Development of three-dimensional effects and stretch for Polymeric Optical Fiber (POF) textiles with double weave structure containing spandex

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Abstract

This paper introduces a weaving method to develop three-dimensional and stretchable Polymeric Optical Fiber (POF) fabrics with double weave. It was discovered from the literature that the appearance and property of existing POF textiles are still quite limited. So far, stretch performance hasn't been realized for POF textiles. Great varieties of POF fabrics are required to meet users' increasing demands. In this study, double weave structure was adapted to create three-dimensional and stretchable POF textiles using Jacquard weaving machine. The goal of this paper is to determine the design parameters of creating three-dimensional and stretchable POF textiles. The new properties for POF textiles were realized by combing double weave and elastic yarns with suitable motifs. The surface dimension and stretch were compared for all the POF samples based on observation and measurement. From the experimental results, it was shown that the POF fabrics woven with the unstitched double weave at substantial transverse areas exhibited the most effective three-dimensional effect and stretch. The POF samples created in this study showcased the characteristics of dimensional surface, great volume, high stretch, as well as unique luminous effects. The study confirmed that by applying double weave in combination with elastic yarns and suitable motifs, the three-dimensional and stretchable POF textiles can be fabricated.

Keywords: double weave, spandex, POF textiles, three-dimensional effect, stretch behavior

1. Introduction

Polymeric Optical Fibers (POFs) are integrated into textile structures with the purpose to achieve illuminating fabrics. POFs are used as the media to transmit light across the fabric to create illumination effects. The light can be delivered by connecting the fabric to an external light source. POF textiles have drawn considerable attention from the researchers and industry for their advantages of flexibility, lightweight and low energy cost. These materials show great potential in applications including fashion, interiors, and healthcare devices (Jing, 2015; Tan, 2013; Zeng, 2015).

The yarn-like property of POFs allows for its direct integration in the textile manufacturing process. There are different methods to fabricate POF textiles such as weaving, knitting and embroidery (Chen, Tan, Henry, & Tao, 2019; Mordon et al., 2015; SHINDO, 2015). Among these methods, the weaving method creates fewer damages to the optical fibers and provides more even light distribution across the fabric. Therefore, weaving is chosen in this study as the fabrication method. POFs can be incorporated in the fabrics through various woven structures, providing unlimited design possibilities to obtain unique appearances and tactility.

POF textiles have been widely used by fashion designers and companies to develop bespoke luminous fashion pieces and interior products. Illuminative dress Neo-Neon was developed by Jeanne Tan in 2013 as shown in Figure 1 (Tan, 2013). Fashion designer Zac Posen also designed an illuminative gown with woven photonic textiles for the 2016 Met Gala red carpet (Figure 2). The dress was made of organza fabrics woven with fiber optics and powered by 30 mini battery packs (Clinton, 2016). The Italian lighting fabric brand DreamLux® (2018) has developed many indoor and outdoor products made of lighting fabrics such as pillows, curtains and tablecloths. These products can provide users with unique visual effects and personalized user experience. Researchers have improved the functions of POF textiles by integrating electronics and interactive technology (Tan, 2015; Wang, Yang, Huang, & Jin, 2012). The materials became interactive, communicative and dynamic. Artist Malin Bobeck Tadaa (2016) also created large interactive installations from photonic textiles. Researchers Gorgutsa, Berzowksa, and Skorobogatiy (2013) adopted double weave to create photonic textiles with varied light effects by controlling the ambient light and guided light. These prototypes and artworks serve as good examples for balancing aesthetics and functions. However, it is revealed from these examples that the appearance and properties of the existing POF textiles are still rather limited. The three-dimensional effects of POF fabrics have been successfully created previously by Jeanne Tan (2014) and Malin Bobeck Tadaa (2016). The design patterns were mostly in organic forms associated with the natural landscape and curved objects. The geometric pattern is missing in the design exploration which limits the POF fabric appearance. Moreover, stretch performance hasn't been realized for the previous POF fabrics. The limited appearance and properties of POF fabrics can restrain their potential uses and illuminating effects. It is crucial to expand the diversities of POF fabrics concerning their properties and appearance.

