River Branch Inspired Janus Textile with Moisture Wicking and UV Resistant Properties

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Research Article

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Abstract

Discontinuous hydrophobic/hydrophilic Janus fabric resembling river branches is prepared by nano-ZnO pretreatment and screen printing for directional water transport and thermal conductivity properties. A river branch-like structure is constructed dexterously, and the effect is quantitatively adjusted by accurately regulating the gap width of hexagon water-transfer-channel. Fabrics based on these rivers branch-like hexagon structure possess enhanced moisture wicking performance, a desired water transport index of 147.26%, which are over seven times higher than conventional cotton fabrics. Meanwhile, nano-ZnO treatment improves the thermal conductivity of cotton fabric, which accelerates the evaporation of sweat on the surface of cotton fabric. Moreover, nano-ZnO cotton fabric shows an outstanding UV resistant property with 145 UPF value. The novel discontinuous hydrophobic/hydrophilic Janus fabric could provide a new strategy for the development of moisture management textiles.

Introduction

Fabrics with directional water transport property have attracted increasing attention due to their capability of providing a comfortable microclimate to wearers who work in extreme hot or cold environment, such as soldiers, athletes, couriers and industrial workers.(Wang et al. 2016b) Directional water transport property(Zhou et al. 2016) relies on the differential capillary effect,(Parada et al. 2017) which pulls the sweat away from human skin through tiny capillary pores by chemical forces or surface tension.(Shou and Fan 2018) Notably, the unique directional water transport property has been developed in the fields of smart textiles,(Bai et al. 2012; He et al. 2020) water harvesting,(Zhang et al. 2017; Zhu et al. 2020) oil/water separation,(Wang et al. 2016a; Li et al. 2018; Yang et al. 2019) medical and so on.(Wang et al. 2019)

Traditional hydrophilic fabric such as cotton are easily wetted by sweat, resulting in uncomfortable clamminess and colds.(Neves et al. 2017) On the contrary, hydrophobic fabric such as polyester are waterproof, (Wang et al. 2019)but it also prevents sweat from evaporating in inner side.(su et al. 2007) In recent years, there are several commercial textiles which provide different levels of directional water transport property. Specifically, the unique four-groove structure makes the Coolmax polyester fiber developed by DuPont have better capillary effect and water transport property.(Kim 2020) In addition, Aerocool moisture wicking fiber developed by Korea Hyosung Corporation and the Wellkey polyester hollow fiber developed by Teijin also have certain water transport property. However, the water transport in such textiles is unidirectional, which means that the inner side of fabrics will still be wetted and attach to the body during the sweat transport process. To address these limitations, fruitful efforts have been made to improve the sweat transport through fabric, which drive water transport in a single direction by hierarchical structure design or surface chemical modification.(Su et al. 2016; Zhao et al. 2017) Many novel structures have been produced based on bionics, such as dragonfly wings,(Jones et al. 2020) spider silk,(Zheng et al. 2010) and cactus,(Ju et al. 2014) which exhibit directional water transport. In general, tree structures are composed of a proportional gradient in a particular direction. According to this, a biomimetic fabric with three layers of tree-shaped structure was reported, showing great moisture management performance.(Miao et al. 2018) In addition to traditional fabrics, many nanofibrous membranes (Fu et al. 2020)have been applied in directional water transport, (Zhang et al. 2020a)in which water can be transported from inner side to outer side. Another commonly used method is surface chemical modification, which forms energy gradient on the fabric surface to realize directional water transport. One useful strategy is Janus wettability,(Yang et al. 2016; Li et al. 2020; Mohammadi Ghaleni et al. 2020) which means that both side of fabric or membrane have completely different wettability. Janus wettability can be reached by surface modification technology, (Wang et al. 2018b)such as UV irradiation,(Zhu et al. 2020)

plasma treatment,(Chen et al. 2018) and electrospray.(Ji et al. 2020; Liang et al. 2020; Zhang et al. 2020b) Consequently, hierarchical structure design and surface chemical modification consistently cooperate together to improve the differential capillary effect.

