Demonstration of an \textit{n-i-p-i} Photovoltaic Device

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**Abstract:**

The fabrication of multi-period GaAs \textit{nipi} doping superlattice solar cells has been demonstrated. A fundamental benefit of the doping superlattice is the modification of the band structure, resulting in the absorption of sub-bandgap photons. Multiple fabrication steps required in the fabrication of the unique design have been characterized. A device has been fabricated and tested, where quantum confinement has been demonstrated within the doping superlattice structure.

![Figure 1: Schematic depicting n-type and p-type contacts grown in the v-groove's that are etched into the nipi epitaxial layers, and the lateral majority carrier transport that results in charge separation. Right side of the figure provides a band diagram depicting the sinusoidal type energy levels in the active region.](image)

**Summary of Research:**

An \textit{n-i-p-i} device consists of repeating \textit{n-type} / intrinsic / \textit{p-type} / intrinsic doped (\textit{nipi}) epitaxial GaAs layers, that are stacked vertically to form a parallel connected multi-period solar cell. The layers form a sinusoidal-like band alignment due to the alternating \textit{n-} and \textit{p-type} dopants [1] as shown in Figure 1. This design results in a high carrier extraction efficiency due to the predominantly drift field dependent minority carrier collection in the growth direction [2]. Higher extraction efficiency is resultant from the band alignment, which quickly sweeps carriers through the junction prior to recombination as long as the designed spacing between each junction is less than the minority carrier diffusion length [3]. The benefits of increased extraction efficiency can be further boosted by modifying the bandgap of the device through quantum confinement. Confinement will occur as the doping layers become increasingly thin, resulting in band formation above the conduction band of the \textit{n-type} material, which is confined between the two \textit{p-type} layers. Similarly, confinement also occurs below the valence band of the \textit{p-type} material. The effective bandgap that is formed as a result of confinement has a large degree of tunability, depending on device design parameters, such as layer thickness and doping [4].

The process used to complete the fabrication of the device requires multiple steps, and a novel method for contacting. Following epitaxial growth of the \textit{nipi} stack, it is required that contacts are formed to promote charge separation laterally in the device as shown in Figure 1. Given the lateral majority carrier flow in this device, it is necessary to contact the sides of the device with a method that is selectively ohmic and highly rectifying to the opposing sides of each doped layer. The approach utilized requires epitaxial regrowth to grow \textit{n-} and \textit{p-type} GaAs in etched trenches that naturally forms ohmic and rectifying barriers to the doped layers. It has been shown that the regrowth methodology is the preferred method for contacting the device [2], and has been investigated more thoroughly.

Devices with a \textit{nipi} epitaxial doping superlattice have been grown and fabricated. The design was chosen to demonstrate quantum confinement in thin \textit{nipi} periods. The device designed with thin \textit{nipi} layers has 12 repeats of a \textit{nipi}
stack with 50 nm thick doped and intrinsic layers, as shown in the SEM of Figure 2. Thin superlattice layers result in quantum confinement, in the troughs of the energy level diagram, while increasing the thickness of the layers would result in the device operating more like a traditional solar cell.

Spectral response was measured for the nipi device, as well as for a baseline pin solar cell and is shown in Figure 3, where the results were normalized to the peak response value. Spectral response results do show a significant boost in the overall response of the device. Integrating under the curve of the bulk response and the sub-band response shows that the percent increase due to quantum confinement in the integrated spectral response is 6.81%, which results in a 4.03% increase in the calculated $J_\infty$ under AM1.5 conditions.

Device characterization demonstrates an absorption peak at 922 nm through spectral response, and photoluminescence. The photoluminescence data as seen in Figure 4 shows multiple additional peaks at lower energy levels, where states are formed in the superlattice. Due to the increased sub-band collection, the potential for the nipi device to provide a performance boost through a tailored bandgap has been demonstrated.

References: