META 2021 Warsaw - Poland

The 11th International Conference on Metamaterials, Photonic Crystals and Plasmonics

Proceedings

ISSN 2429-1390

metaconferences.org

Heat transfer regulation for textiles using tailorable metallic wires

Muluneh G. Abebe[1], Eric Khousakoun[2], Jeremy Odent[3], Jean-Marie Raquez[3], Sylvain Desprez[2], and Bjorn Maes[1]

[1] Micro- and Nanophotonic Materials Group, Research Institute for Materials Science and Engineering, University of Mons, 20 Place du Parc, B-7000 Mons, Belgium
[2] Materia Nova, Avenue N. Copernic 3, B-7000, Mons, Belgium
[3] Laboratory of Polymeric and Composite Materials, University of Mons, 20 Place du Parc, B-7000 Mons, Belgium
*corresponding author, E-mail: bjorn.maes@umons.ac.be

Abstract

We numerically explore the concept of dynamic, switchable infrared transmittance using electromagnetic and thermal calculations, for the use of smart, temperature regulating textiles. We discuss the photonic effects of metallic and shape-memory-polymer coated mono-filaments on the temperature dependent transmittance of the textile fabric

1. Introduction

Passive personal thermal management using smart textiles, which could provide localized thermal regulation, has become a center of attention. This nano- and micro-photonics driven technology is regarded as an efficient strategy to facilitate efficient thermal comfort and personal health. It is also considered as a potential solution to meet climate control targets, and move towards a low carbon economy, by decreasing the energy cost for heating and cooling.

At a normal skin temperature of 34 °C, our skin emits Infrared Radiation (IR) with peak wavelength around 9.5 µm, and this IR heat dissipation contributes to more than 50% of the total body heat loss in indoor environments. Therefore, with proper photonic IR management, one can tailor and design passive temperature regulating textiles. Currently, a few types of such fabrics have been proposed and developed for cooling purposes [1], for heating purposes [2], and for both functionalities at once [3]. However, there is a long way to go when it comes to a perfect dynamically operating passive temperature regulating textile fabric.

In this work, we present a Dynamic Transmissivity Switch Textile (DTST) technology, a novel approach for a dynamic temperature regulating textile fabric that allows controlling the IR transmission by adapting to the ambient temperature and humidity. The IR transmissivity switch-based fabric allows us to control the thermal heat transfer between the human body and the ambient. We perform an extensive numerical study of the photonic properties of the proposed design geometry. These electromagnetic simulation results allow one to determine optimized geometric parameters that correspond to heating and cooling functionality.

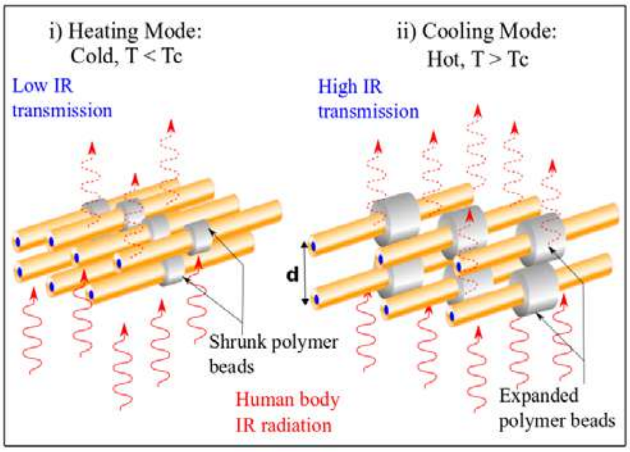

Figure 1: Schematic illustration of DTST and the working principle: (i) Heating mode and (ii) cooling mode.

2. Design working principle

The DTST has two operation modes: the heating mode for a warming functionality, and the cooling mode for a cooling functionality (see Fig. 1). The two modes coexist in one fabric simultaneously. Meanwhile, there is a passive switching mechanism that allows switching from one mode to the other. Here, shape memory polymer beads are proposed as a driving force for passive switching. Recent studies have reported that polymers such as bio-based polylactide-urethane and polyurethane show shape memory properties around the human body temperature [4].

For example, at a predetermined comfort zone temperature below a critical temperature T_c the polymer beads keep a particular geometry. When the temperature rises above T_c, the polymer beads expand, thus increasing the separation distance d between two consecutive mono-filaments. This results in a new geometric configuration with an expected increased IR transmissivity. On the other hand, when the ambient temperature drops below T_c, the polymer beads shrink, thus decreasing d. As a result, the initial geometric configuration will change, and the IR transmissivity decreases.