Owing to the promising application in moisture management textiles, directional water transport textiles have received increasing attention. Considerable achievements have been received. For example, Wang et al. (Wang et al. 2018c)proposed smart moisture wicking fabric with antigravity directional water transport and quick-dry performance based on biomimetic Murray membranes. Cai et al. (Fan et al. 2020)prepared a 3D transport fabric with advanced water transport property by coating discontinuous hydrophobic pattern on inner side and discontinuous superhydrophilic pattern on outer side. Qin et al.(Mao et al. 2019)fabricated one-dimensional (1D) fiber with controllable water transport performance by combining tree-like structure design and material optimization together. Unfortunately, few researches on synergistic effect of heat dissipation and water evaporation have been reported. Conventional fabrics such as cotton typically have low thermal conductivity.(Längauer et al. 2021) More importantly, the thermal conductivity of such fabrics can be regulated on a small scale by changing the fibrous density or structure. We adopt nano zinc oxide to increase the thermal conductivity of fabric without noticeably changes of fabric moisture and air permeability. High thermal conductivity not only improve heat transfer, but also accelerate sweat evaporation.

Herein, we fabricate a hydrophobic/hydrophilic Janus cotton fabric with asymmetric wettability for directional water transport by nano-ZnO treatment and single-side discontinuous hydrophobic screen-printing method. Significantly, the synergistic effect of the thermal conductivity performance and the differential capillary effects resulted in the outstanding directional water transport property of the obtained fabric. More vividly, the design of hydrophobic pattern which resembling river branch water transfer channel endows the cotton fabric with greatly improved water transport and diffusion capacity. As a result, the obtained cotton fabric was able to spontaneously pull the body-generated sweat away from the skin, thus providing an extremely dry and cool microclimate to the wearer, indicating an attractive prospect for the smart moisture wicking textiles.

Experimental Section

Materials

Nano Zinc oxide (nano-ZnO) and Cetyltrimethoxysilane were available from the Shanghai Macklin Biochemical Technology Co., Ltd. Triton was obtained from Shanghai Taitan Technology Co., Ltd. Titanate coupling agent was purchased from the Nanjing Chuangshi Reagent Co., Ltd. Thickener and adhesive were supplied by the Wuxi Feinuo Co., Ltd. Cotton fabric ($250 \text{ g}\cdot\text{m}^{-2}$) was purchased from a local factory, the densities of cotton fabric is 280×270 (ends/10 cm).

Preparation of Nano-ZnO Dispersion

1.5% titanate coupling agent was dissolved in deionized water, and then 1.5% nano-ZnO particles and 1.5% dispersant Triton were added, and stirred it magnetically for 15 minutes. Finally, ultrasonic dispersion was performed for 1h to obtain a dispersion solution of nano-ZnO, and then tested for particle size.

Preparation of Nano-ZnO Cotton Fabric

The cotton fabric was dipped into the nano-ZnO finishing solution, which was prepared by using titanate coupling agent and dispersant to disperse nano-ZnO solution under ultrasonication. The prepared fabric was immersed in

the nano-ZnO finishing solution with a mass concentration of 20 g/L. Treat it in a constant temperature shaker at 30°C for 25 min, and then proceed to the finishing process of drying (80°C, 3 min) and baking (150°C, 130 s). The dried fabric was used for UV resistance test.

Preparation of Printed Cotton Fabric

Cetyltrimethoxysilane (HDTMS) (2 wt%), thickener (4 wt%), pigment (1 wt%) and deionized water (93 wt%) were mixed under mechanical stirring (2000 rpm). Screen-printing technology was used to construct a discontinuous hydrophobic hexagon pattern with 5mm side length on inner side of the cotton fabric. After drying (80°C, 10 min) and baking (150°C, 5 min), the obtained fabrics were washed thoroughly to remove the thickener, and then dried the sample at 80°C. The printed cotton fabric is called discontinuous hydrophobic/hydrophilic Janus fabric.

