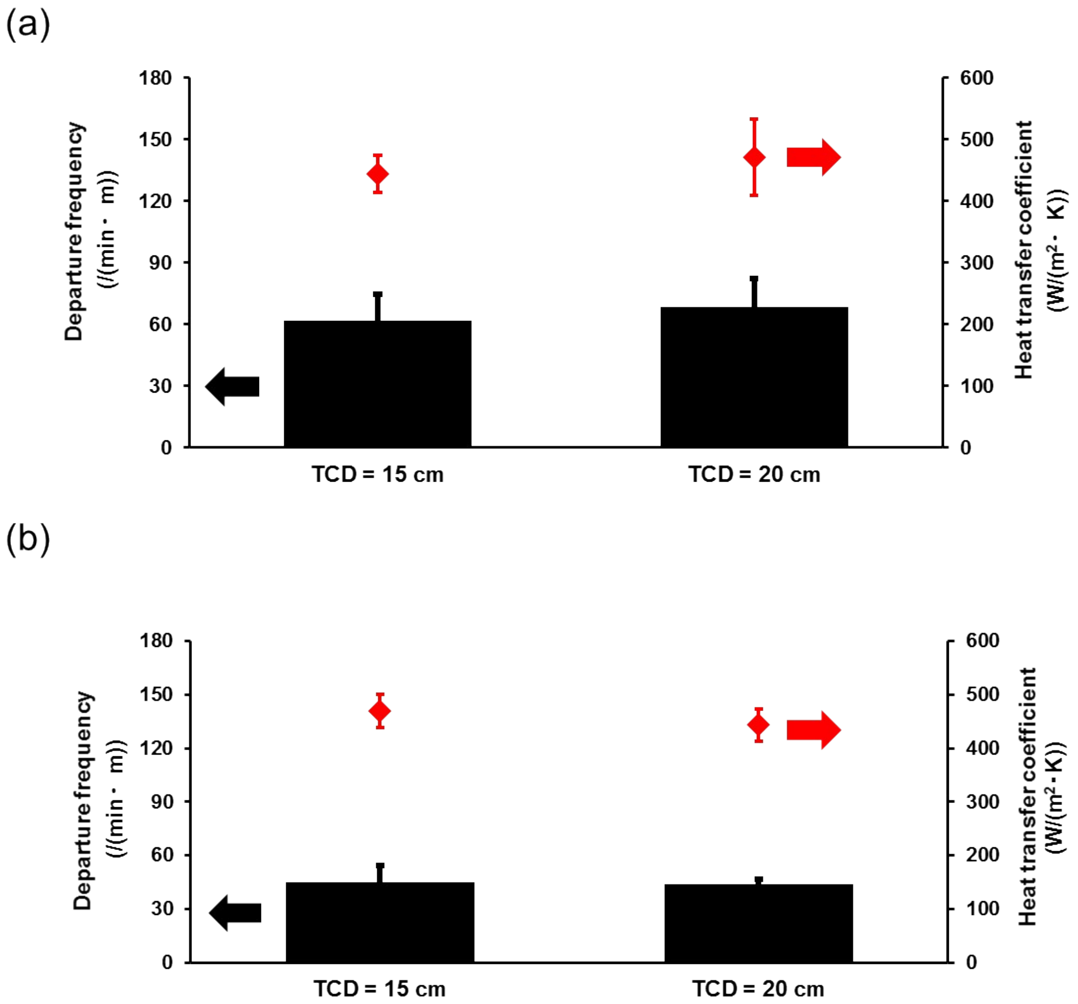

Fig. S12 Heat transfer coefficients (red diamonds) and departure frequencies of condensed water droplets (black bars) of surfaces prepared using 17 wt% PTFE in the case of TCD = 15 cm and 20 cm on (a) Al and (b) Cu tubes.

Movies showing condensation on all coated surfaces are available in ESI movie S1–12. Movies of condensation on Al surfaces coated with PTFE using electrospinning solutions containing 100 wt%, 66 wt%, 33 wt%, 23 wt%, and 17 wt% PTFE (TCD = 20 cm) and 17 wt% PTFE (TCD = 15 cm) are available in ESI movie S1, 2, 3, 4, 5, and 6, respectively. Meanwhile, movies of condensation on Cu surfaces coated with PTFE using electrospinning solutions containing 100 wt%, 66 wt%, 33 wt%, 23 wt%, and 17 wt% PTFE (TCD = 20 cm) and 17 wt% PTFE (TCD = 15 cm) are presented in ESI movie S7, 8, 9, 10, 11, and 12, respectively.