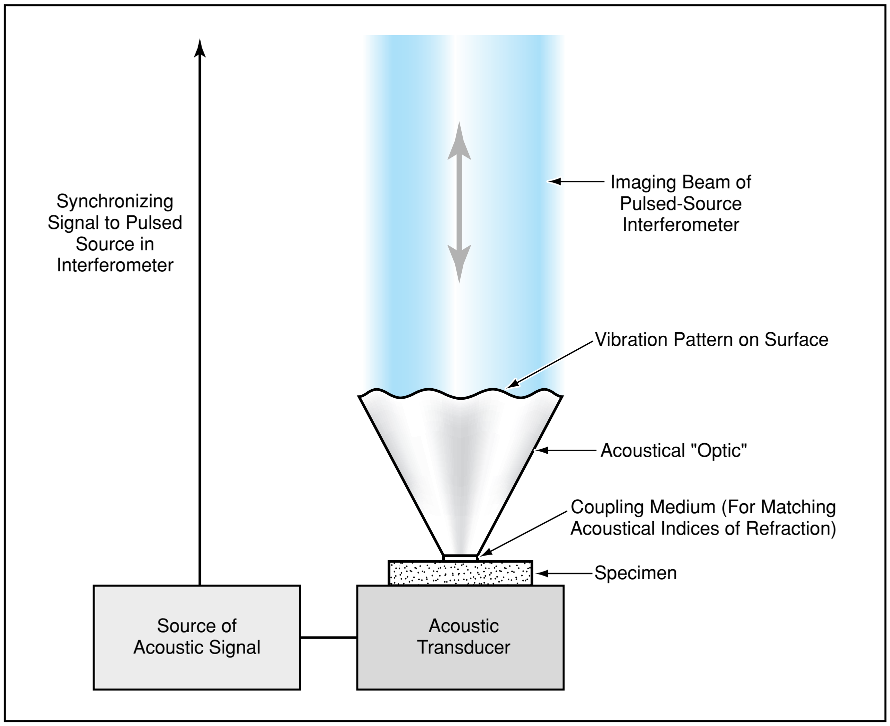
Pulsed-Source Interferometry in Acoustic Imaging

Buried features as small as 30 nm could be resolved.

NASA's Jet Propulsion Laboratory, Pasadena, California

A combination of pulsed-source interferometry and acoustic diffraction has been proposed for use in imaging subsurface microscopic defects and other features in such diverse objects as integrated-circuit chips, specimens of materials, and mechanical parts. A specimen to be inspected by this technique would be mounted with its bottom side in contact with an acoustic transducer driven by a continuous-wave acoustic signal at a suitable frequency, which could be as low as a megahertz or as high as a few hundred gigahertz (see figure). The top side of the specimen would be coupled to an object that would have a flat (when not vibrating) top surface and that would serve as the acoustical analog of an optical medium (in effect, an acoustical "optic").



A **Pulsed-Source Interferometer** would be used to measure the phase and amplitude of a vibration pattern related to acoustic diffraction by microfeatures in the specimen. The pattern would then be used to compute an acoustic image of the microfeatures.

Microfeatures within the specimen would diffract the acoustic wave. The diffracted wave would propagate through the acoustical "optic," forming a vibration pattern on the top surface. The vibration pattern would be measured twice by use of a pulsed-source optical interferometer; the first measurement would be taken in phase, the second 90° out of phase with the acoustic signal at its source. The amplitude and phase of the vibration pattern, and thus of the acoustic field, would be computed from the two measurements. Then by use of a diffraction formula, the acoustic pattern would be computationally propagated back into the specimen to obtain an acoustic image of the internal microfeatures.