Characterization and Measurements

Fourier transform infrared (FT-IR) spectra

The Fourier transform infrared (FT-IR) spectra of the samples were monitored with a NICOLET is10 transform infrared instrument (Thermo Fisher Scientific, Co. Ltd., China) with the wavenumber range from 400 to 4000 cm^{-1} .

XRD spectra

The structures of the cotton fabric and nano-ZnO fabric were characterized by X-ray diffractometer from Japan over the 2θ range of 5 – 60°.

Scanning electron microscopy (SEM)

Scanning electron microscopy (SEM, SU1510, Hitachi) was used to observe the surface topography of cotton fabric, nano-ZnO fabric and discontinuous hydrophobic/hydrophilic Janus fabric.

Energy dispersive spectroscopy (EDS)

The elemental distribution of the nano-ZnO fabric was characterized by energy dispersive spectroscopy (EDS) on an EDAX-DX-4 energy dispersive analyzer.

Contact angle (CA)

The contact angle (CA) of the cotton fabric and nano-ZnO fabric measurements were carried out by a Drop Shape Analyzer 100 (Krüss, German) using liquid droplets of 5 μL in volume. The size of nano-ZnO dispersion was tested with a nano particle size analyzer, and each sample was tested 3 times, and the test results were averaged.

UV protection factor test

The transmittance and UV protection factor (UPF) of nano-ZnO fabric was determined with a UV protection tester (Darong, YGB 912E, China).

Temperature change test

The temperature change of nano-ZnO fabric was recorded using a thermographic system (varioCAM hr head680, Infratec ESM GmbH). The photographs and videos were taken by a digital camera.

Moisture management test

The water transport property of discontinuous hydrophobic/hydrophilic Janus fabric was measured with a model M290 liquid moisture management tester from Hong Kong according to the GB/T 21655.2–2009 standard.

Moisture permeability test

According to GB/T 12704.1–2009 Determination of Fabric Moisture Permeability, moisture permeability of samples was measured to obtain the mass of water vapor passing vertically through a unit area sample within a specified time under a unit water vapor pressure difference.

Air breathability test

The air breathability of fabrics was tested before and after single-sided discontinuous hydrophobic screen-printing. Each piece of fabric was measured 10 times on different positions, the average value was recorded.

Results And Discussion

Schematic diagram

In order to prepare uniform and stable nano-ZnO dispersion, the dispersant triton and titanate coupling agent were mixed with the nano-ZnO solution, and then the mixture was ultrasonically emulsified for 1h. Cotton fabric was finished with nano-ZnO dispersion by impregnating to improve the thermal conductivity of fabric. As revealed by particle size analysis, the size of nano-ZnO dispersion varied from 300 to 800nm, and the average nano particle size was 458 nm (Fig. 1a). The PDI (dispersion index) was a uniform and stable dispersion of 0.159. As shown in Fig. 1b, SEM images of nano-ZnO, which shows the uniformity of the nano-ZnO particles.

Then, single-sided discontinuous hydrophobic finishing was performed on the cotton fabric by screen printing. The resulted fabrics with a resembling river branches hexagon water-transfer-channel which greatly improved the water transport performance of the fabric (Fig. 1d). Figure 1c illustrates the preparation process of discontinuous hydrophobic/hydrophilic Janus fabric. The improvement of the thermal conductivity of cotton fabric will accelerate the evaporation of sweat on the surface of cotton fabric, which is beneficial to the improvement of the thermal and wet comfort of the fabric. As the preparing method is easy to practice, it contributes a novel approach to the fabrication of directional water transport textiles.

Characterization of Nano-ZnO Cotton Fabric

A commercial cotton fabric was used as the substrate due to its suitable thickness and denseness. According to the SEM image (Fig. 2a, b), the surface of cotton fabric is smooth (Fig. 2a). As shown in Fig. 2b, the cotton fiber is covered by a layer of nano-ZnO particles, which increases the roughness of the cotton fiber, indicating the success in loading the nano-ZnO particles onto the cotton fabric. The chemical compositions of the nano-ZnO coated cotton fabric surface were examined through the EDS analysis. As shown in Fig. 2(c-e), elemental mappings of the nano-ZnO cotton fabric show that the distribution of C and Zn is uniform across the whole nano-ZnO cotton fabric surface, demonstrating that nano-ZnO are well dispersed on the cotton fabric.

