Review Letters direct experimental proof of the hypothesis. They used x-ray scattering to study a deeply undercooled TiZrNi liquid to demonstrate the correlation between the nucleation barrier and growing ISRO with decreasing temperature. Beamline electrostatic levitation (BESL), a technique recently developed by Kelton, made the experiments possible, allowing *in situ* x-ray diffraction studies on electrostatically levitated droplets.

The researchers used containerless processing to study 2.3–2.5-mm-diameter TiZrNi droplets, which were melted using a YAG laser and charged positively by using ultraviolet light followed by levitation in vacuum (10^{-7} Torr) between electrostatic plates. Decoupling between heating and positioning using electrostatic levitation showed an improvement over electromagnetic levitation techniques, allowing undercooling studies on a wider range of materials.

In the case of the TiZrNi system investigated, the researchers found that the increasing ISRO is responsible for the nucleation of the metastable icosahedral *i*-phase formed in the first of two recalescence events (a 105 K temperature rise), instead of the thermodynamically stable polytetrahedral C14 Laves phase, which forms just a few seconds later, recognized by a second recalescence (a 25 K temperature rise). Recalescence is the process whereby the liberated heat of fusion causes a temperature rise during solidification. Since the driving free energy for the formation of the C14 phase is larger, the preferred nucleation of the *i*-phase indicates a smaller nucleation barrier, consistent with the x-ray evidence that the short-range order in the supercooled liquid is closer to that of the *i*-phase than to that of the C14 structure.

A better understanding of the physics of undercooled liquids is of technological importance, particularly the elucidation of the reasons for the unusual stability of undercooled liquids against crystallization in order to gain better control of their nucleation behavior. Commercial interests lie in the manufacture of glass fibers from undercooled oxide melts, making accessible novel fibers for structural, optical, and medical applications as well as oxide glasses for infrared and laser applications in telecommunications and consolidated nanostructured metallic glasses.

ALFRED A. ZINN

Geometry Can Provide Interlocking of Protective Tiles for the Space Shuttle

One of the critical components on the space shuttle is its thermal protection system (TPS). The TPS consists of various materials applied externally, primarily in the form of tiles, to the outer structural skin of aluminum and graphite epoxy. During reentry of the shuttle from earth orbit, the TPS protects the skin from overheating and failure due to the frictional heating of high-speed contact with the earth's atmosphere.

A weakness of the TPS is that mechanically it is not a cohesive system. Each of the tiles is an independent unit, and damage to or failure of one tile can cascade into overall catastrophic failure. Yuri Estrin (Technical University of Clausthal, Germany) along with A.V. Dyskin, E. Pasternak, H.C. Khor from the University of Western Australia and A.J. Kanel-Belov from the International University of Bremen, Germany have proposed a new concept for the design of the tile-covering, based on topological interlocking of the tiles.

The basis of their proposal, as published in the June issue of *Philosophical Magazine Letters*, is the idea of geometrically subdividing a continuous layer into fragments that are topologically interlocked. One example of this for a planar plate is the "osteomorphic block," which includes a class of shapes that allow for masonry-like assemblies. The contacting surfaces are curved such that the concave surface of one element meshes with the convex surface of a neighboring element, resulting in interlocking. Since the interlocking is independent of the material and block dimensions, it is possible to use different materials and varying dimensions, so long as they fit into a cohesive whole. In the case of the space shuttle, most of its surfaces are nonplanar, and the thermal cladding will require the use of nonplanar osteomorphic blocks (tiles).

One major advantage of the interlocking structure is that even if individual tiles are cracked or damaged, they will still be held in place by neighboring tiles. Thermal expansion of the tiles can be accommodated by the inclusion of gaps between the tiles, provided that the gaps are small and do not affect the interlocking.

The recent tragic loss of the Space Shuttle Columbia and its crew of seven astronauts underlines the safety concerns of every system that makes up the spacecraft. There is strong evidence that a piece of foam from one of the booster rockets struck and damaged the carbon-fiber composite panel on the edge of the left wing of the shuttle (part of the TPS not protected by tiles). Although topologically interlocked tiles might not prevent similar disasters in future spacecraft, they may form a safer TPS for the parts of the spacecraft where tiles are used.

GOPAL R. RAO

Shock-Wave Modulation of the Dielectric Constant of Photonic Crystals Produces Optical Phenomena

Dielectric photonic crystals are opening promising new methods to control the propagation of light. E. Reed, M. Soljacic, and J. Joanapoulous of the Massachusetts Institute of Technology, through numerical simulations and analytical theory, have explored the phenomena associated with light scattering from a shocklike wave in a photonic crystal. They have uncovered three phenomena, which they reported in the May 23 issue of *Physical Review Letters*. The first is the transfer of light frequency from the bottom of a bandgap to the top (up-conversion) or vice versa (down-conversion). The second is the capture of light of significant bandwidth in a localized region at the shock front for a controlled period of time. And the third is the possibility of achieving a decrease in the bandwidth of the propagating light. The researchers reported that when light is captured at the shock front, it is possible to observe reemission at a tunable pulse rate, and at a tunable frequency with a narrowing bandwidth.

