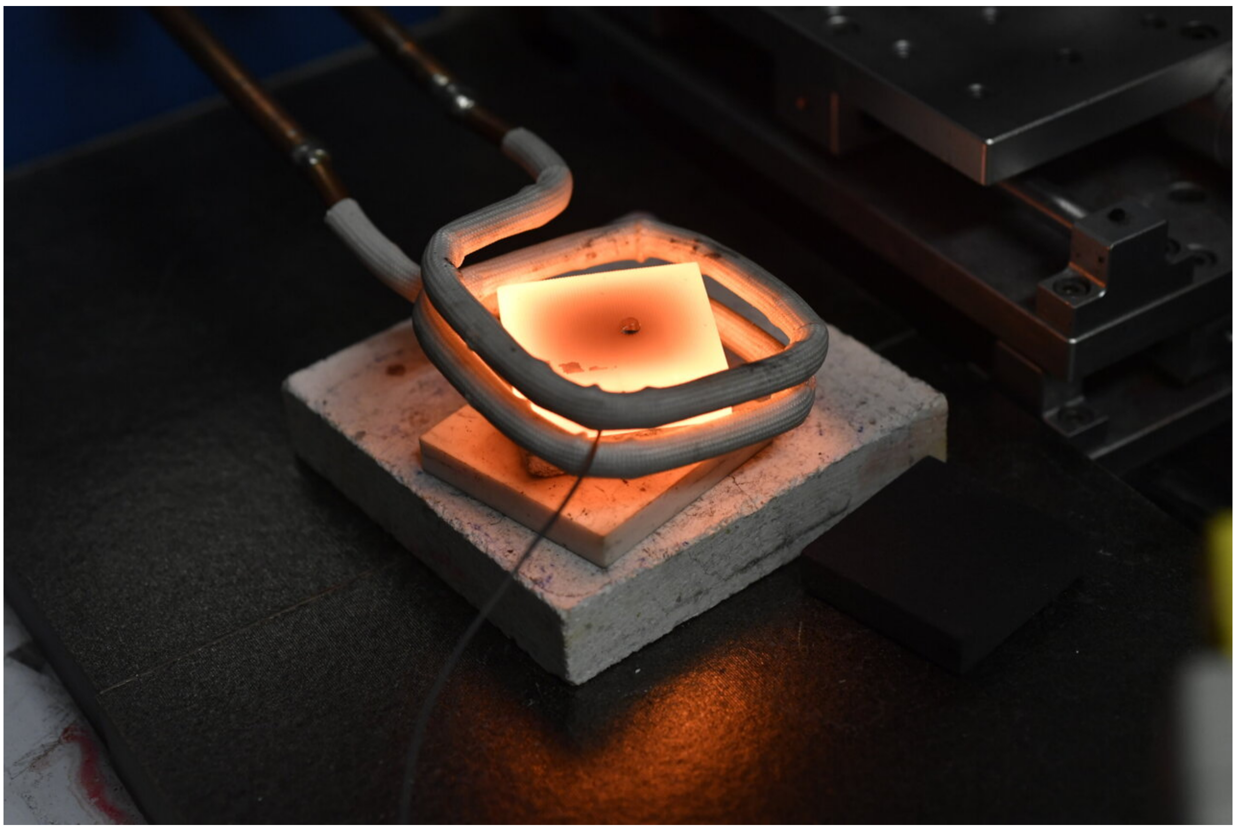
Structured thermal armor achieves liquid cooling above 1,000°C and solves challenge presented by Leidenfrost effect

January 26 2022



In the Leidenfrost effect, an insulating vapor layer is produced and heat transfer is dramatically reduced. Credit: City University of Hong Kong

