a larger society. Scientists themselves are members of a society, and their behaviors reflect their milieu. Guanxi helps top Chinese scientists become CAS/CAE members largely because guanxi is important in today's China. However, reliance on guanxi is not unique to Chinese science. In American science, social networks, especially those developed in graduate programs, affect attainment of academic positions and achievement recognition. Long *et al.* found that the prestige of a graduate program and mentor is highly predictive of first academic employment, whereas preemployment productivity is not (*13*). Zuckerman reported that mentoring relationships matter even for the most coveted reward in science—the Nobel Prize (*13*)—because mentors who have won the prize are well positioned to nominate their former students.

Recognition of scientists' accomplishments, such as membership in prestigious societies and top prizes, appropriately rewards scientists for their contributions to humanity (*2*, *3*, *11*). However, evaluation of scientific merit is never easy. Quantifiable criteria—such as publication and citation counts—can be misleading. In China, where the state's influence is strong and pervasive, bureaucracy could easily lead to more corruption (*9*). Therefore, evaluation by peer scientists in the same field remains the best and the most feasible option. Peers, however, are not infallible; their evaluations can be subjective. Adding to established literature in sociology, Fisman *et al.* remind us that science is ultimately a social institution affecting, and affected by, human behavior. ■

REFERENCES

1. R. K. Merton, *The Sociology of Science: Theoretical and Empirical Investigations* (Univ. Chicago Press, Chicago, 1973), pp. 267–278.
2. J. Cole, S. Cole, *Social Stratification in Science* (Univ. Chicago Press, Chicago, 1973).
3. Y. Xie, A. A. Killewald, *Is American Science in Decline?* (Harvard Univ. Press, Cambridge, MA, 2012).
4. C. A. Moss-Racusin, J. F. Dovidio, V. L. Brescoll, M. J. Graham, J. Handelsman, *Proc. Natl. Acad. Sci. U.S.A.* **109**, 16474 (2012).
5. R. Fisman, J. Shi, Y. Wang, R. Yu, *Social Ties and Favoritism in Chinese Science*, NBER Working Paper No. 23130, February 2017; see www.nber.org/papers/w23130.
6. N. Lin, in *The Chinese Triangle of Mainland China, Taiwan, and Hong Kong: Comparative Institutional Analysis*, A. So, N. Lin, D. Poston, Eds. (Greenwood, Westport, CT, 2001), pp. 153–166.
7. C. Zhang, Y. Xie, *Urban Studies* **50**, 3011 (2013).
8. Y. Xie, C. Zhang, *Proc. Natl. Acad. Sci. U.S.A.* **111**, 9437 (2014).
9. Y. Shi, Y. Rao, *Science* **329**, 1128 (2010).
10. R. K. Merton, *The Sociology of Science: Theoretical and Empirical Investigations* (Univ. Chicago Press, Chicago, 1973), pp. 286–324.
11. H. Zuckerman, *Scientific Elite, Nobel Laureates in the United States* (Free Press, New York, 1977).
12. C. Cao, *China's Scientific Elite* (Routledge, London, 2004).
13. J. S. Long, P. D. Allison, R. McGinnis, *Am. Sociol. Rev.* **44**, 816 (1979).

10.1126/science.aam5408

OPTICAL METAMATERIALS

Metamaterials for perpetual cooling at large scales

A glass-polymer film can cool structures by radiating heat, even under direct sunlight

By **Xiang Zhang**

The cold universe is a vast but freely available heat sink that has been largely neglected in the past and has a great potential to store and dissipate the enormous waste heat we generate every day on Earth. On page 1062 of this issue, Zhai *et al.* develop a metamaterial—a class of engineered material with exotic properties not found in nature—to cool room-temperature objects perpetually by dumping heat to outer space through infrared (IR) thermal radiation (*1*).

Thermal radiation in the form of electromagnetic waves is the primary way for Earth to dissipate ~170 pW of the incoming solar irradiation (*2*). At room temperature, thermal radiation peaks at ~10 µm IR wavelength, which lies in the so-called atmospheric window (*3*). The radiation within this spectral window passes directly through the atmosphere layer to the cold, outer space with little absorption and reemission. This is why we feel chilly when standing outside on a clear and calm night.

