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Daytime Radiative Cooling with Polydimethylsiloxane Films Inspired byFlower Petals

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Abstract
Radiative cooling is an ecofriendly cooling method that has been deemed to be a possible solution for global warming. Recent works have created costly nanophotonic radiators that can bring considerable temperature reduction but are not suitable for mass production. Herein, we report the results of inexpensive PDMS films with patterns of rose petals and lily petals. Similar to artificial regular patterns, these films inspired by the nature can enhance the radiative cooling effect. The results show that the geometric structure of the petals can help promote radiative cooling, creating a maximum temperature difference of 6 °C with the bare metal plate. Further, the inspired films might not only perform daytime radiative cooling but also serve as useful resources in desertification. The results of this manuscript are essential as they add to the existing pool of knowledge in mechanical engineering, potentially having a significant impact on global energy consumption.

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I. Introduction

1.1 Radiative cooling

Although there have been numerous efforts to address global warming, the demand for air conditioners (ACs) is constantly growing.[1] Since the emission of hydrofluorocarbons (HFCs), potent greenhouse gases that contribute to stratospheric ozone depletion,[2]increase according to AC demand, it is necessary to develop ecofriendly cooling methods. Radiative cooling is one potential method that can positively influence global energy consumption.[3] Radiative cooling is a process by which an object loses heat by thermal radiation, not by consumption of electricity. All bodies above absolute zero (0 K) emit electromagnetic radiation, and thus, can lose heat. Terrestrial objects at ambient temperature have a thermal radiation peak around the transparency window in the atmosphere (from 8 µm to 13 µm); as a result, it is possible for an object to radiate heat to outer space through this transparency window.[4] Under direct sunlight, however, the heat from conduction, convection, solar radiation, and atmospheric radiation offset the pure radiative cooling effect of an object, resulting in an imperceptible temperature reduction.[5] To achieve a significant temperature reduction in daylight, we should minimize the heat absorption from the sun. Because the solar radiation spectrum is distributed in the visible to near-infrared (NIR) range, we can minimize the heat absorption of an object by increasing its reflectivity in the visible and NIR region, while maximizing its emissivity within the transparency window.[6,7]

Although Raman et al. [8] proposed a photonic structure that cools to 4.9 ˚C below ambient air temperature, nanophotonic films may not be suitable for mass production because of their expensive fabrication process.[9] In 2019, Zhou et al. [3] found that polydimethylsiloxane (PDMS) can work as a cost-efficient material cooler owing to its transparency in the visible and NIR region and high emissivity in the atmospheric window.[10]

1.2 Geometric patterns on the film

The planar PDMS emitter proposed by Zhou et al. [3] can be improved in various ways: in the emissivity spectra of PDMS films, several dips are found under the atmospheric window.[10] These dips lower the emitter's cooling effect because an ideal emitter has an absorption near unity in the 8–13 µm range. To remove the dips, Lee and Luo [11] created a micrometer-sized pyramid structure on top of a planar film. By smoothly changing the refractive index at the PDMS/air interface, the pyramid structure successfully eliminated the observed dips, with an emissivity near unity in the atmospheric window.[11] Such effects of geometric patterns in radiative cooling have also been found in nature, through various biological structures, such as the natural fluffs of a beetle. The corrugated and triangular-shaped hair of Saharan silver ants is an optical structure that enhances both solar reflectivity and MIR emissivity.[12] The shell-cylinder structure of the white beetle *Goliathus goliatus* also exhibits broadband reflectivity and radiative heat dissipation.[13]

While other studies applied the geometric patterns of insects in PDMS films, the effect of flower petal patterns on PDMS films has yet been examined. Temperature is a fundamental factor for all forms of lives, including plants. [13] Considering that plants, such as tomatoes, get affected by high temperature stress in seed germination and flowering, [14] we can deduce that petal structures of some flowers may have evolved to have thermoregulation capabilities in high climates. In this research, we created PDMS films inspired by the geometric patterns of flower petals. Dai et al. [15] Park et al. [16], and Koch et al. [17] showed that the petal surface is covered by numerous micro-pyramids with nanoscale cuticular foldings on top. The diameters of small hemisphere-like hills on the petal surface are between 20 and 30 μm, which aligns with the size range where the radiative cooling effect is maximized.[11] Noting that rose petals resemble the aforementioned geometric patterns, we hypothesized that PDMS films with the pattern of a rose petal will have a radiative cooling effect similar to those with regular pyramid patterns. Our work demonstrates that flower petals can be another inexpensive, eco-friendly material that could improve the existing cooling system, enhancing the radiative cooling effect of PDMS films.