A research team led by scientists from City University of Hong Kong

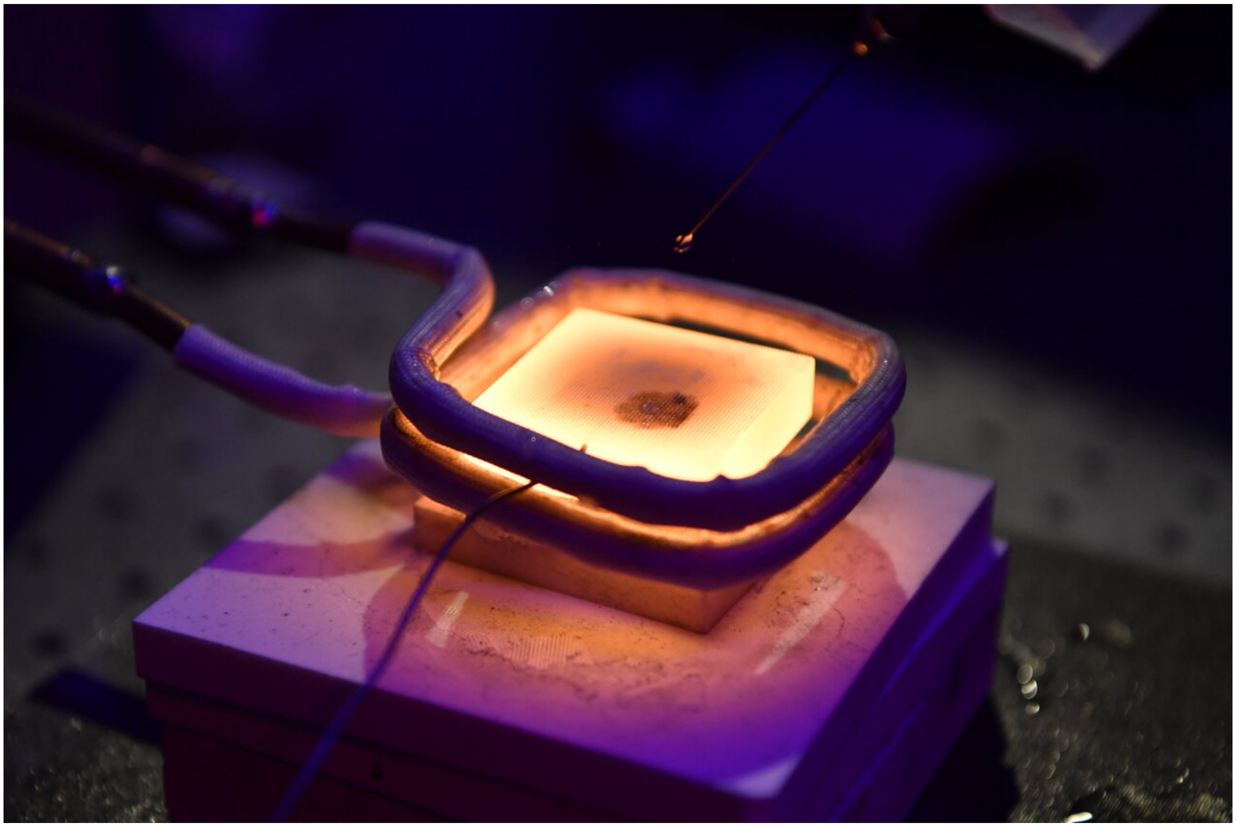
(CityU) has recently designed a structured thermal armor (STA) that achieves efficient liquid cooling even over 1,000°C, fundamentally solving a 266-year-old challenge presented by the Leidenfrost effect. This breakthrough can be applied in aero and space engines, as well as improve the safety and reliability of next-generation nuclear reactors.

The research has been led by Professor Wang Zuankai from CityU's Department of Mechanical Engineering (MNE), Professor David Quéré from the PSL Research University, France, and Professor Yu Jihong, Director of the International Center of Future Science, Jilin University and Senior Fellow of the Hong Kong Institute for Advanced Study at CityU.

The findings were published in the latest issue of the highly prestigious scientific journal *Nature*.

The Leidenfrost effect is a physical phenomenon discovered in 1756, which refers to the levitation of drops on a surface that is significantly hotter than the liquid's boiling point. It produces an insulating vapor layer and dramatically reduces heat transfer performances at high temperatures, which makes liquid cooling on the hot surface ineffective. This effect is most often detrimental and it has remained a historic challenge to suppress this effect.