The pulsed-source interferometer has already been demonstrated, in a different application, to afford an amplitude resolution as small as 1 nm. With refinements in design and operation, it should be possible to resolve amplitudes an order of magnitude smaller. If, in addition, the acoustic frequency were at least 30 GHz, then it should be possible to image features as small as 30 nm. The ability to image at such high resolution would be a significant contribution to the art of nondestructive microscopy. Of course, lower acoustic frequencies could be used to image larger features in applications in which the highest resolution is not needed.

This work was done by Kirill Shcheglov, Roman Gutierrez, and Tony K. Tang of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*
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Thermo-Electron Ballistic Coolers or Heaters

These devices may surpass currently available thermoelectric devices.

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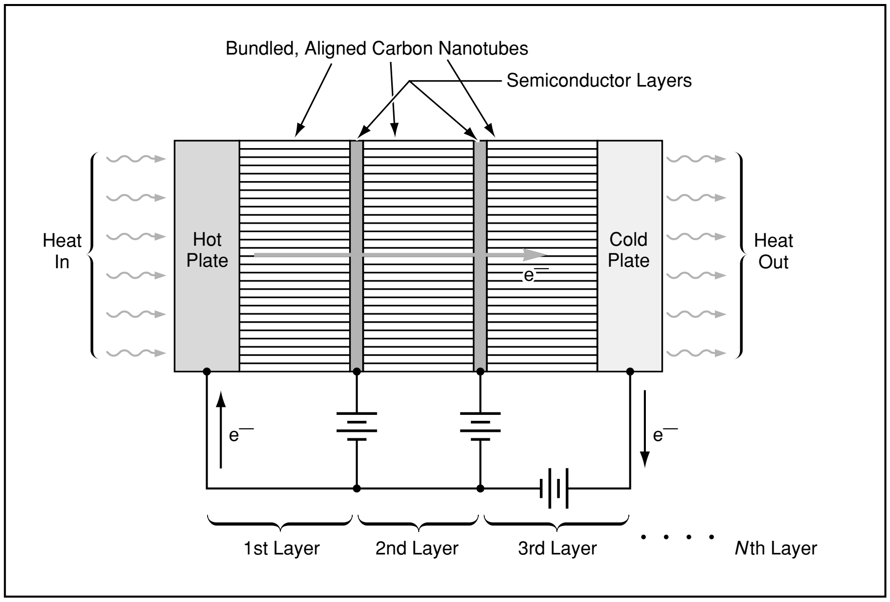
Electronic heat-transfer devices of a proposed type would exploit some of the quantum-wire-like, pseudo-superconducting properties of single-wall carbon nanotubes or, optionally, room-temperature-superconducting polymers (RTSPs). The devices are denoted thermo-electron ballistic (TEB) coolers or heaters because one of the properties that they exploit is the totally or nearly ballistic (dissipation or scattering free) transport of electrons. This property is observed in RTSPs and carbon nanotubes that are free of material and geometric defects, except under conditions in which oscillatory electron motions become coupled with vibrations of the nanotubes. Another relevant property is the high number density of electrons passing through carbon nanotubes — sufficient to sustain electron current densities as large as 100 MA/cm^2. The combination of ballistic motion and large current density should make it possible for TEB devices to operate at low applied potentials while pumping heat at rates several orders of magnitude greater than those of thermoelectric devices. It may also enable them to operate with efficiency close to the Carnot limit. In addition, the proposed TEB devices are expected to operate over a wider temperature range.

A typical TEB device (see figure) would include an electrically and thermally conductive plate, denoted the hot plate, on the side from which heat is to be transferred; *N* layers (*N* = 3 in the figure) of bundled and aligned carbon nanotubes interspersed



0A **TEB Device** would exploit thermionic emission, ballistic transport of electrons in carbon nanotubes, and Schottky barriers at nanotube/semiconductor interfaces. The thickness of each nanotube layer would be of the order of 5 µm.

with N – 1 semiconductor layers; an electrically and thermally conductive plate, denoted the cold plate, on the side to which heat is to be transferred; and small batteries or other DC electric power sources and wiring connected to the hot and cold plates and to the semiconductor layers. Under the influence of the electric potential field applied by the DC sources, some of the thermally agitated electrons would be adiabatically swept away from the hot plate into the first layer of nanotubes. (Because of this mode of operation, the device could also be called a thermionic cooler or heater.) The applied electric field would accelerate the electrons moving in the nanotubes, giving them enough kinetic energy to overcome the Schottky barrier at the nanotube/semiconductor interface. Consequently, the Schottky barrier would act as a one-way valve for energetic electrons.