II. Method

For the experiment, a total of four 3cm by 7cm PDMS samples were created, two plain PDMS films, one rose-petal-like, and the other lily-petal-like. PDMS films were prepared using a Sylgard 184 elastomer kit with a base-to-curing-agent mass ratio of 10:1. A two-step PDMS replication technique [15] was used to create the films. We first made a negative PDMS mold out of each flower petal, and the final positive pattern substrates were created by pouring PDMS into the PDMS mold. To measure the temperature of the films, the AZ88598 digital thermometer channels were inserted into the hardened PDMS so that the two were firmly attached to each other. Note that the net cooling loss of the substrate can be represented as [8]where $T_{rad}$is the radiator temperature. The radiative cooler under daylight is not only affected by solar irradiance $q_{sun}$and atmospheric thermal radiation $q_{atm}(T_{amb})$, but also by $q_{cond}+_{conv}$, the heat loss due to conduction and convection between the cooler and the adjacent air. During the experiment, the substrates remained inside an insulator covered with foil and bubble wrap to minimize $q_{cond}+_{conv}$. Tin foil was used to reflect sunlight as much as possible, and the bubble wrap was used to minimize the thermal conduction between the film and the external environment. A small hole was then created in the middle so that the radiation of the film could pass through. We punched six holes with a needle in the bubble wrap to allow a small amount of air flow between the insulator and the outside, to prevent the insulator from becoming an oven, trapping the heat from sunlight. The experiment was performed for nine hours from 09:00 to 18:00.

$$qnet = qrad(Trad) - qatm(Tamb) - qsun - qcond+conv \quad (1)$$

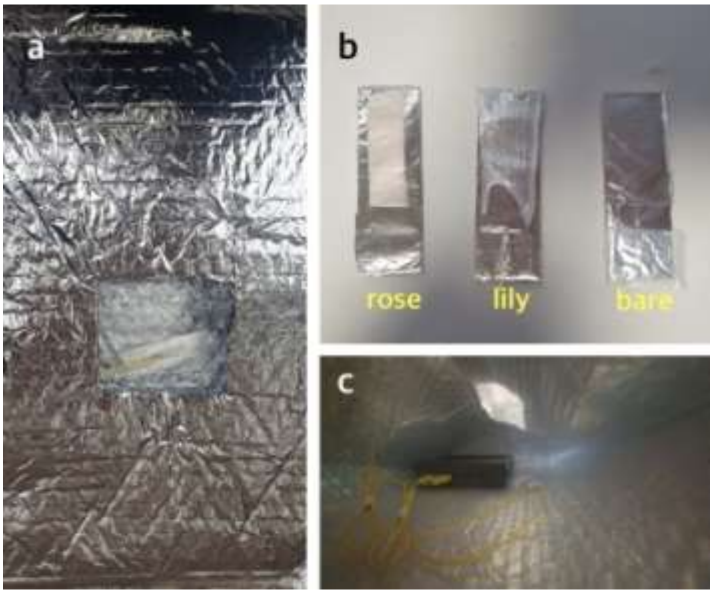

Figure 1: Image of the top of insulator b three PDMS substrates c inside set up of the insulator

III. Results And Discussion

As mentioned by Dai et al.,[15] the rose-petal-like PDMS substrate had small hills on the scale of 20 to 30 μm, successfully replicating the geometric pattern of the rose petal. The two temperature graphs in Figure 1 show that both the rose petal-like and lily petal-like PDMS substrates had a cooling effect, as the bare metal plate had a much higher surface temperature throughout the day. The bare metal plate and rose-petal-like PDMS substrate had a maximum temperature difference of 6 ˚C, the bare plate having a temperature of 32.1 ˚C and the film a temperature of 26.1 ˚C, measured at 18:21:48 pm.

Although the bubble wrap worked as an effective insulator, it is questionable whether it fully allowed the film's radiation to pass through. The low transparency of the bubble wrap in the 8–13 µm wavelength range could have reduced the cooling effect of the PDMS film, absorbing some of the film's radiation.

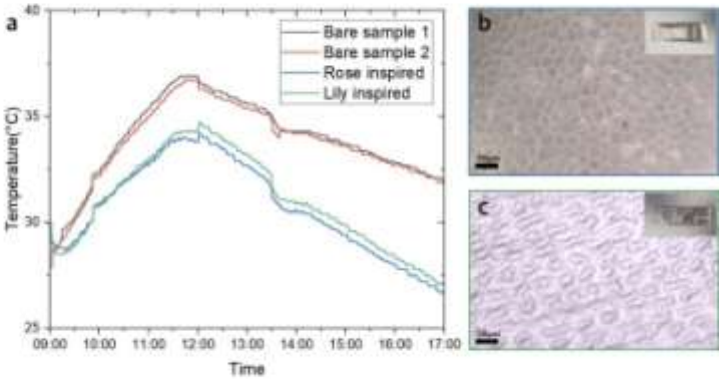

Figure 2: Time-temperature graph of two bare samples, rose and lily sample b,c OM images of rose-petal-like and lily-petal-like PDMS substrate

