Journal of ELECTRONIC MATERIALS, Vol. 42, No. 11, 2013
DOI: 10.1007/s11664-013-2685-x


# Numerical Simulation and Analytical Modeling of InAs nBn Infrared Detectors with *p*-Type Barriers

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This paper presents finite-element one-dimensional numerical simulations and analytical modeling for ideal (diffusion current only) nBn detectors with *p*-type barrier layers. The simulations show that the current–voltage $J(V)$ and the dynamic resistance versus voltage $R_D(V)$ relations, both dark and illuminated, are in excellent agreement with the equations for ideal back-to-back photodiodes. We present a depletion approximation model for the nBn detector, analogous to that for the conventional *p*–*n* junction photodiode, based on new boundary conditions on the hole concentrations versus voltage at the edges of the nBn barrier layer. We show that these nBn boundary conditions are identical to those for ideal back-to-back photodiodes, justifying the applicability of back-to-back photodiode equations to describe the ideal nBn detector. The simulations for the space-charge regions show a low-bias-voltage regime and a high-bias-voltage regime. The integrated space-charge densities in the layers adjacent to the barrier layer vary linearly with bias voltage. Negative dynamic resistance occurs because the bias voltage changes the effective thickness of the thin-base layers that generate diffusion current. We present a new formulation of the model for ideal back-to-back photodiodes with a more elegant and transparent set of equations for $J(V)$ and $R_D(V)$.

**Key words:** InAs, nBn, infrared detector, back-to-back photodiodes, photodiode, numerical simulation

## INTRODUCTION

The nBn detector is a new type of semiconductor infrared detector that was introduced relatively recently.[1,2] This new detector consists of a narrow-gap *n*-type absorber layer, a wide-gap depleted barrier layer, and a narrow-gap *n*-type contact layer. The barrier layer presents a large barrier in the conduction band that eliminates electron flow, and the nBn detector operates as a unipolar unity-gain detector.

A key benefit of the nBn architecture is that, for a wide range of design parameters, there is no depletion region in the narrow-gap layers, thereby eliminating the space-charge generation–recombination (g–r) dark currents that have plagued conventional InAs and InAsSb junction photodiodes and severely limited their applicability for high sensitivity requirements at lower temperatures. Another key benefit of the nBn architecture is self-passivation. The narrow-gap absorber layer is buried beneath a wide-gap barrier layer, effectively eliminating surface effects. Yet another benefit is that the nBn detector architecture lends itself readily to bias-selectable two-color detector applications.

The nBn detector requires that the valence bands of the three layers line up closely to allow hole transport between the absorber and collector layers. This requirement has so far restricted applications of the nBn detector to InAs or $InAs_{1-x}Sb_x$ ($x \approx 0.1$) absorber layers and $AlAs_xSb_{1-x}$ barrier layers,

(Received January 12, 2013; accepted July 4, 2013; published online August 16, 2013)