thicknesses of layers, this device could be made to operate in either of two regimes (see figure):

- Under low bias, in a resonant-interband-tunneling regime, in which electrons would traverse valence subband states in GaSb or
- Under moderate bias, in an intraband-resonant-tunneling regime, in which electrons would traverse conduction subband states in InAs. Computational simulations have led to an expectation that the interband regime would yield better performance.

This work was done by David Z.-Y. Ting, Xavier Cartoixà, and Thomas C. McGill of Caltech; Jeong S. Moon, David H. Chow, and Joel N. Schulman of HRL Laboratories, LLC; and Darryl L. Smith of Los Alamos National Laboratory for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Refer to NPO-30635, volume and number of this NASA Tech Briefs *issue, and the page number.*

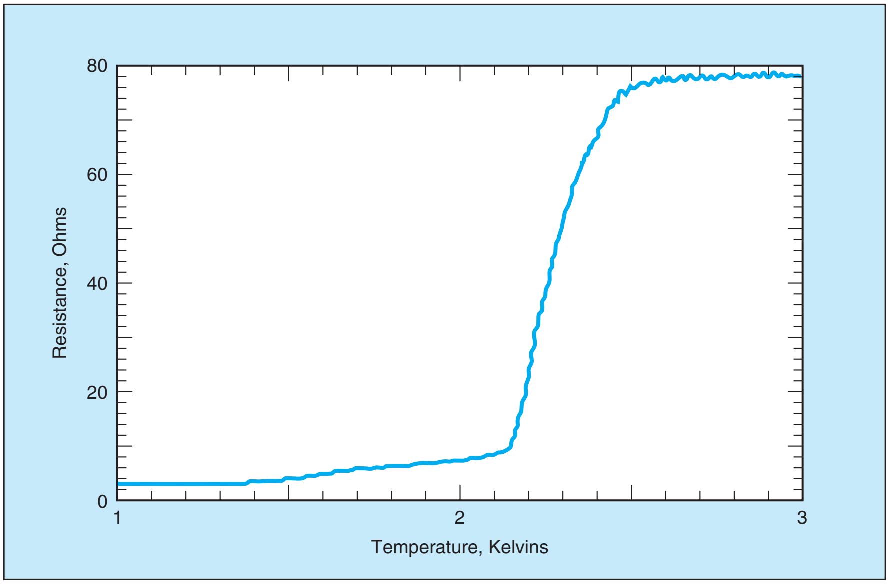
Diffusion-Cooled Tantalum Hot-Electron Bolometer Mixers

Lower TCs should translate to lower noise and lower required local-oscillator power.

NASA's Jet Propulsion Laboratory, Pasadena, California

A batch of experimental diffusion-cooled hot-electron bolometers (HEBs), suitable for use as mixers having input frequencies in the terahertz range and output frequencies up to about a gigahertz, exploit the superconducting/normal-conducting transition in a thin strip of tantalum. The design and operation of these HEB mixers are based on mostly the same principles as those of a prior HEB mixer that exploited the superconducting/normal-conducting transition in a thin strip of niobium and that was described in "Diffusion-Cooled Hot-Electron Bolometer Mixer" (NPO-19719), *NASA Tech Briefs*, Vol. 21, No. 1 (January 1997), page 12a.

One reason for now choosing tantalum instead of niobium arises from the fact that the superconducting-transition temperature (T_C) of tantalum lies between 2 and 3 K, while that of niobium lies between 6 and 7 K. Theoretically, the input mixer noise of a superconducting HEB is proportional to T_C and the power demand on the local oscillator that supplies one of the input signals to the mixer is proportional to T_C^2. The lower noise and power demand associated with the lower T_C of tantalum could make tantalum HEBs more attractive, relative to niobium HEBs, in applications in which there are requirements to minimize noise and/or to provide mixers that can function well using the weak signals generated by typical solid-state local oscillators. Of course, to reach the required lower T_C, it is necessary to use more complex cryogenic equipment. Fortunately, such equipment (e.g., helium-3 cryostats) is commercially available.



DC Resistance of an HEB was measured as a function of temperature from below to above T_C. Except for the lower T_C, this plot is similar to the resistance-vs.-temperature plots of niobium HEBs. The nonzero-resistance "foot" of this plot is an effect of normally conductive gold contact pads at the ends of the device.

In order to make a practical tantalum HEB, it is necessary to overcome a challenge posed by the fact that thin films of tantalum tend to contain grains of two different crystalline phases. The presence of the two phases would be unacceptable in a practical device because (1) the additional electron scattering at the grain boundaries would tend to suppress the diffusion-cooling mechanism, and (2) the different T_Cs of the two phases would lead to broadening of the transition.

The present HEB mixers contain tantalum microbridges having lengths of 100 to 400 nm, widths of 100 to 200 nm, and thicknesses of 10 nm. The bridges were made from a 10-nm-thick film of tantalum deposited by sputtering onto a 1.5-nm-thick seed layer of niobium on a silicon wafer. The niobium seed layer was used to promote the growth of one of the two crystalline phases (the α phase) to ensure the required crystalline purity and thereby keep the superconducting transition (see figure) as sharp as possible.