As displayed in Fig. 2f, FT-IR spectrogram of cotton fabric and nano-ZnO cotton fabric. The peak at 3337 cm^{-1} was derived from -OH stretching vibration, and 1168 cm^{-1} , 1104 cm^{-1} , 1058 cm^{-1} , and 1023 cm^{-1} appeared in the spectrum of cotton fabric were derived from -C-O-C- stretching vibration, which constitute the characteristic absorption peaks of cotton fabric. After using titanate coupling agent to finish cotton fabric with nano-ZnO, two new characteristic peaks appeared. (Liu et al. 2012) The bands at 1718 cm^{-1} were associated with stretching

vibration of phospholipid bond formed by the reaction of the coupling agent and the -OH on the cotton fabric,(Salla et al. 2012) respectively. In addition, the absorption peak around 816 cm^{-1} is corresponding to the bending vibration of the C-H in the para-substituted benzene ring of the coupling agent, indicating that nano-ZnO was loaded in the cotton fabric. The crystalline structures of nano-ZnO fabric were identified by X-ray diffraction (XRD). The XRD patterns of nano-ZnO fabric are described in Fig. 2g. Cotton fabric has corresponding cellulose I structure at $2\theta = 14.89^\circ$, 16.39° , and 22.62° characteristic diffraction peaks. After finishing with nano-ZnO, not only the characteristic diffraction peaks of cellulose I-type structure appeared on the cotton fabric at $2\theta = 14.89^\circ$, 16.39° , 22.62° , but also nano-ZnO (100), (101), (110) crystal planes appeared at $2\theta = 31.79^\circ$, 36.37° , 56.67° , (Wang et al. 2017, 2018a) which proved that nano-ZnO was finished on the cotton fabric.

Wettability of Nano-ZnO Cotton Fabric and Printed Cotton Fabric

The moisture wicking performance of the fabrics were enhanced by adjusting the surface wettability. Through the video obtained from the experiment, we observed and compared the water droplet wetting of cotton fabric and nano-ZnO cotton fabric from 0 s to 0.15 s. The water contact angle of cotton fabric and nano-ZnO cotton fabric are measured, and the results are shown in Fig. 3(a-c). It is shown that cotton fabric has strong hydrophilicity. In Fig. 3c, it can be seen that the cotton fabric after nano-ZnO pretreatment also has strong hydrophilicity, indicating that nano-ZnO pretreatment will not affect its hydrophilicity, and will not affect the next step of discontinuous hydrophobic printing.

Through single-sided discontinuous hydrophobic screen-printing method, the inner side (the side contacting the skin) is partially hydrophobic and the outer side (the side that does not touch the skin) is hydrophilic. In the same way, the wettability of printed cotton fabric was observed and compared with the video obtained from the experiment. Water contact angle of discontinuous hydrophobic area and discontinuous hydrophilic area are measured, and the results are shown in Fig. 3(d-f). Cotton fabric after hydrophobic treatment possess extremely strong hydrophobicity while other parts without hydrophobically finishing have strong hydrophilicity. As shown in Fig. 3e, water contact angle of those hydrophilic parts decreases dramatically to 0° in the first 0.2 s. On the contrary, cotton fabric after hydrophobic treatment remains 130° in the first 0.2 s and decrease slightly in 1 minute or even longer. Single-sided discontinuous hydrophobic screen-printing makes the inner and outer layers of the cotton fabric own different moisture absorption, which provide a differential capillary effect and realize the unidirectional moisture transport function of the cotton fabric. The sweat produced by the pores of the human body transfers from the inner surface of the cotton fabric to the outer surface and evaporates rapidly. Thus, discontinuous hydrophobic screen-printing fabric possess the ability of one-way water transport.