Figure 1. Illuminative dress Neo-Neon designed by Jeanne Tan (2013)

Figure 2. Illuminative gown for 2016 Met Gala red carpet designed by Zac Posen (2016)

Weaving plays an important role in changing the properties of the POF textiles. The woven fabrics normally appears stable and lack of stretch. This study aims to develop a new type of POF textiles which are three-dimensional and stretchable, using double weave structure and spandex to extend the fabrics' appearance and property. The design parameters of creating three-dimensional and stretchable POF textiles will be determined in this study. Double weave has more variations of warp placement which will create more possibilities to separate the layers of the fabrics and create varieties in forms. Moreover, incorporating elastic materials such as spandex can provide the woven fabric with stretch potential (Mathur, ElNashar, Hauser, & Seyam, 2008). This research will propose a new method of creating a unique form and property of POF fabrics by combining double weave structure with suitable motifs and elastic materials. POF textiles with a three-dimensional effect and stretch can be obtained. The new properties can further broaden the potential of POF textiles for new applications.

2.Materials and methods

2.1 Materials

In this study, the POF fabric samples were produced by directly integrating POFs in the weave structure via Jacquard weaving. Jacquard weaving is chosen in this study for its capability of producing more intricated designs. Jacquard loom used in the study is STAUBLI Jacquard Head JC6, Dornier Weaving Loom PTV 8/J with 8192 hooks. The yarn parameters were listed in Table 1. The warp yarns were white polyester, with the yarn weight of 100 Denier. The weft contained two systems which were POFs and spandex. POFs were implemented as the first weft system and 0.25mm POFs were used in this study for the better flexibility. Spandex yarns were implemented as the second weft yarns. Spandex with the elastic property was used to provide the fabric stretch. 32 Spandex was chosen to be compatible with the diameter of POFs. The warp density was 47ends/cm and the weft density was 15picks/cm. The weft ratio of POFs and spandex was 1 POF: 1 spandex.

Table 1. Warp and weft parameters for the POF samples

Warp		Weft	
Warp yarns	100D polyester	Weft yarns	Weft 1: 0.25mm POFs Weft 2: 32 spandex Weft ratio: 1POF to 1spandex
Warp density	47 ends/cm	Weft density	15 picks/cm

2.2 Weaving POF textiles with double weave structure

The double weave structure is adapted in this study to provide more creative possibilities. Double weave structure is a type of complex weave structure that contains two independent groups of warp and weft systems interlacing with each other. The separate systems of warp and weft can construct two independent layers within the fabrics. Double weave consists of two types of structures which are unstitched double weave and stitched double weave. Two layers can stay separate without the stitches which will be called unstitched double weave. Stitched double weave refers to the structure that joins two layers together to form one layer by interlacing stitches. The combination of unstitched double weave and stitched double weave help to create pocket forms, as well as possibilities to separate yarns with different properties to be woven respectively into two independent layers. When one layer is woven with a non-stretch weft while the other layer is woven with a stretch weft, the highly contrasting tension between two layers is created. The stretch layer retracts and forces the non-stretch layer to protrude and form a blister (Figure 3). In this study, the stiffness of POFs is higher than conventional yarns which will make the blister even more effective. The design variations of double weave are more complex, which include different placement of the unstitched layers and the stitched layers, different weaves for face and back layers. This leads to the great potential of creating new properties for POF textiles which cannot be achieved by the conventional single-layer weave structure. Because of the increased design variations, the design and production process for double weave POF textiles also became more complicated.

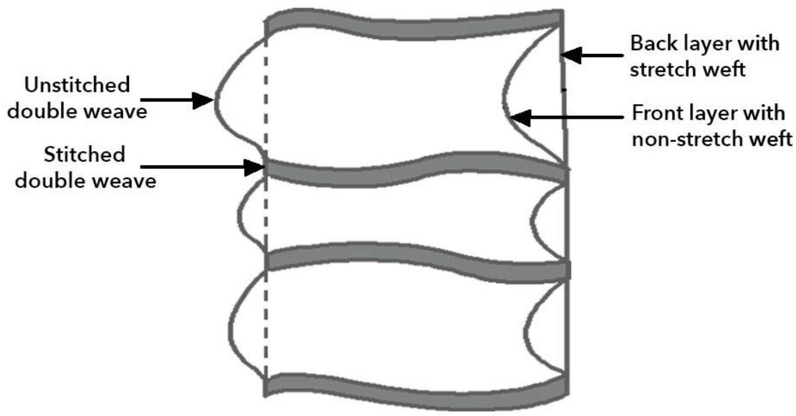


Figure 3. The blister effect created by combining stretch weft and non-stretch weft with double weave

