



## nBn Infrared Detector Containing Graded Absorption Layer

Potential applications include environmental monitoring, firefighting, law enforcement, and medical diagnosis.

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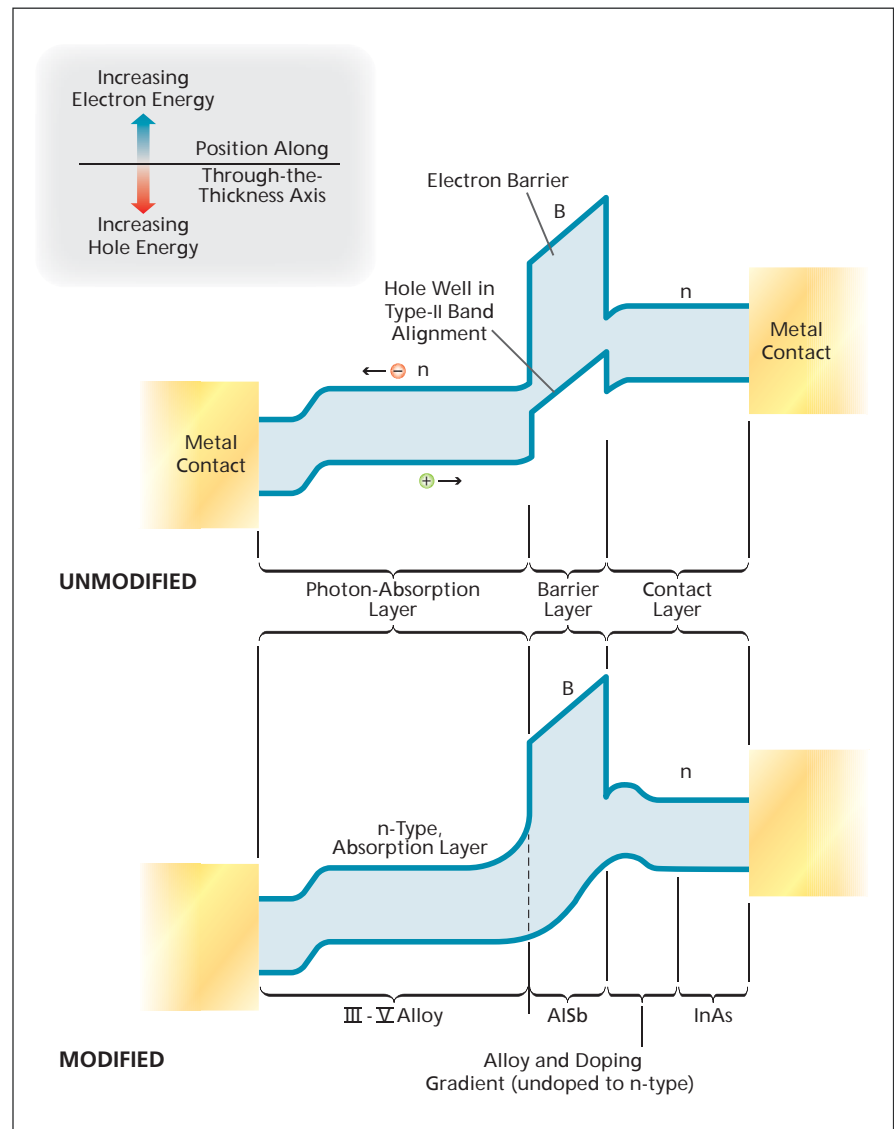
It has been proposed to modify the basic structure of an nBn infrared photodetector so that a plain electron-donor-type (n-type) semiconductor contact layer would be replaced by a graded n-type III-V alloy semiconductor layer (i.e., ternary or quarternary) with appropriate doping gradient. The abbreviation "nBn" refers to one aspect of the unmodified basic device structure: There is an electron-barrier ("B") layer between two n-type ("n") layers, as shown in the upper part of the figure. One of the n-type layers is the aforementioned photon-absorption layer; the other n-type layer, denoted the contact layer, collects the photocurrent.

The basic unmodified device structure utilizes minority-charge-carrier conduction, such that, for reasons too complex to explain within the space available for this article, the dark current at a given temperature can be orders of magnitude lower (and, consequently, signal-to-noise ratios can be greater) than in infrared detectors of other types. Thus, to obtain a given level of performance, less cooling (and, consequently, less cooling equipment and less cooling power) is needed. [In principle, one could obtain the same advantages by means of a structure that would be called "pBp" because it would include a barrier layer between two electron-acceptor-type (p-type) layers.] The proposed modifications could make it practical to utilize nBn photodetectors in conjunction with readily available, compact thermoelectric coolers in diverse infrared-imaging applications that could include planetary exploration, industrial quality control, monitoring pollution, firefighting, law enforcement, and medical diagnosis.

The modifications are meant to address an aspect of the basic unmodified device structure that limits the performance advantages to photons having wavelengths less than either of two specific values: 3.4 or 4.4  $\mu\text{m}$ . These values correspond to bandgaps associated with two specific semiconductor alloy com-

positions (InAs or InAsSb, respectively), either of which could be used in the photon-absorption layer. For reasons that, once again, are too complex to describe within the space available for this article, these two compositions are the only ones that afford the energy-band structures needed to obtain the desired combination of adequate

photogenerated current and reduction of dark current with AlSb barrier. For other values, depending on the type of energy-band alignment, there arise, in the B layer, a valence-band well for holes. Undesirably, holes will be trapped in the valence-band well, with consequent reduction of collectable hole photocurrent through tunneling



These Energy-Band Diagrams, simplified and not to scale, pertain to an example of an unmodified nBn photodetector and a corresponding modified nBn photodetector, both with bias applied via the metal contacts.

of holes to the conduction band and buildup of charge at the Bn (i.e., at the barrier and n-contact) interface.