In the same manner as described above, thermally agitated electrons in each semiconductor layer would be made to travel through the next nanotube layer to the next semiconductor layer, and so forth until the electrons reach the cold plate, from whence they would be removed via an ohmic contact into the wiring. The closed electric circuit would maintain charge neutrality, supplying electrons to the hot plate and semiconductor layers to replace those removed by thermionic emission and applied electric fields. In addition to a DC potential applied between the hot and cold plates, DC bias potentials could be applied to the semiconductor layers to control the quantum-mechanical tunneling of electrons through the Schottky barriers.

It will be necessary to perfect a number of techniques in order to fabricate TEB devices. Among these are techniques for (1) depositing RTSPs or growing highly pure, aligned single-wall carbon nanotubes on electrically and thermally conductive substrates that can serve as hot and cold plates; (2) cutting the nanotubes to make clean, flat planes on which semiconductor layers can be deposited; and (3) depositing RTSPs or growing highly pure, aligned single-wall carbon nanotubes on the semiconductor layers. The overall thickness of a TEB device would be determined largely by the number of carbon-nanotube layers, the length (≈5 µm) of the nanotubes in each layer, and the thicknesses of the semiconductor layers. It should be possible to make TEB devices so thin that they could be incorporated into or onto flexible structures.

This work was done by Sang H. Choi of **Langley Research Center**. *Further information is contained in a TSP [see page 1]. LAR-16222*

Optoelectronic Apparatus Measures Glucose Noninvasively

The concentration of glucose is obtained through a combination of interferometry and polarimetry.

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An optoelectronic apparatus has been invented as a noninvasive means of measuring the concentration of glucose in the human body. The apparatus performs polarimetric and interferometric measurements of the human eye to acquire data from which the concentration of glucose in the aqueous humor can be computed. Because of the importance of the concentration of glucose in human health, there could be a large potential market for instruments based on this apparatus.

The apparatus (see figure) includes a light source equipped with a linear polarizer and a quarter-wave retarder to generate a beam of circularly polarized light. The beam is aimed at an eye at an angle of incidence (θ_i) chosen so that after refraction at the surface of the cornea, it travels through the aqueous humor and impinges on the crystallin lens at the Brewster angle [$\theta_b = \arctan(n_l/n_h)$, where n_l and n_h are the indices of refraction of the lens and the aqueous humor, respectively]. The portion of the beam that enters and passes through the eye is denoted the probe beam. The portion of the beam reflected from the cornea is further reflected by a mirror and used as a reference beam for low-coherence interferometry.

The Brewster-angle arrangement causes the portion of the probe beam reflected from the lens to be linearly polarized perpendicular to the plane of incidence (which here coincides with the plane of the page). As the reflected probe beam traverses the aqueous humor, glucose molecules rotate its plane of polarization. This rotational effect is well established: It is characterized by previously determined, wavelength-dependent proportionality between (1) the angle of rotation of the plane of polarization and (2) the product of the concentration of glucose and the length of the optical path through the solution (in this case, aqueous humor) that contains the glucose. Hence, if one can measure the rotation of polarization of the reflected light and the length of its path through the aqueous humor, one can calculate the concentration of glucose by use of the aforementioned proportionality.

After leaving the eye, the reflected probe beam enters beam splitter 1. Part of the probe beam passes through beam splitter 1 and goes to a polarimetric sensor, which