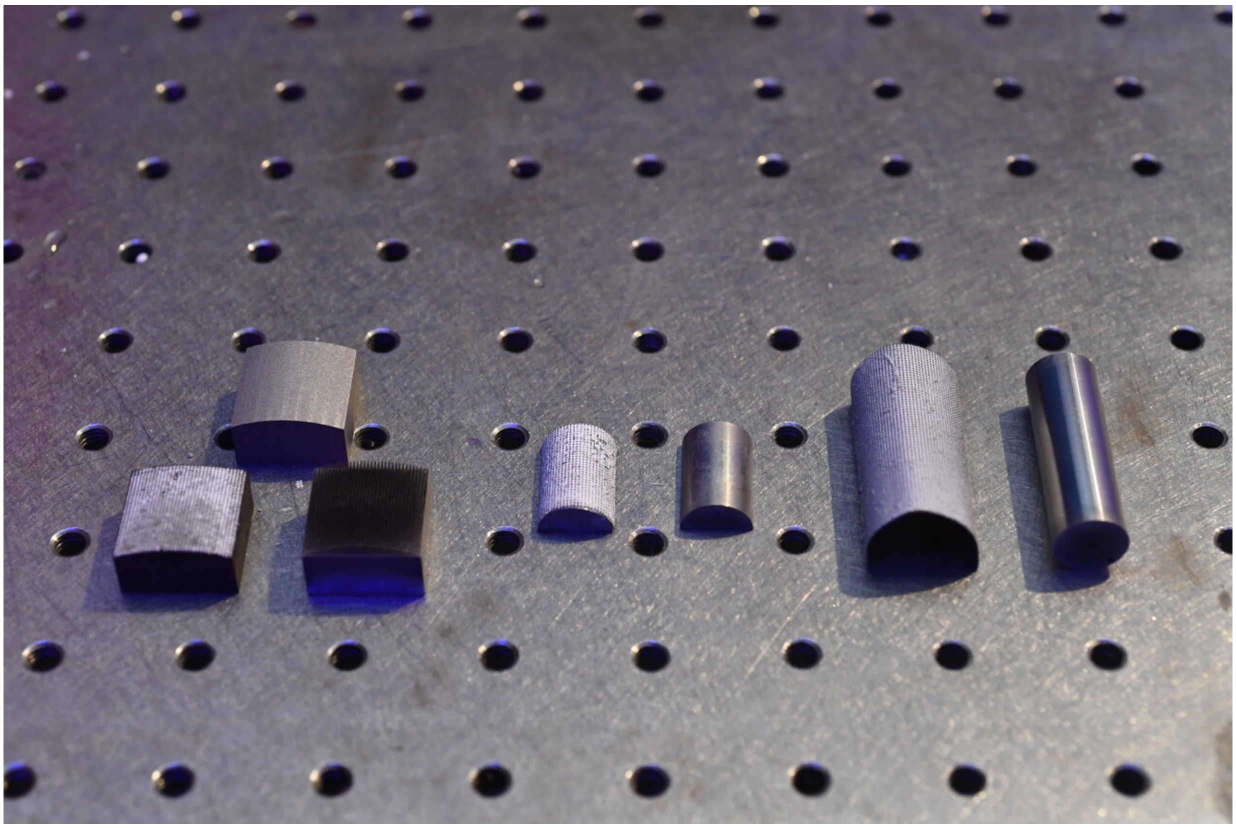
The CityU-led team constructed a multitextured material with key elements that have contrasting thermal and geometrical properties. The rational design for the STA superimposes robust, conductive, protruding pillars that serve as thermal bridges for promoting heat transfer; an embedded thermally insulating membrane designed to suck and evaporate the liquid; and underground U-shaped channels that evacuate the vapor. It successfully inhibits the occurrence of the Leidenfrost effect up to 1,150 °C and achieves efficient and controllable cooling across the temperature range from 100°C to over 1,150°C.