Moisture Wicking Property of Printed Cotton Fabric

Regarding the fact that different hydrophilic-hydrophobic proportion of the cotton fabric surface would affect the transfer speed of sweat and the one-way water transport ability, the screen-printing patterns with different hydrophilic and hydrophobic ratios are designed. More vividly, once the sweat excreted from human skin touches the inner side, it transfers along the hydrophilic area preferentially which represents the gap width of hexagon water-transfer-channel, just like a river branch. In the discussion of hydrophobic screen-printing section, C stands for cotton fabric, C-Z stands for cotton fabric finished only with nano-ZnO, and C-X% stands for cotton fabrics with single-sided discontinuous hydrophobic treatment, C-Z-25%, C-Z-50%, and C-Z-75% respectively represent the cotton fabric treated with single-sided discontinuous hydrophobic treatment after nano-ZnO finishing (X% is the percentage of hydrophilic area to hydrophobic area). C-Z-H represents the cotton fabric treated with single-sided continuous hydrophobic treatment after nano-ZnO finishing.

Moisture wicking functionality of discontinuous hydrophobic/hydrophilic Janus fabric was tested by M290 liquid moisture management tester, and the results are shown in Table 1. Wetting time is the time when the fabric starts to be wetted. The higher the hydrophilicity of the cotton fabric, the faster it will be wetted. Since cotton fabrics inherently have good hydrophilicity, the wetting time of the fabrics before and after hydrophobic finishing is relatively fast. The wetting time of C-Z, C-Z-75%, C-Z-50%, C-Z-25% and C-Z-H, indicates that the fabric has the ability to quickly absorb moisture. The water absorption rate also reflects the ability of the cotton fabric to absorb water. For C-Z-75%, C-Z-50%, C-Z-25% and C-Z-H, the top surface shows lower water absorption rate than the bottom surface, this is because C-Z-75%, C-Z-50%, C-Z-25%, C-Z-H have undergone hydrophobic treatment, and the treated hydrophobic area make the water absorption rate of the fabric decline. According to the water absorption rate, single-sided discontinuous hydrophobic screen-printing fabric has a better ability to absorb moisture. The max wetted radius reflects the diffusion capacity of moisture in the cotton fabric. In comparison with cotton fabric, the max wetted radius of C-Z-75%, C-Z-50%, C-Z-25%, C-Z-H have been improved. The spreading speed of liquid water is the diffusion rate of fabric when wetting to the maximum wetted radius, which reflects the rapid drying ability of the cotton fabric. The different spreading speed of top surface and bottom surface indicate that the cotton fabric can quickly evaporate water, which is beneficial to moisture transfer and evaporation in the air. Comparing results of C-Z-75%, C-Z-50%, C-Z-25%, all the samples have the directional water transport property. Moreover, it was worth mentioning that C-Z-50% has the largest difference in spreading speed between the top surface and bottom surface which implying that sample C-Z-50% has a preferable directional water transport property. The one-way transport capability is the ratio of the water content difference between the top surface and bottom surface to the total test time, which reflects the directional water transport property directly. Cotton fabric does not possess a directional water transport property with the one-way transmission index of 19.58. After single-side continuous hydrophobic finishing, the one-way transmission index increases to 45.97. However, C-Z-75%, C-Z-50%, C-Z-25% reach 94.35, 147.26, 63.57 respectively. As for C-Z-50%, the one-way transmission index was highest implying that C-Z-50% possess an enhanced directional water transport property.

Table 1
Moisture management test of cotton fabric with different hydrophilic and hydrophobic ratios

Samples	Wetting times(s)		Absorption rate(%/s)		Max wetted radius(mm)		Spreading Speed(mm/s)		One way transport capability
	Top Surface	Bottom Surface	Top Surface	Bottom Surface	Top Surface	Bottom Surface	Top Surface	Bottom Surface	
C-Z	2.044	0.403	27.22	22.79	15	15	3.48	11.62	19.58
C-Z-75%	0.325	0.325	23.98	25.34	10	10	2.01	12.93	94.35
C-Z-50%	6.575	0.325	16.41	22.19	10	10	1.31	12.78	147.26
C-Z-25%	3.528	0.325	23.85	26.54	10	15	1.96	13.26	63.57
C-Z-H	2.747	0.325	22.72	25.46	10	10	2.26	12.87	45.97

Suitable screen-printing patterns make the fabric's directional water transport property better. When the hydrophobic area is less occupied, the cotton fabric does not have the directional water transport property. While the hydrophobic area is too large, its directional water transport property will be affected. As a result, it cannot transport the moisture from the inner surface of the cotton fabric to the outer surface quickly. In conclusion, it was obvious that hydrophobic pattern played strong part in improving the performance of directional water transport.