2.3 The three-dimensional effect and stretch property of POF textiles

The three-dimensional effects of POF textiles were observed based on its appearances such as forms and volumes. The stretch behavior of POF textiles was assessed by measuring the fabric contraction rate. Fabric contraction can be defined as the decrease in fabric length or width after it was cut off the loom compared to its on-loom fabric dimension (Kennamer, Mayne, & Berkley, 1956). When the fabric is weaving on the loom, the tension on the warp beam prevents the elastic yarns from crimping. Once the fabric is removed from the loom, the elastic yarns will crimp and lead to fabric contraction. The fabric contraction rate was calculated based on below Formula (1) (Almetwally & Mourad, 2013).

$$\text{Fabric stretch rate (\%)} = \frac{L_{on\text{-}loom} - L_{off\text{-}loom}}{L_{on\text{-}loom}} \times 100 \qquad (1)$$

Where $L_{on\text{-}loom}$ refers to fabric length when the fabric stays on the loom; $L_{off\text{-}loom}$ refers to fabric length after the fabric is taken off the loom

2.4 Experiments

Experiments were carried out on the Jacquard loom. Eight samples were designed and developed with the double weave structure based on varied motifs including both geometric and wavy patterns. Figure 4 shows the visual inspirations. As shown in the inspirations, the dimensional shapes were created with materials such as paper. The stiffness of the paper provided the stability to form the dimensions. Each pattern followed a certain structural configuration including the placement of the creases. For example, the origami shapes were constructed by the folding structures. Similar to paper materials, POFs are relatively stiff compared to the conventional textile materials. There is potential in POF textiles for creating three-dimensional effects when certain structural configurations are applied to the patterns.

Weave and motif designs for the experimental samples were illustrated in the below Table 2. The motifs were re-entrant hexagons(a), rotating triangles(b), divided rectangular(c), zig-zag(d), interlaced waves(e), wide waves(f), medium waves(g) and narrow stripes(h). The weave structure combined both unstitched double weave and stitched double weave. Both face and back layer were woven as plain weave. The weft system of POFs was woven on the face layer while the weft system of spandex was woven on the back layer. The proportion of the face warp and face filling to back warp and back weft was 1 end face to 1 end back. The weave structure diagrams are shown in Figure 5. For re-entrant hexagon(a), wide waves(f), medium waves(g) and narrow stripes(h), the substantial surface areas were designed with unstitched double weave structure while the thin outlines were designed with stitched double weave structure. For the rotating triangles(b), zig-zag(d) and interlaced waves(e) patterns, the unstitched double weave was placed at the white areas and the stitched double weave was placed at the color areas. For the weave design with divided rectangular motif(c), the green and blue blocks were designed as unstitched double weave with both POFs and spandex. Pink vertical lines that divided two-color blocks were designed as stitched double weave to emphasize the blister effects at the pocket areas. The yellow rectangular was woven without spandex.