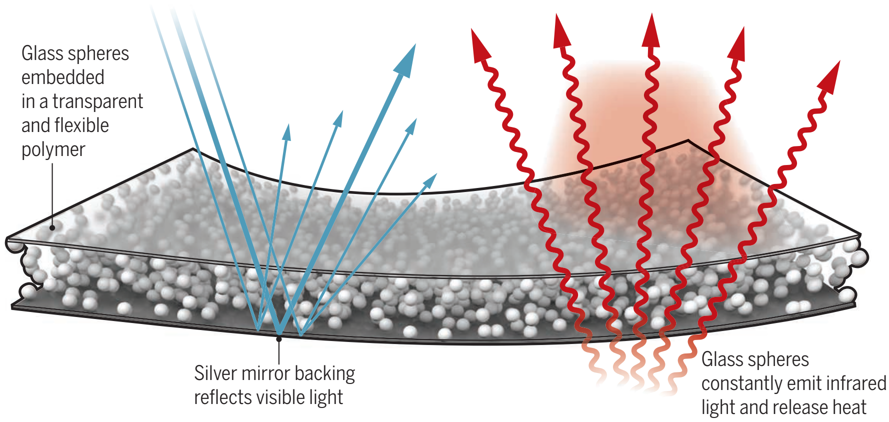
Nanoscale Science and Engineering Center, 3112 Etchverry Hall, University of California, Berkeley, Berkeley, CA 94720, USA; Materials Sciences Division, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720, USA. Email: xiang@berkeley.edu

Nocturnal radiative cooling has been exploited in warm climates for building cooling (*4*). Daytime radiative cooling, however, is fundamentally limited because most naturally available IR-emissive materials also absorb sunlight at visible and near-IR wavelengths and heat up rapidly under the Sun. The solar power density overwhelms the room-temperature radiation spectrum for the wavelengths that are shorter than 4 µm; effective daytime radiative cooling demands a material that reflects all of the light at wavelengths shorter than 4 µm while being fully emissive for longer wavelengths. Recently, nanophotonic structures with tailored spectral responses were designed for passive daytime radiative cooling (*5*, *6*). They can reflect most of the sunlight but remain highly emissive in the IR. When facing toward the sky, the photonic structures cool themselves below the ambient temperature under direct sunlight through the net outgoing energy flux.

Passive radiative cooling consumes no electricity nor refrigerant. Once deployed, the cooling effect is perpetual as long as the object temperature is higher than that of the outer space. The primary challenge with passive radiative cooling, however, is to produce these photonic structures in a simple, scalable, and yet cost-effective way

A flexible route to coolness

In previous approaches, intricate crystalline nanostructures emitted thermal infared light. Zhai *et al*. use larger glass spheres (~10 µm diameter) in a flexible polymer to create a scalable, thin-film cooling material.



GRAPHIC: C. BICKEL/*SCIENCE*

for large-scale energy applications. The nonperiodic layered nanophotonic structure showed good performance (*6*), but its required nanometer precision control of the thin films is still a challenge for scaling up to the size of meters, which is needed for even a small (kilowatt-scale) cooling system.

The unprecedented properties of a metamaterial such as negative refraction and superlensing originates from its internal structures instead of its chemical constituents (*7*). Because its structural unit cell is often smaller than the wavelength of interest, practical implementations of optical metamaterials have always been challenging. Zhai *et al.* devised a glass-polymer metamaterial in which a set of glass microspheres were randomly and uniformly dispersed in a visibly transparent polymer matrix. Because of the surface phonon-polariton Mie resonance excited at room temperature on the glass surface, this amorphous metamaterial has a maximal broadband emissivity—near the blackbody limit across the entire atmospheric window—that results in cooling of the material itself (*8*). Both the polymer and glass are transparent to the full solar spectrum, so the hybrid metamaterial minimally absorbs and reflects most solar energy when backed with a thin silver mirror (see the figure).

Zhai *et al.* demonstrated an average radiative cooling flux greater than 110 W m^{-2} in a continuous 3-day field test. This energy flux is at a rate similar to that of photovoltaic solar cell energy conversion but with the great advantage of running both day and night. More impressively, the key roadblock for large area deployment of radiative cooling was removed. Because the material is amorphous and flexible, the authors developed a glass-polymer hybrid manufacturing technique to produce the microstructured metamaterial, which can be made as films several meters in length in a continuous roll-to-roll manner. Using such a scalable metamaterial, they demonstrated passive water cooling by nearly 10 Celsius degrees below ambient temperature without use of electricity.

"The impact of such a passive radiative cooling without use of electricity for building applications alone can be immense."