The lower part of the figure depicts the energy-band structure for one of the proposed modified device structures. In this case, the plain n-type contact layer would be replaced with a graded III–V alloy layer with proper doping gradient from undoped to doped n contact. The valence band potential dip can be eliminated under proper bias condition. In a different modification, not shown in the

figure, the plain photon-absorption layer could be replaced with a chirped strain-layer superlattice. In either modification, the graded or chirped structure would provide an energy ramp that would serve as a smooth path for transport of minority charge carriers. The valence-band hole trap and the associated undesired effects would be eliminated.

*This work was done by Sarath D. Gunapala, David Z. Ting, Cory J. Hill, and Sumith V. Bandara of Caltech for NASA's Jet Propulsion Laboratory.*

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## Atomic References for Measuring Small Accelerations

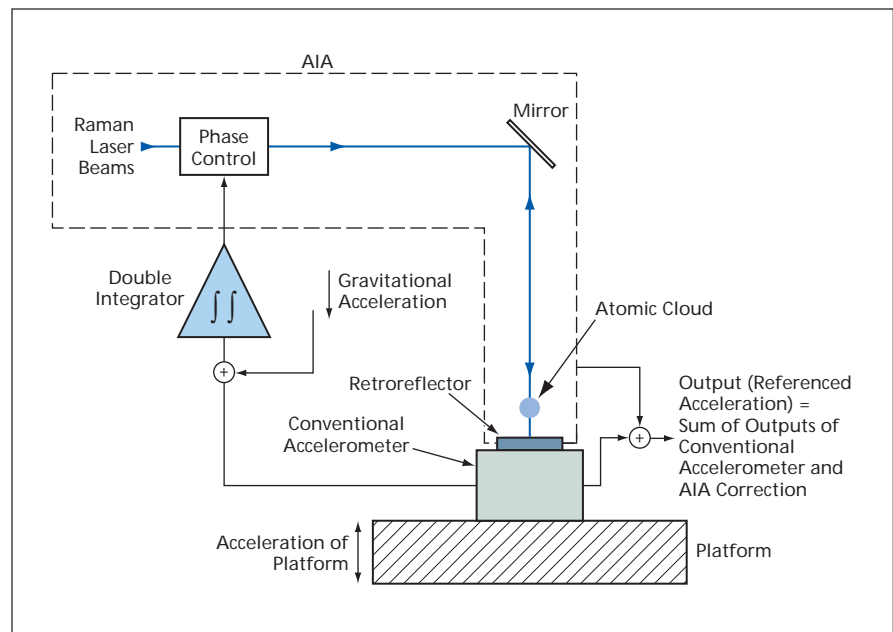
These systems may be used in military and geological applications.

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Accelerometer systems that would combine the best features of both conventional (e.g., mechanical) accelerometers and atom interferometer accelerometers (AIAs) have been proposed. These systems are intended mainly for use in scientific research aboard spacecraft but may also be useful on Earth in special military, geological, and civil-engineering applications.

Conventional accelerometers can be sensitive, can have high dynamic range, and can have high frequency response, but they lack accuracy and long-term stability. AIAs have low frequency response, but they offer high sensitivity, and high accuracy for measuring small accelerations. In a system according to the proposal, a conventional accelerometer would be used to perform short-term measurements of higher-frequency components of acceleration, while an AIA would be used to provide consistent calibration of, and correction of errors in, the measurements of the conventional accelerometer in the lower-frequency range over the long term.

A brief description of an AIA is prerequisite to a meaningful description of a system according to the proposal. An AIA includes a retroreflector next to one end of a cell that contains a cold cloud of atoms in an ultrahigh vacuum. The atoms in the cloud are in free fall. The retroreflector is mounted on the object, the acceleration of which is to be measured. Raman laser beams are directed through the cell from the end opposite the retroreflector, then pass back through the cell after striking the retroreflector. The Raman laser beams together with the cold atoms measure



An Atom-Interferometer Accelerometer (AIA) and a conventional accelerometer would be connected in a feedback loop, such that the net acceleration measurement would be that of the conventional accelerometer plus a correction term provided by the AIA.

the relative acceleration, through the readout of the AIA, between the cold atoms and the retroreflector.

A system according to the proposal could be realized in several alternative implementations. In the simplest implementation (see figure), the conventional accelerometer and the retroreflector of the AIA would be mounted on a platform, the acceleration of which was to be measured. The phase of the Raman laser beams is frequency-chirped to remove the known gravity acceleration. From the output of the conventional accelerometer, the equivalent phase shift of the AIA is converted

through the electronic double integrator. This phase is electronically fed forward to a Raman laser phase shifter such that it cancels out the phase shift in the AIA due to the acceleration read by the conventional accelerometer. The remaining part of the AIA phase shift would be used to compute a residual acceleration that would be applied as a correction to the acceleration measurement of the conventional accelerometer.

*This work was done by Lute Maleki and Nan Yu of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).  
NPO-43776*