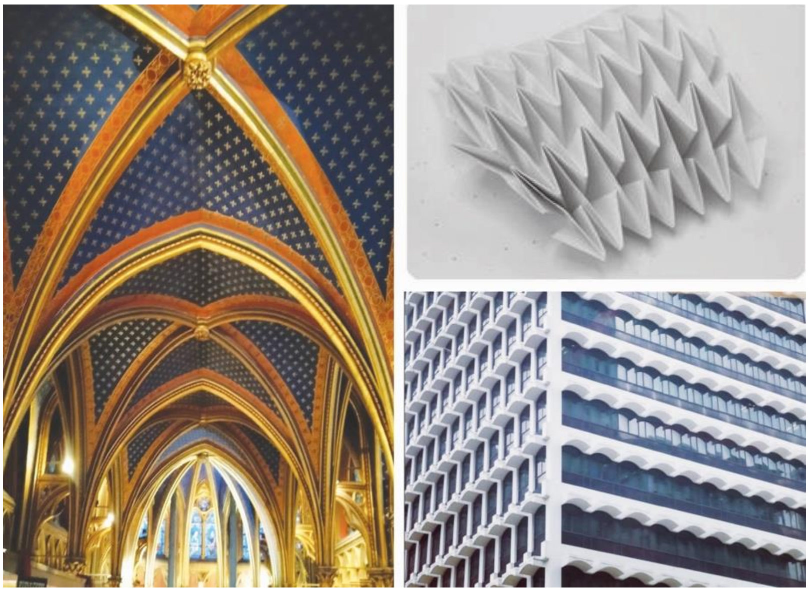
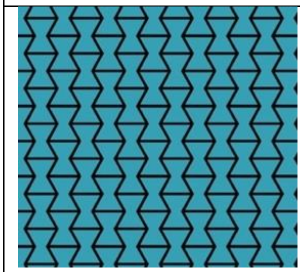
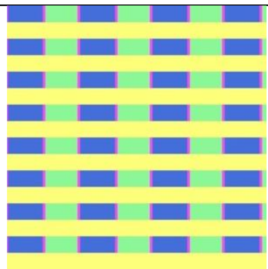
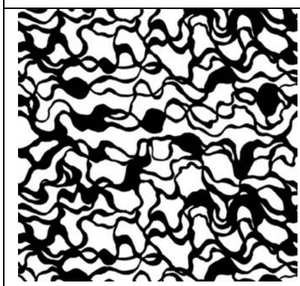
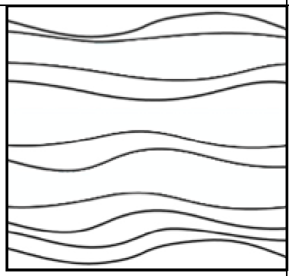
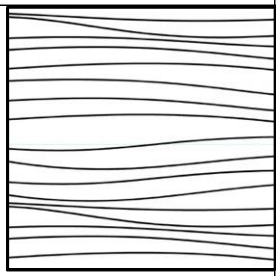
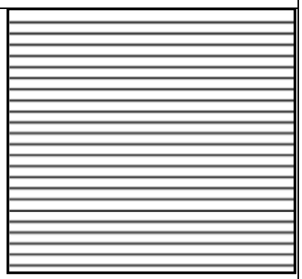
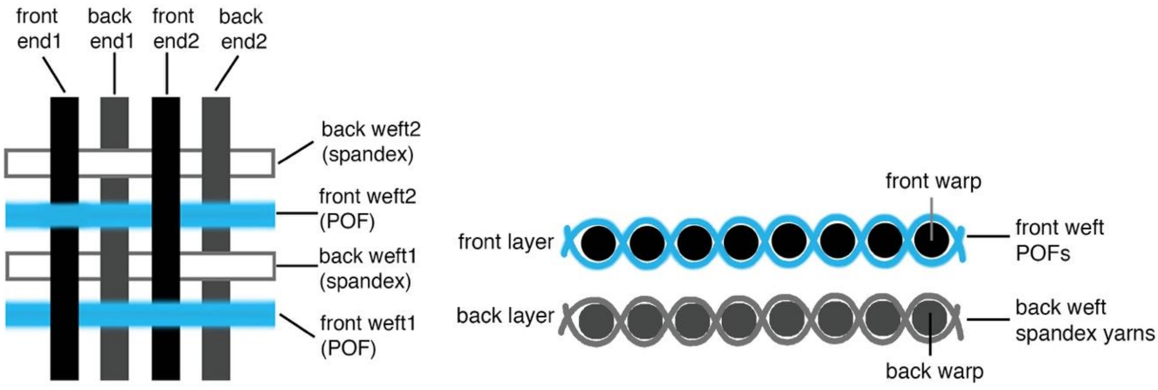


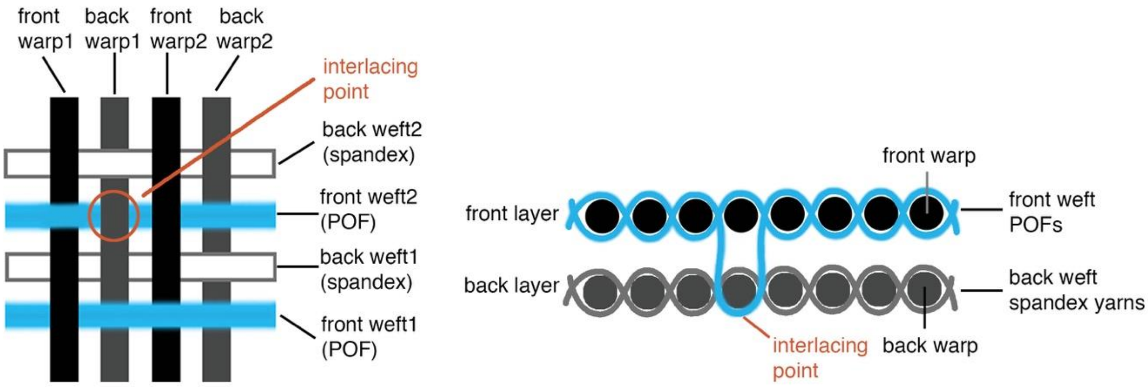
Figure 4. Design inspirations with three-dimensional forms