IV. Conclusion

Through this research, we have confirmed that PDMS films with patterns replicating those of flower petals have a cooling effect similar to those of films with artificial patterns. The research could be further expanded by trying patterns of various flower petals, such as cactus flower petals. As mentioned earlier, Wu et al. [12]found that the geometric structure of the hair of Saharan silver ants promoted radiative cooling. Considering that cactuses survive in extremely hot climates, similar to ants, the geometric pattern of their petals may have evolved to reduce their surface temperature, which can be potentially utilized in the PDMS film structure. Furthermore, cactus-inspired films might not only perform daytime radiative cooling but also make effective use of resources on an increasingly desertified planet. Compared with artificially patterned films created through photolithography, flower-petal-inspired films are much more conducive to mass production, since the pattern mold can be readily obtained in nature.

References

[1]. Catalanotti S, Cuomo V, Piro G, Ruggi D, Silvestrini V and Troise G (1975) The radiative cooling of selective surfaces. *Solar Energy* 17(2): 83–89.

[2]. Comlekcioglu, Nuray, and M. Kemal Soylu. "Determination of high temperature tolerance via screening of flower and fruit formation in tomato." *Yyu J Agr Sci* 20.2 (2010): 123-130.

[3]. Dai S, Zhu Y, Gu Y and Du Z (2019) Biomimetic fabrication and photoelectric properties of superhydrophobic ZnO nanostructures on flexible PDMS substrates replicated from rose petal. *Applied Physics A* 125(2): 1–11.

[4]. Hossain MM, Jia B, and Gu M (2015) A metamaterial emitter for highly efficient radiative cooling. *Advanced Optical Materials* 3(8): 1047–1051.

[5]. Isaac M and Van Vuuren DP (2009) Modeling global residential sector energy demand for heating and air conditioning in the context of climate change. *Energy Policy* 37(2): 507–521.

[6]. Koch K, Bhushan B and Barthlott W (2009) Multifunctional surface structures of plants: an inspiration for biomimetics. *Progress in Materials Science* 54(2): 137–178.

[7]. Lee E and Luo T (2019) Black body-like radiative cooling for flexible thinfilm solar cells. *Solar Energy Materials and Solar Cells* 194: 222–228.

[8]. Mandal J, Fu Y, Overvig AC, Jia M, Sun K, Shi NN, Zhou H, Xiao X, Yu N, and Yang Y (2018) Hierarchically porous polymer coatings for highly efficient passive daytime radiative cooling. *Science* 362(6412): 315–319.

[9]. Park YN, Gang M, Seo YH and Kim BH (2011) Artificial petal surface based on hierarchical micro-and nanostructures. *Thin Solid Films* 520(1): 362–367.

[10]. Raman AP, Abou Anoma M, Zhu L, Rephaeli E and Fan S (2014) Passive radiative cooling below ambient air temperature under direct sunlight. *Nature* 515(7528): 540–544.

[11]. Srinivasan A, Czapla B, Mayo J and Narayanaswamy A (2016) Infrared di- electric function of polydimethylsiloxane and selective emission behavior. *Applied Physics Letters* 109(6): 061905.

[12]. Wu W, Lin S, Wei M, Huang J, Xu H, Lu Y, and Song W (2020) Flexible passive radiative cooling inspired by saharan silver ants. *Solar Energy Materials and Solar Cells* 210: 110512.

[13]. Xiang, Bin, et al. "Global emissions of refrigerants HCFC-22 and HFC-134a: Unforeseen seasonal contributions." *Proceedings of the National Academy of Sciences* 111.49 (2014): 17379-17384.

[14]. Xie D, Yang Z, Liu X, Cui S, Zhou H and Fan T (2019) Broadband omni- directional light reflection and radiative heat dissipation in white beetles goliathus goliatus. *Soft Matter* 15(21): 4294–4300.

[15]. Yin X, Yang R, Tan G, and Fan S (2020) Terrestrial radiative cooling: Using the cold universe as a renewable and sustainable energy source. *Science* 370(6518): 786–791.
[16]. Zhou L, Song H, Liang J, Singer M, Zhou M, Stegenburgs E, Zhang N, Xu C, Ng T, Yu Z, e*t al*. (2019) A polydimethylsiloxane-coated metal structure for all-day radiative cooling. *Nature Sustainability* 2(8): 718– 724.

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