Dynamic thermal regulating textiles using wrinkles for emission control

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ABSTRACT

We numerically and experimentally explore the concept of surface wrinkling for modulating the infrared emissivity using electromagnetic and thermal calculations, for application towards passive temperature regulating textiles.

INTRODUCTION

Passive personal thermal management using smart textiles, which could provide localized thermal regulation, has become a center of attention. This technology is regarded as an efficient strategy to facilitate efficient thermal comfort and personal health. Moreover, it is considered as a potential solution to meet climate 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 IR management, one can tailor and design passive temperature regulating textiles (PTRT). Currently, a few types of PTRTs have been proposed and developed for cooling purposes [1], for heating purposes [2], and for both functionalities at once [3,4]. However, there is a long way to go when it comes to a perfectly operating dynamic PTRT. In this communication, we show a dynamic way of controlling the emissivity of the outer textile layer, which employs a temperature responsive shape memory polymer to generate wrinkling structures, facilitating a controlled heat loss channel to the ambient.

MATERIALS AND METHODS

The fundamental concept behind the proposed model is to dynamically tune the IR emissivity of the outer textile layer. It is particularly interesting that varying the surface emissivity using wrinkling can show a strong effect on the thermal resistivity, resulting in two different modes of operation: cooling and heating [see Fig. 1(a)]. Using any material with a moderate to high emissivity around the peak human body emission wavelength facilitates the purpose, so we used SiO_2 in our calculations. Meanwhile, for the dynamic nature of the model, we propose Poly (N-isopropylacrylamide) (PNIPAM) due to its ability to operate around body temperature. It shrinks when the temperature increases and stretches when the temperature decreases. To study the emissivity, we numerically investigate a sinusoidal wrinkling profile, as shown in Fig. 1(b), with period d = 4 µm, thickness t =10 µm and amplitude h = 6 µm. Normal incident radiation is considered for two different polarizations, Transverse Electric (TE) and Transverse magnetic (TM). However, the human body emits unpolarized IR, thus, we take the average of the results for both polarizations to model unpolarized light. Floquet periodic boundary conditions are used on the right and left to simulate an infinitely wide structure.

RESULTS AND DISCUSSION

Figure 1(c) shows the spectral emissivity of two different textile surface geometries, wrinkled (blue curve) and flat (red). Even though both surfaces show high emissivity and similar peaks in the spectra, due to the material property of SiO_2 [see inset Fig. 1(c)], one can see that the magnitude of the emissivity for the wrinkled surface is significantly higher than the flat surface, particularly around 10 um. Indeed, the deep wrinkles act as a mode coupler, consequently enhancing the absorption (and hence emissivity) significantly due to phonon-polariton resonances (see peak of k in inset of Fig. 1(c)). Also, the subwavelength nature of the wrinkling structure can decrease reflection, again increasing the emissivity. The weighted average emissivity based on human body radiation at 34 °C is around 0.65 for a wrinkled surface, and around 0.4 for a flat surface, so leading to a large change in emissivity of ~0.25.

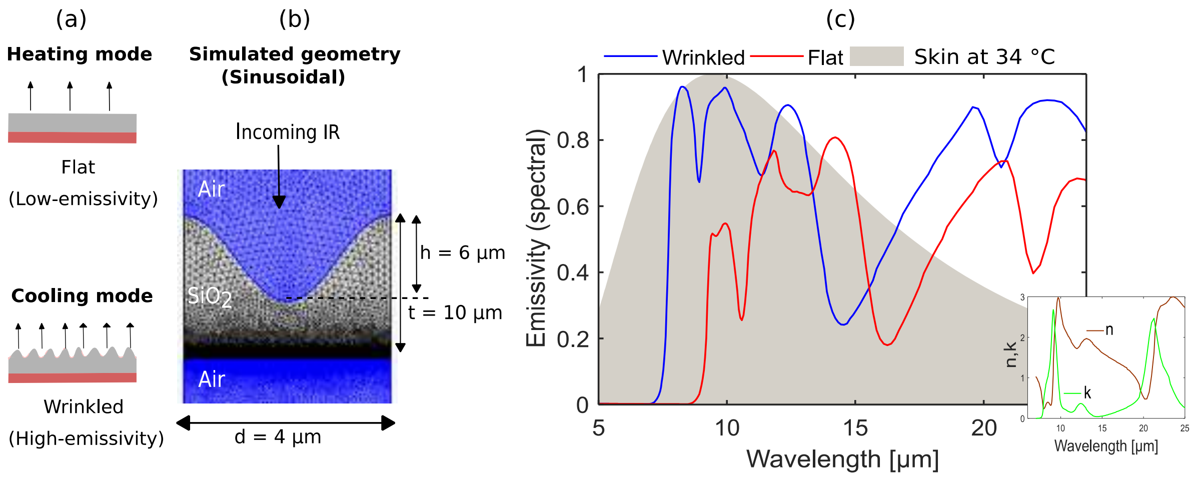

Figure 1. (a) Schematic of heating and cooling mode. (b) Simulated geometry with parameters. (c) Spectral emissivity of wrinkled surface (blue), flat surface (red) and skin at 34 °C (grey), inset is the index of SiO_2.

CONCLUSION

We demonstrate that a wrinkling structure can enhance the emissivity of a surface with a magnitude of ~0.25, which can be further improved by changing various parameters such as the thickness. The dynamic nature of this design allows to switch between two operating modes. This functionality provides cooling (low emissivity) and heating (high emissivity) for the textile user, thus leading to an extended setpoint temperature range, with an increased thermal comfort and lower energy costs.

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