Table 2. Weave and motif designs for eight POF samples

(a) Re-entrant hexagons	(b) Rotating triangles	(c) Divided rectangular	(d) Zig-zag
			
unstitched double weave stitched double weave	unstitched double weave stitched double weave	unstitched double weave stitched double weave single weave	unstitched double weave stitched double weave
(e) Interlaced waves	(f) Wide waves	(g) Medium waves	(h) Narrow stripes
			
unstitched double weave stitched double weave	unstitched double weave stitched double weave	unstitched double weave stitched double weave	unstitched double weave stitched double weave



(a) unstitched double weave structure



(b) stitched double weave structure

Figure 5. Top view and cross-sectional view of both unstitched double weave structure (a) and stitched double weave structure (b)

3. Results and discussion

The three-dimensional effects and stretch for POF samples were successfully developed and obtained in the experiment using double weave structures. These two new properties were examined based on observation and measurement. Table 3 showed the produced POF samples with both non-illuminated and illuminated views.

3.1 Three-dimensional effect of POF fabrics

Based on the observation, all the POF samples exhibited some degree of three-dimensional effects. Medium waves(g), narrow stripes(h) and wide waves(f) showed the most significant three-dimensional effects. However, the three-dimensional effects were not as significant for the samples developed from re-entrant hexagon(a), rotating triangles(b), divided rectangular(c), and zig-zag(d) and interlaced waves(e) motifs. The illuminating effect of POF samples was also observed. It can be shown from the images that the illumination also became three-dimensional (Figure 6). The injected light was traveling in curved paths when compared to POF fabrics with a planar surface.

Table 3. The woven samples with non-illuminated and illuminated views

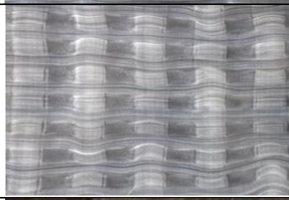
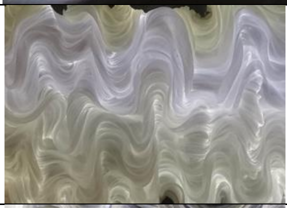
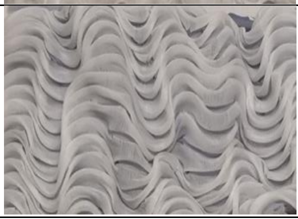
Sample No.	Non-illuminated POF samples	Illuminated POF samples
(a) Re-entrant hexagons		
(b) Rotating triangles		
(c) Divided rectangular		
(d) Zig-zag		
(e) Interlaced waves		
(f) Wide waves		
(g) Medium waves		
(h) Narrow stripes		

Figure 6. The three-dimensional illuminance of POF sample(g) when attaching to multicolor LEDs

3.2 Stretch behavior of POF fabrics

To examine their stretch behavior, the contraction rate was measured for the POF samples. Figure 7 demonstrated the stretched state and relaxed state of the POF sample. The measurement results were listed in Table 4. Based on the results, it was concluded that sample (a), (b), (c), (d), (e) showed some stretch and sample (f), (g), (h) demonstrated the highest degree of stretch with the contraction rate over 40%.