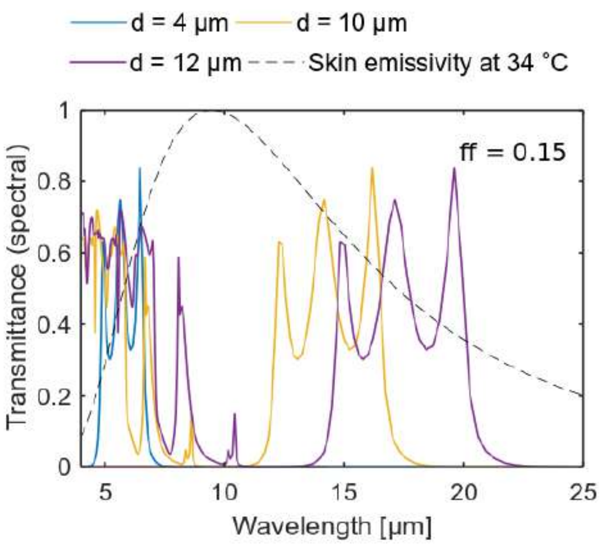

Figure 2: Calculated spectral transmittance for a fixed *ff* = 0.15 and varying *d* = 4, 10, and 12 µm.

To study the IR transmission of the proposed textile design, we employed a numerical finite-element method simulation using COMSOL Multiphysics v5.3. Figure 2 illustrates the numerically calculated spectral transmittance as a function of wavelength for a fixed filling factor *ff* = 015 and varying *d* = 4, 10, and 12 µm. It also shows the spectral emissivity of the human body at 34 °C skin temperature (dashed curve).

From Fig. 2, one observes that the spectral transmittance curves behave differently in several wavelength regions due to various photonic effects. It is possible to study these effects by choosing one spectral curve, for example, *d* = 10 µm (orange). For the larger wavelength region starting from a cut-off wavelength of 18 µm, it exhibits a wide stopband, called the plasmonic gap. Interestingly, this gap does not originate from the geometry of the design, rather from the physical property of the metal wires. Consequently, right below the plasmonic gap, there exists a first transmission band that extends from 12 to 17 µm. Furthermore, the three resonance transmission peaks present in the first transmission band are due to a Fabry-Pérot type cavity effect. Due to the geometric design, there exists a structural 'photonic' bandgap below the first transmission band extending from about 9 to 12 µm. And finally, there is a second transmission band below 9 µm.

The above photonic effects are present in all spectral curves, so we can assess the influence of changing *d* in the process of IR transmittance. When *d* increases, the spectral curve shifts to a longer wavelength region and, when d decreases, to a shorter wavelength region. With this shift, one thus shifts the plasmonic gap, the first transmission band, and the structural bandgap. As a result, for larger *d* (but not too large), the transmission band is underneath the maximum of the human body emissivity curve, leading to more transmission of IR thermal radiation from the skin to the environment. This allows DTST to operate in the cooling mode. On the other hand, for smaller *d*, the plasmonic gap is underneath the human body emissivity curve. Consequently, very low IR thermal radiative transfer from skin to the environment is realized; in this case, DTST is operating in the heating mode.

In order to assess the thermal performance, we performed one-dimensional steady-state heat transfer calculations. In the thermal calculations, one considers a constant body heat generation of Q = 70 W/m^2 for a sedentary individual with a skin temperature of 34 °C. We assume a typical air gap of 1 mm for the microclimate thickness. This calculation gives the environmental setpoint temperature (the temperature at which a sedentary individual remains comfortable). The typical natural setpoint temperature window for human comfort in office seating is 2 °C (21-23 °C). With DTST one is allowed a much larger ~16 °C temperate window, as this textile can provide a thermal comfort with the lowest setpoint at 9.5 °C and the highest setpoint at 25.7 °C.

3. Conclusions

In this work we demonstrate a personal radiative temperature regulating fabric based on a Dynamic Transmissivity Switch Textile (DTST). The proposed design is constituted from metal-coated mono-filaments and shape-memory-polymers beads, which enable the design to interact more effectively with IR radiation and to respond in a dynamic manner. Furthermore, the design benefits from various IR photonic effects to control the transmission of thermal radiation, and provides a suitable thermal comfort for users. Numerical calculations show a promising possibility of exploiting these photonic geometries for tailoring the IR transmittance from the human body to the environment. DTST possesses a ~16 °C ambient setpoint temperate window, which is by far the largest setpoint window reported.

Acknowledgement

This work is supported by the INTERREG PHOTONITEX project.

References

[1] Peng, Y. *et al.* (2018). Nanoporous polyethylene microfibres for large-scale radiative cooling fabric. *Nature Sustainability*, 105-112.

[2] Cai, L. *et al*. (2017). Warming up human body by nanoporous metallized polyethylene textile. *Nature Communications*, 8(1).

[3] Hsu, P. *et al.* (2017). A dual-mode textile for human body radiative heating and cooling. *Science Advances,* 3(11).

[4] Z Jahid, M. A. *et al.* (2018). Fabric coated with shape memory polyurethane and its properties. *Polymers,* 10, 1–13.