Photonic enhancements to tailor the comfort of radiative textiles

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Abstract: Personal radiative heat regulation by photonic engineered textiles can contribute to a decreased energy consumption in buildings by expanding the range of comfortable ambient conditions. Here, we propose dual-mode photonic designs (a static and a dynamic one), which modulate the emissivity to provide thermal regulation in both cold and hot environments. The first design is a Janus-yarn fabric that tunes statically via fabric flipping, while the second design is dynamic by utilizing a shape-memory polymer.

As humanity experiences the consequences of climate change, we need to address the global energy crisis [1]. Surprisingly, more than half of our energy consumption goes to the heating and cooling of largely empty spaces in residential and commercial buildings. Therefore, the concept of personal thermal management, which creates a localized thermal regulation, can become crucial to lower consumption. Recently, micro-photonic thermal management in textiles has captivated the attention. Since radiative transfer accounts for about 50% of heat dissipation from the human body, a suitable photonic thermal management strategy allows one to design temperature regulating textiles, which are preferably passive, so without an external energy source. Several state-of-the-art fabrics based on various structures were designed and fabricated for passive, dual-mode (both heating and cooling) thermal management [2-5].

We propose a Janus-yarn fabric (Fig. 1a) where the core working principle relies on the outer surface emissivity. The functionality stems from the Stefan-Boltzmann radiative emission law, stating that the total power radiated from an object is proportional to its emissivity ε. Thus, changing this emissivity from high to low strongly reduces the radiative heat transfer to the ambient. Therefore, when the highly emissive layer of the fabric – dielectric micro-fibers in a specific configuration – faces the ambient, the surface acts as an infrared radiator, creating a cooling effect in a hot environment.

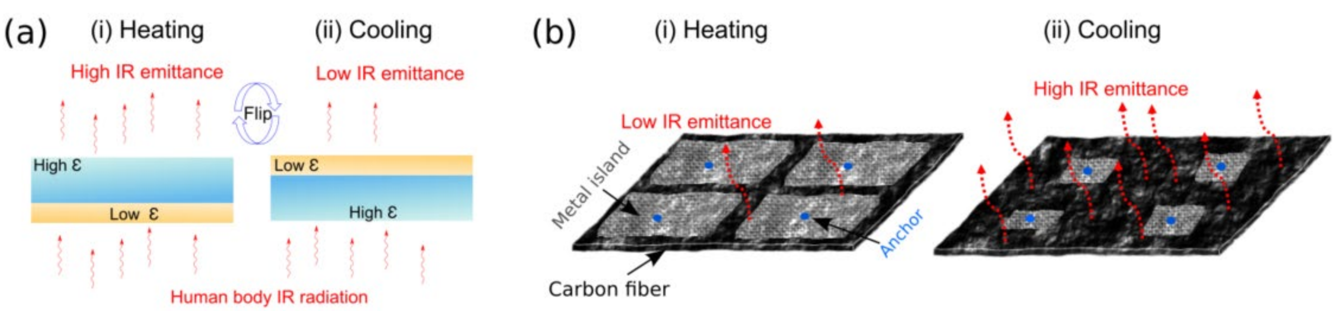

Figure 1. Schematic of the design working principles: (a) Janus-yarn fabric, (b) dynamic fabric.

On the other hand, when it is cold, flipping the same fabric exposes the low emissivity side – highly reflecting metallic microfibers – to the ambient, acting as radiative insulation, thus delivering a heating function. Furthermore, because the fabric is constituted out of yarns, which are bundles of fibers, it provides the required air permeability and water-vapor transmission for standard thermal comfort. By tailoring the yarn structure, an emissivity contrast $\Delta\varepsilon = 0.72$ can be achieved, resulting in a significant 13.1°C setpoint temperature window, with the wearer staying comfortable between 11.3 and 24.4°C [4].

The second proposed design is a dynamic emissivity switch textile (DEST), also for dual-mode regulation, and using the fabric's outer surface emissivity modulation. The fabric is constituted from a highly emissive bottom layer and with low-emission islands on top, which are thermo-mechanically dynamic (Fig. 1b). To this end the islands are made from temperature-sensitive shape-memory polymer nanofibers using electrospinning and coated with a metal, while the bottom layer is composed of carbon fibers. This design operates in two modes, heating and cooling. When the ambient is cold, the fabric is in heating mode, the polymer expands, allowing the low-emissive islands to stretch and cover the high-emissive layer (Fig. 1b(i)). This increases the island-coverage factor (i.e., island area/bottom layer area) and substantially lowers radiation emission to the ambient (i.e., low effective emissivity). When the ambient is hot, the fabric is in cooling mode, the polymer shrinks; thus, the low-emissive island surface area reduces, exposing the bottom high-emissive layer to the ambient (Fig. 1b(ii), low island-coverage factor). This results in a higher effective emissivity of the outer surface, thus strong radiative emission to the ambient. By introducing an optimized metal coating on the nanofibers, one can achieve an effective emissivity contrast of about 0.8, which translates to a wide ambient setpoint window.

The combination of photonic infrared effects and state-of-the-art materials design can thus lead to various interesting developments for personal temperature regulation and decreased energy consumption.

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