Figure 7. Stretched state (left) and relaxed state(right) of POF sample(h)

Table 4. The contraction rate of eight POF samples

Sample No.	Motifs	Fabric on-loom length (cm)	Fabric off-loom length (cm)	Contraction rate
(a)	Re-entrant hexagon	20	18.5	7.5%
(b)	Rotating triangles	20	18.5	7.5%
(c)	Divided rectangular	20	17	15%
(d)	Zigzag	20	16	20%
(e)	Interlaced waves	20	17	15%
(f)	Wide waves	31	17	45.2%
(g)	Medium waves	63	28	55.6%
(h)	Narrow stripes	42	20	52.4%

3.3. Discussion

From the observation and measurement, it can be found that as the stretch level of the POF fabrics increased, the three-dimensional effects also became more significant. Two properties were associated with each other and can be discussed as one unit. It was shown from the results that the incorporation of double weave and elastic yarns was crucial for creating POF fabrics with three-dimensional effects and stretch. Specific structural configurations were applied to the patterns. The unstitched double weave and stitched double weave were combined and need to be placed at the alternative positions in order to form the pocket areas. The main reason for achieving the surface dimension at the unstitched double weave areas lay in the significant difference in elasticity and stiffness between the POFs and spandex. Spandex yarns are highly elastic, however the POFs are non-stretchable and stiffer. POFs and spandex yarns were woven independently in two separate layers at the unstitched double weave areas. This allowed the spandex yarns to retract at the back layer which pushed the non-stretchable POFs to form the blisters at the front layer.

Motif design is another critical design element that influences the level of three-dimensional effect and stretch of the POF fabrics. Motif designs were varied for the eight samples in the experiment. Wide waves(f), medium waves(g) and narrow stripes(h) showed the most significant three-dimensional effect and stretch, which may be due to the substantial transverse space which allowed the spandex yarns to crimp more freely. In comparison, the surface dimension and stretch for the rest of the samples (a), (b), (c), (d), (e) were not as effective. This may be due to the lack of continuous pattern under the unstitched double weave, the transverse space was broken up by the in-between lines or patterns woven with the stitched double weave.

Three samples (f), (g), (h) which exhibited the most significant three-dimensional effect and stretch were furtherly compared. The common ground for three samples was that they all contained transverse pocket areas woven with the unstitched double weave. However, the width of the transverse pocket areas was different for each sample. The effectiveness of surface dimension and stretch for three samples is sample(g)> sample(h)> sample(f). To compare the average width of transverse pocket space between the stitched lines for three samples, the result is sample(f) > sample(g) > sample (h). The results showed that sample(g) was designed with the most appropriate width of pocket areas to achieve the most effective surface dimension and stretch. The width of pocket areas for sample(g) is in between sample(f) and sample(h). As the width increased (sample f), the arched POF pocket areas tend to flatten down and become more planar. When the width decreased (sample h), the spandex yarns in the back layer didn't provide as much shrinkage force, thereby the volume of the arched POF pocket dropped in comparison with sample (g). Based on the above discussion, it was concluded that the appropriate motif design is very important to increase the degree of three-dimensional effect and stretch.

4. Conclusions

In this study, POF fabrics with three-dimensional effects and stretch were designed and produced successfully via Jacquard weaving. The design guidelines were also provided. The effectiveness can be achieved when double weave was adapted with proper structural configurations, while incorporating spandex yarns and suitable motif designs. The adoption of the double weave allowed for the separation of POFs and spandex into two separate layers. The incorporation of elastic materials provided stretch for the POF fabric, as well as the high elasticity contrast between the POF layer and the spandex layer. By arranging the unstitched double weave and stitched double weave alternatively, the blister effects were created where POFs arched at the front and spandex crimpled at the back. This double weave design contributed to the dimensional surface. The results also demonstrated that the motif designs influenced the degree of three-dimensional effects and stretch behavior. Both geometric and wavy patterns were explored in this study. Eight POF samples were designed with varied motifs including re-entrant hexagons(a), rotating triangles(b), divided rectangular(c), zig-zag(d), interlaced waves(e), wide waves(f), medium waves(g) and narrow stripes(h). The transverse wavy and stripy patterns worked very effectively, however the geometric patterns didn't work as well. Sample (g) designed with transverse pocket areas in proper width achieved the most significant three-dimensional effect and stretch, suggesting that appropriate motif design can increase the degree of both properties. This study has focused on the design aspects including weave structures and motif designs. Further work can also examine the influence of weave density on both properties and include more diverse yarns. The creation of three-dimensional effects and stretch for POF fabric enriches and diversifies its appearance and properties. The illuminating effects of POF fabric also became three-dimensional, allowing light to travel in curved paths. The new properties can provide unique visual effects and tactile qualities for the viewers and users. This expansion of POF fabric properties may also help to further create the potentials for new applications.

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