The researchers said that shocked photonic crystals can be an alternative to nonlinear materials for frequency switching, and they also can be powerful materials for the manipulation of light pulses for quantum information. In their analysis, for illustrative purposes, the researchers modeled their photonic crystals with a part containing the shock wave and an unshocked part. They assumed that the period of the shocked crystal is half of that of the original crystals and that the shock wave moves into the unshocked part of the crystal at a given velocity. They describe the computed time-dependent optical phenomena in terms of the changes in time of the numbers of unit cells in each part of the crystal. For practical purposes, they considered the effect on a photonic crystal, for example a silicon/silicon dioxide multilayer, shocked to a strain of a few percent. From their analysis, the researchers find that shining light into this crystal will result in reflected light with a frequency shift of the order of 1%, a pulse rate of 10 GHz for light of

1 µm wavelength, and an expected band narrowing of a factor of 10.

ROSALIA SERNA

Nanoclusters of Niobium Display Nonmetallic Properties at Ultracold Temperatures

While searching for signs of superconductivity in nanometer-scale clusters of the metal niobium, researchers at the Georgia Institute of Technology found that the material stops behaving as a metal when the clusters—of up to 200 niobium atoms—are cooled to low temperature. The electrical charges in the clusters suddenly shift, forming dipoles, as the temperature is lowered below a transition temperature that depends on cluster size.

"This is very strange, because no metal is supposed to be able to do this," said Walter de Heer, a professor in the School of Physics at the Georgia Institute of Technology. "These clusters become spontaneously polarized, with electrons moving to one side of the cluster for no apparent reason. One side of each cluster becomes negatively charged, and the other side becomes positively charged. The clusters lock into that behavior." In bulk metals—including niobium clusters at room temperature—electrical charge is normally distributed equally throughout the sample unless an electric field is applied to them.

This ferroelectric phenomenon has so far been observed in clusters of niobium, vanadium, and tantalum—three transition metals that in bulk form become superconducting at about the same temperature that the researchers observe formation of dipoles in the tiny clusters. De Heer believes this discovery will provide insights into superconductivity.

For the smallest clusters, as reported in the May 23 issue of *Science* by de Heer and collaborators R. Moro, X. Xu, and S. Yin, the strength of the dipole effect varies dramatically according to size. Clusters composed of 14 atoms display strong effects, while those made up of 15 atoms show little effect. Above 30 atoms, clusters with even numbers of atoms display stronger dipole effects than clusters with odd numbers of atoms.

De Heer attributes the size sensitivity to the quantum size regime, which is related to restrictions on how electrons can move in very small clusters.

To produce and study the clusters, the researchers use a custom-built apparatus that includes a detector able to count and characterize several million particles per hour. First, a laser beam is used to vaporize the niobium, creating a cloud of metallic vapor. A stream of ultracold helium gas is then injected into a vacuum chamber housing the vapor, causing the niobium gas to condense into particles of varying sizes. Under pressure from the helium, the particles exit through a small hole in the chamber's wall, creating a 1-mm-wide jet of particles that passes between two metal plates before hitting the detector.

At intervals 1 min apart, the metal plates are energized with 15,000 V, creating a strong electrical field. The field interacts with the polarized niobium nanoclusters, causing them to be deflected away from the detector. Unpolarized clusters remain in the beam and are counted by the detector.

By comparing detector readings while the plates are energized against the readings when no field is applied, the researchers learn which clusters carry the dipole. By varying the temperature and voltage, the research team can study the impact of these changes on the effect.

"By studying several different metals, we found that those that are superconducting in bulk have this effect, and those that are not superconducting do not have it. That strengthens our belief that this is connected to superconductivity in some way that we don't yet understand," de Heer said.

Radiotracer Diffusion Measurements of Isotope Motion in a Metal Alloy above the Glass-Transition Temperature Support Mode-Coupling Theory

The discovery of alloys formed from bulk metallic glass has offered a host of applications ranging from casings for mobile phones to golf clubs. Like conventional glasses, these alloys are processed by supercooling the melt though the glass transition. Much effort has been made into understanding the atomic motion in the supercooled melt and the dynamics of the glass transition. Recently, researchers at Kiel University have measured diffusion and the isotope effect in a Pd-based metallic alloy from the glassy state to the equilibrium liquid. The scientists said that the results, reported by V. Zöllmer, K. Rätzke, F. Faupel, and A. Meyer in the May 16 issue of *Physical Review Letters*, provide direct evidence of the decay of activation barriers due to the onset of liquidlike motion.

According to Faupel, who holds the Chair for Multicomponent Materials at Kiel, the most striking result is that the onset of liquidlike motion upon heating the metallic glass is not observed at the caloric glass-transition temperature,

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