There are still challenges yet to be addressed for the implementation of radiative cooling metamaterials into applications. Given that the cooling occurs on both sides of metamaterials, detailed thermal design will be important to maximize the cooling rate for the substrate side, and effective heat exchange strategies therefore must be developed. In addition, the IR radiation transport inside metamaterials caused by volumetric multiple scattering among the random Mie resonating glass spheres should be carefully studied so as to further maximize the total emissive power. Other issues should also be carefully investigated, such as how weather conditions negate cooling performances and how the polymer-based metamaterial maintains its performance during long-term outdoor exposure.

Although extraction of the 110 W m^{-2} heat flux is a relatively low cooling rate, these designed metamaterials should find promising application for cooling large systems such as buildings in warm climates (*9*). Presently, air conditioning uses ~6% of all of the electricity produced in the United States, and as a result, more than 100 million metric tons of carbon dioxide are released into the atmosphere each year. The impact of such a passive radiative cooling without use of electricity for building applications alone can be immense. The broad use of radiative cooling technology not only leads to energy savings but also reduces fluorinated greenhouse gases from refrigerants used in conventional air conditioners, thus improving air quality. At higher temperatures T, passive radiative cooling can be drastically enhanced because the outgoing radiative flux is proportional to T^4 according to the Stefan-Boltzmann law. This scalably manufactured metamaterial may enable transformative cooling farms for power plants and data centers, which consume unsustainable amounts of water and electricity.

Although radiative cooling is promising, the better use of this waste energy can be more desirable. For example, the waste heat could be converted into electricity by using thermoelectric devices. Nevertheless, the passive radiative cooling demonstrated here unleashes the immense potential of using the cold universe as a new avenue of keeping us cool on Earth. ■

REFERENCES

1. Y. Zhai *et al.*, *Science* **355**, 1062 (2017).
2. F. D. Stacey, P. M. Davis, *Physics of the Earth* (Wiley, 1977).
3. R. Hillenbrand, T. Taubner, F. Keilmann, *Nature* **418**, 159 (2002).
4. X. Lu *et al.*, *Renew. Sustain. Energy Rev.* **65**, 1079 (2016).
5. E. Rephaeli, A. Raman, S. Fan, *Nano Lett.* **13**, 1457 (2013).
6. A. Raman *et al.*, *Nature* **515**, 540 (2014).
7. Y. Liu, X. Zhang, *Chem. Soc. Rev.* **40**, 2494 (2011).
8. J. A. Schuller, R. Zia, T. Taubner, M. L. Brongersma, *Phys. Rev. Lett.* **99**, 107401 (2007).
9. N. Fernandez, W. Wang, K. Alvine, S. Katipamula, Pacific Northwest National Laboratory Report no. PNNL-24904, Richland, WA (2015).

10.1126/science.aam8566

SYNTHETIC BIOLOGY

Yeast genome, by design

Scientists are inching closer to generating a synthetic eukaryotic cell

By **Krishna Kannan**[1] *and* **Daniel G. Gibson**[1,2]

A core theme in synthetic biology, "understanding by creating," inspired the effort to generate the first synthetic cell, JCVI-Syn1.0 (*1*). The project Sc2.0 is elevating this concept by attempting to create a synthetic version of a more evolved organism, *Saccharomyces cerevisiae*, a eukaryotic single-celled yeast. In a set of papers in this issue (*2*–*8*), scientists of the Sc2.0 project who previously constructed a single yeast chromosome (*9*) now report constructing five additional yeast chromosomes (more than one-third of the entire genome) (see the photo). Using a variety of phenotypic assays and structural and functional genomics techniques, the researchers observed that the synthetic chromosomes drive biological processes just like the natural, native chromosomes.

The quintessential first step toward creating a synthetic organism is the careful design of the genomic material, which ultimately controls every physiological process in the cell. Project Sc2.0 built a software framework, BioStudio, to generate chromosomal designs (*2*). A set of rules were applied while designing each chromosome, including removal of repetitive regions and introns (except for the *HAC1* intron), recoding of TAG stop codon to TAA (allowing TAG to be repurposed), and the relocation of transfer RNA genes into a neochromosome. In addition, sites (loxPsym) were introduced throughout the chromosome at the 3′ ends of nonessential genes for chemically-inducible genome rearrangements (through Cre-recombinase). This allowed the selection of desired phenotypes and the examination of corresponding genotypes (synthetic chromosome rearrangement and modification by loxP-mediated evolution, or SCRaMbLE). Despite the many variations (thousands) introduced during the construc-

[1]*Synthetic Genomics, Inc., 11149 North Torrey Pines Road, La Jolla, CA 92037, USA.* [2]*J. Craig Venter Institute, 4120 Capricorn Lane, La Jolla, CA 92037, USA. Email: dgibson@syntheticgenomics.com*