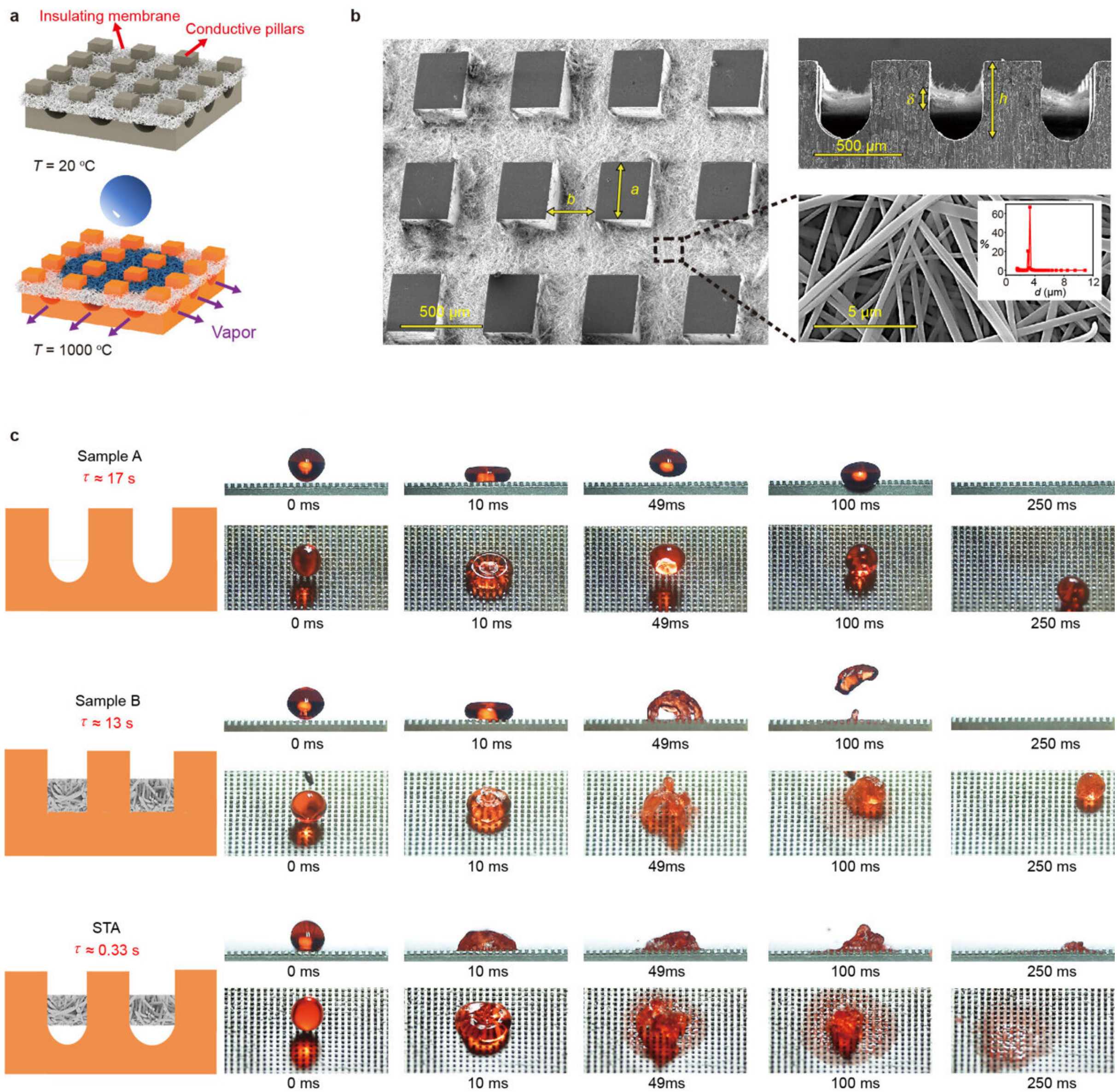
The STA successfully inhibits the occurrence of the Leidenfrost effect even up to 1,150 °C and achieves efficient liquid cooling. Credit: City University of Hong Kong

"This multidisciplinary research project is truly a breakthrough in science and engineering, since it mixes surface science, hydro- and aero-dynamics, thermal cooling, material science, physics, energy and engineering. Searching for novel strategies to address the liquid cooling of high-temperature surfaces has been one of the holy grails in thermal engineering since 1756. We are fortunate to fundamentally suppress the occurrence of the Leidenfrost effect and thereby provide a paradigm shift in liquid thermal cooling at extremely high temperatures, a mission that has remained uncharted to date," said Professor Wang.