The results of microwave impedance tests of one of the experimental tantalum HEBs have been interpreted as signifying that the 3-dB roll-off frequency for mixer conversion efficiency can be expected to be about 1 GHz, neglecting the effect of electrothermal feedback. End effects are small enough (as illustrated by the smallness of the "foot" of the resistance-versus-temperature curve in the figure) that it should be possible to use devices as short as 100 nm and possibly even shorter. Inas-much as the thermal-relaxation time for diffusion cooling is proportional to the square of the device length, the 100-nm-long devices should be capable of "raw" speeds of about 16 GHz. Since only a few gigahertz of bandwidth is needed for most mixer applications, it is expected that tantalum HEBs will be fast enough even in the presence of slowing effects of electrothermal feedback, which is present in most bolometer mixer circuits.

This work was done by Anders Skalare, William McGrath, Bruce Bumble, and Henry LeDuc of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-30695

Tunable Optical True-Time Delay Devices Would Exploit EIT

Adjustable delays up to milliseconds would be generated within small volumes.

NASA's Jet Propulsion Laboratory, Pasadena, California

Tunable optical true-time delay devices that would exploit electromagnetically induced transparency (EIT) have been proposed. Relative to prior true-time delay devices (for example, devices based on ferroelectric and ferromagnetic materials) and electronically controlled phase shifters, the proposed devices would offer much greater bandwidths. In a typical envisioned application, an optical pulse would be modulated with an ultra-wideband radio-frequency (RF) signal that would convey the information that one seeks to communicate, and it would be required to couple differently delayed replicas of the RF signal to the radiating elements of a phased-array antenna. One or more of the proposed devices would be used to impose the delays and/or generate the delayed replicas of the RF-modulated optical pulse. The beam radiated or received by the antenna would be steered by use of a microprocessor-based control system that would adjust operational parameters of the devices to tune the delays to the required values.

EIT is a nonlinear quantum optical interference effect that enables the propagation of light through an initially opaque medium. A suitable medium must have, among other properties, three quantum states (see Figure 1): an excited state (state 3), an upper ground state (state 2), and a lower ground state (state 1). These three states must form a closed system that exhibits no decays to other states in the presence of either or both of two laser beams: (1) a probe beam having the wavelength corresponding to the photon energy equal to the energy difference between states 3 and 1; and (2) a coupling beam having the wavelength corresponding to the photon energy equal to the energy difference between states 3 and 2. The probe beam is the one that is pulsed and modulated with an RF signal.

If a properly adjusted probe pulse is sent into the medium in the absence of the coupling beam, the atoms completely absorb the pulse and jump from state 1 to state 3. This absorption is what makes the medium opaque. In the presence of the coupling beam, states 2 and 3 become coupled, preventing the absorption of the probe beam and thereby rendering the medium transparent to the probe beam. At resonance (that is, when the laser wavelengths correspond exactly to the differences between the energy levels of the quantum states of the medium), the index of refraction of the medium is exactly 1. At slightly different frequencies, the degree of cancellation of absorption of the probe beam is less and the index of refraction differs. The nature of the variation of the slope of the index of refraction as a function of wavelength is such as to substantially reduce the group velocity of a probe light pulse.

The reduction in group velocity can be exploited to slow and even stop the pulse. If the coupling pulse is turned off when the probe pulse reaches the middle of the medium, the probe pulse becomes trapped in the quantum states of the medium. The ratio between the numbers of atoms in states 1 and 2 is a measure of the ratio between the electric-field strengths of the probe and the coupling beams immediately before turn off. Also, the quantum state of the RF modulation of a stopped light pulse is stored in the spin quantum state of the medium. After a desired delay, the quantum state of the medium can be interrogated optically: Turning the coupling beam back on causes the regeneration of the optical pulse, complete with the RF modulation.

Suitably prepared clouds of alkali atoms (e.g., clouds of optically cooled sodium vapor) have been observed to exhibit EIT and would be used as the initially opaque media in the proposed devices. Recent experiments in compact cells (<1 cm^3) of alkali-atom vapors have demonstrated that light pulses can be effectively decelerated to speeds of tens of meters per second and even stopped for controlled amounts of time that can range from microseconds to milliseconds. In contrast, to obtain millisecond delays by use of optical fibers, it would be necessary to make the fibers hundreds of kilometers long, and the delays would not be adjustable because the lengths would not be adjustable.

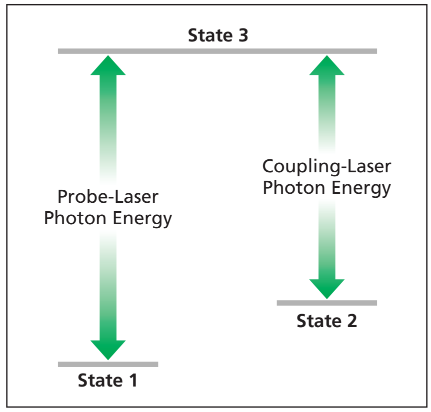


Figure 1. A **Closed System of Three Quantum States** that are accessible via laser beams is among characteristics essential for electromagnetically induced transparency.

A simple example of a device according to the proposal is depicted schematically in Figure 2. A probe laser beam would be split into two parts: an undelayed (reference) beam and a beam to be delayed. A single probe pulse would be generated, yielding a single reference pulse. The probe pulse would be trapped in the medium, then released by use of suitably timed coupling pulses. If the coupling pulses were cycled on and off several times with sufficient rapidity while the probe pulse was still inside the medium, then several differently delayed replicas of the probe pulse would be generated.

This work was done by Igor Kulikov, Leo DiDomenico, and Hwang Lee of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
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