The curves in Fig. 4 were the moisture content curves of the upper (inner) surface and the lower (outer) surface of different samples. The blue curve represents bottom (Outer side) surface while the green curve refers to the top (Inner side) surface. For the raw cotton fabric, the water content curves on both sides almost overlap, which means that the blank cotton fabric does not possess the performance of directional water transmission. It can be seen from Fig. 4(b-e) that the water content of the outer side has always been much higher than that of the inner side. It is supposed that water can transport more quickly from hydrophobic side to hydrophilic side. As a result, water will spread in multiple directions to increase the diffusion area. The upper surface moisture content of C-Z-50% increased remarkably to 517% in the first 20 s, and then gradually decreased to 450%. But the maximum moisture content of the bottom surface was 330%, which was lower than that of the upper surface. The great difference of moisture content between upper surface and bottom surface implied that C-Z-50% possessed an improved directional water transport property, which is consistent with the data in the Table 1.

The moisture permeability results of cotton fabrics with different hydrophilic/hydrophobic ratios are shown in Table 2. The result of cotton fabric is 326.61 g/(m²·h). With the hydrophobic screen-printing area increases, the moisture permeability of the printed cotton fabric gradually decreases. Due to the large number of hydroxyl groups on the cellulose molecule, the cotton fabric has a higher moisture regain rate and good moisture absorption performance. After finishing with hydrophobic agent, some of the hydroxyl groups on the cellulose molecules are blocked, resulting in a drop of moisture regain. Compared to the best directional water transport property of C-Z-50%, the slight change in moisture permeability can be ignored.

Table 2
Moisture permeability test of cotton fabric with different hydrophilic and hydrophobic ratios

Samples	Weight before moisture absorption M ₁ /g	Weight after moisture absorption M ₂ /g	Weight difference(g)	Moisture permeability g/(m ² .h)
C-Z	154.641	155.564	0.923	326.61
C-Z-75%	154.862	155.769	0.907	320.95
C-Z-50%	155.150	156.045	0.895	316.70
C-Z-25%	155.481	156.369	0.888	314.23
C-Z-H	153.789	154.606	0.817	289.10

With respect to the air permeability, cotton fabric reaches 206.70 mm/s. As the ratio of hydrophilic and hydrophobic areas decrease, the hydrophilic area decreases, and the air permeability of printed cotton fabric reduces correspondingly (Fig. 5b). This is due to the hydrophobic finishing of the cotton fabric affect its air permeability. Compared to the best directional water transport property of C-Z-50%, the slight change in air permeability can be ignored.

Thermal Property of Printed Cotton Fabric

The thermal conductivity of printed cotton fabric was tested by heating pad and FLIR infrared camera. The heating pad was set at 39°C to ensure that the fabric on the heating pad was maintained at about 37°C. The self-made microenvironment was used to simulate the microclimate of human skin. The temperature of cotton fabric and printed cotton fabric were measured with a FLIR infrared camera every 10 s until the temperature of the sample was maintained in a stable temperature range.

As shown in Fig. 6(b, c), printed cotton fabric heats up faster than the cotton fabric because the nano-ZnO possess certain thermal conductivity. Simulating the human skin environment, printed cotton fabric owns a higher heat absorption rate. As shown in Fig. 6a, the temperature change of two curves after 40 s is not obvious, because the two fabric has reached a balance with the surrounding thermal environment. However, printed cotton fabric obtains a higher surface temperature after the balance, which also proves the improvement of the thermal conductivity of the cotton fabric after nano-ZnO finishing. On the other hand, it means that compared with the cotton fabric, printed cotton fabric can take away more heat from the skin through thermal conduction in the same time.