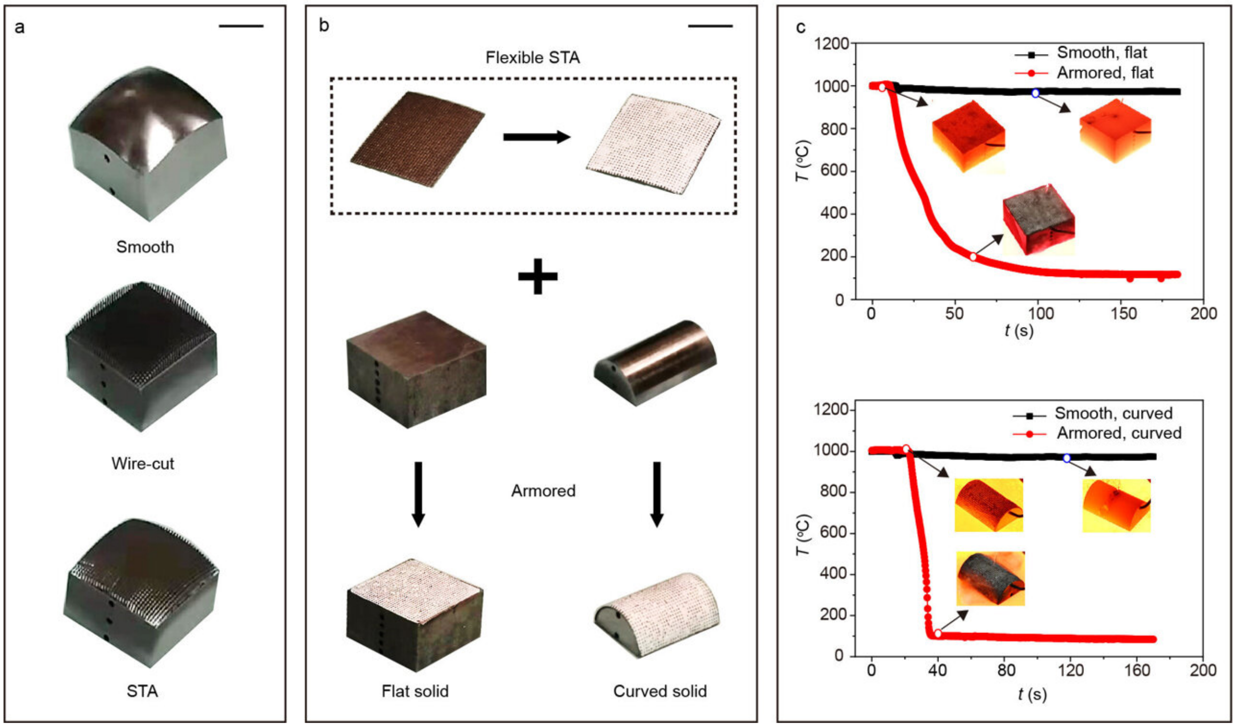
Professor Wang pointed out that current thermal cooling strategies under extremely high temperatures adopt air cooling measures rather than effective liquid cooling owing to the occurrence of the Leidenfrost effect, especially for applications in aero and space engines and next-generation nuclear reactors.



The STA can be designed to be flexible, which possesses huge potential for practical applications. Credit: City University of Hong Kong



(a) A STA consists of an array of thick pillars acting as thermal bridges and holding an insulating superhydrophilic membrane that wicks the incoming liquid. This membrane is positioned so as to create channels that can evacuate the vapor (purple arrows). (b) The membrane is made of nanometric silica fibers that are capable of resisting temperatures of up to approximately 1,200°C.(c) High-speed side and top views of water drops (dyed in orange and having a volume of 17 μl) contacting Sample A (no membrane), Sample B (no channel) and Sample C (STA), all brought to 1,000 °C. Water on Sample C gets constantly pinned and sucked by the membrane, which leads to a lifetime of 0.33s, approximately 50 times smaller than that on Samples A & B. Credit: Jiang, M. et al.



(a) A smooth spheroidal piece of steel can be covered by thick pillars after wire cutting. Inserting a membrane in the pillars provides a curved STA. (b) STA can also be made on thin films of steel, which makes it flexible. The films can be welded onto flat or cylindrical solids. (c) The armours are tested to be able to provide rapid and efficient cooling, as evidenced by the drop in temperature (red data). Credit: Jiang, M. et al.

"The designed STA can be fabricated to be flexible, eliminating the need for additional manufacturing, especially for those surfaces that are hard to be textured directly. This is why the STA possesses huge potential for practical applications," added Professor Wang.

More information: Zuankai Wang, Inhibiting the Leidenfrost effect above 1,000 °C for sustained thermal cooling, *Nature* (2022). DOI: 10.1038/s41586-021-04307-3.
www.nature.com/articles/s41586-021-04307-3

Provided by City University of Hong Kong