slot antenna designed following this approach. Intended for use as part of a radiometer operating at a frequency of 10.7 GHz, this antenna was fabricated from dimensions defined exclusively by results of computational simulations. The final design was found to be well optimized and to yield performance exceeding that initially required.

This work was done by R. B. Gosselin of **Goddard Space Flight Center**. *Further information is contained in a TSP (see page 1).*
GSC-14747-1

Carbon-Nanotube Schottky Diodes

These devices can outperform conventional Schottky diodes at submillimeter wavelengths.

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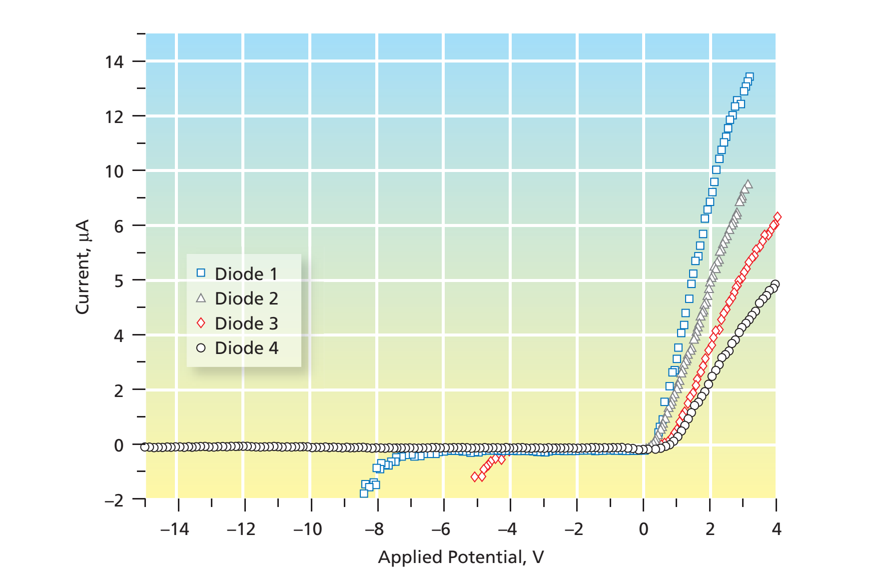
Schottky diodes based on semiconducting single-walled carbon nanotubes are being developed as essential components of the next generation of submillimeter-wave sensors and sources. Initial performance predictions have shown that the performance characteristics of these devices can exceed those of the state-of-the-art solid-state Schottky diodes that have been the components of choice for room-temperature submillimeter-wave sensors for more than 50 years.

For state-of-the-art Schottky diodes used as detectors at frequencies above a few hundred gigahertz, the inherent parasitic capacitances associated with their semiconductor junction areas and the resistances associated with low electron mobilities limit achievable sensitivity. The performance of such a detector falls off approximately exponentially with frequency above 500 GHz. Moreover, when used as frequency multipliers for generating signals, state-of-the-art solid-state Schottky diodes exhibit extremely low efficiencies, generally putting out only microwatts of power at frequencies up to 1.5 THz.

The shortcomings of the state-of-the-art solid-state Schottky diodes can be overcome by exploiting the unique electronic properties of semiconducting carbon nanotubes. A single-walled carbon nanotube can be metallic or semiconducting, depending on its chirality, and exhibits high electron mobility (recently reported to be $\approx 2 \times 10^5$ cm^2/V-s) and low parasitic capacitance. Because of the narrowness of nanotubes, Schottky diodes based on carbon nanotubes have ultra-small junction areas (of the order of a few square nanometers) and consequent junction capacitances of the order of 10^{-18} F, which translates to cutoff frequency >5 THz. Because the turn-on power levels of these devices are very low (of the order of nanowatts), the input power levels needed for pumping local oscillators containing these devices should be lower than those needed for local oscillators containing state-of-the-art solid-state Schottky diodes.

In terms that are necessarily simplified for the sake of brevity, a carbon-nanotube-based Schottky diode is fabricated in a process that features evaporative deposition of dissimilar metal contacts onto opposite ends of a semiconducting single-walled carbon nanotube. One of the metals (platinum in initial experiments) is chosen to have a work function greater than that of the carbon nanotube, so as to form an ohmic contact. The other metal (titanium in initial experiments) is chosen to have a work function less than that of the carbon nanotube, so as to form a Schottky contact. These metals are then covered with outer layers of gold. The figure shows the rectifying behavior of four experimental devices fabricated in such a process.



Rectifying Behavior is apparent in the DC current-versus-voltage characteristics of four experimental carbon-nanotube-based Schottky diodes that were fabricated on the same substrate.

To reduce the effective series resistance, it is preferable to fabricate such a device in the form of a set of multiple parallel single-wall carbon nanotubes, grown on the same substrate, bridging the gap between the higher- and the lower-work-function metal contact. Usually, in such a case, some of the carbon nanotubes turn out to be metallic and, hence, must be removed to obtain the desired rectifying behavior. Removal can be effected by a previously published procedure in which the semiconducting nanotubes are gated off and the metallic ones are selectively burned out.

This work was done by Harish Manohara, Eric Wong, Erich Schlecht, Brian Hunt, and Peter Siegel of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

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