UV Protective Property of Nano-ZnO Cotton Fabric

Nano-ZnO has good ultraviolet resistance, thus nano-ZnO cotton fabric possess certain UV protective property. Through UV resistance test of nano-ZnO fabric, the UPF (ultraviolet protection factor value), UVA (sunlight ultraviolet radiation with wavelength of 315 nm-400 nm) and UVB (sunlight ultraviolet radiation with wavelength of 280 nm-315 nm) transmittance are analyzed (Fig. 7). The results show that the UV transmittance of cotton fabric is higher, which indicates that the cotton fabric has no UV protective property. As the content of nano-ZnO in dispersion increases gradually, the UV transmittance values of the nano-ZnO cotton fabric decreases correspondingly. When the content of nano-ZnO in dispersion reaches to 20 g/L, the UV protection factor (UPF) values of cotton fabric maintain a certain range of balance, which means the adsorption of cotton fabric and nano-ZnO particles is saturated. In order to avoid unnecessary consumption, the optimal mass concentration of nano-ZnO is 20 g/L. Nano-ZnO has the function of scattering and absorbing ultraviolet rays. When irradiated by ultraviolet rays in sunlight, electrons in the valence band of ZnO are excited, and hole-electron pairing effects will occur. Thus, it has the function of absorbing ultraviolet rays. Compared to the wavelength of ultraviolet light, the particle size of nano-ZnO is very small, so it can scatter ultraviolet light in all directions. This scattering law of ultraviolet light conforms to the Rayleigh light scattering law. Nano-ZnO not only has good thermal conductivity, but also has certain UV protective property, which makes nano-ZnO play an important role in the development of functional textiles.

Conclusions

In summary, discontinuous hydrophobic/hydrophilic Janus fabric with asymmetric wettability was prepared by nano-ZnO pretreatment and single-side discontinuous hydrophobic screen printing. The design of hydrophobic pattern resembling river branches hexagon water-transfer-channel which greatly improved the water transport and diffusion performance of the fabric. Under the combined action of the hydrophobic pattern and the hydrophilic region, the discontinuous hydrophobic/hydrophilic Janus fabric possesses a higher directional water transport property of 147.26%, and an excellent UPF of 145 for UV protection. Moreover, it is worth mentioning that printed cotton fabric possesses a desired thermal conductivity, which is beneficial to the improvement of directional water transport property. This unique concept may have inspired the design of moisture-absorbing, breathable and sports textiles, making it promising for the application of smart textiles.

Declarations

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Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors. In this experiment, we did not collect any samples of human and animals.

Informed consent Informed consent was obtained from all individual participants included in the study.

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Figures

Figure 1

a Analysis of particle size of nano-ZnO dispersion. b SEM images of nano-ZnO. c Schematic diagram. d The nature phenomenon of river branch (left) and schematic demonstration of the moisture wicking process (right).

Figure 2

a SEM images of cotton fabric. b SEM images of nano-ZnO cotton fabric. c-e EDS of cotton fabric and nano-ZnO cotton fabric. f FTIR of cotton fabric and nano-ZnO cotton fabric. g XRD of cotton fabric and nano-ZnO cotton fabric.

Figure 3

a Line chart of contact angle change. b Analysis of contact angle of cotton fabric. c Analysis of contact angle of nano-ZnO cotton fabric. d Line chart of contact angle change. e Analysis of contact angle of discontinuous hydrophilic area. f Analysis of contact angle of discontinuous hydrophobic area.

Figure 4

Moisture management test. a C-Z. b C-Z-75%. c C-Z-50%. d C-Z-25%. e C-Z-H.

Figure 5

a Moisture permeability of printed cotton fabric. b Air permeability of printed cotton fabric.

Figure 6

a Line chart of temperature change of cotton fabric and nano-ZnO cotton fabric in 60s. b IR schematic diagram of temperature change of cotton fabric. c IR schematic diagram of temperature change of nano-ZnO cotton fabric.

Figure 7

UV protective property of nano-ZnO cotton fabric with different nano-ZnO mass concentration.

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