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Determination of Doping Levels in InP Nanopillars Using Photoluminescence Measurements

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Abstract

Indium phosphide nanopillars possess potential to become pivotal materials in the production of energy-efficient optoelectronic devices. These nanopillars have previously been shown to produce optically-pumped lasers [1] and are currently being evaluated as solar cell material. However, rapid and convenient methods for characterizing impurity doping levels are important for device development. Conventional methods of doping level characterization, such as Hall effect and 4-point-probe measurements, are difficult to perform due to the nanoscale electrical contacts required [2]. To improve the characterization procedure, a novel contactless I-V method is proposed, which can be used to determine the doping level through photoluminescence measurements. The contactless I-V doping level was compared to that of 4-point-probe measurements with decent agreement, attesting to the efficacy of the contactless I-V method.

Introduction

III-V materials are currently a popular area of research due to their broad impact in device fabrication [1], [3]. Even among the III-V materials, InP stands out due to its ease of integration with silicon and its low surface recombination velocity compared to materials like InGaAs [4]. This makes InP nanopillars attractive for solar cell, APD, and laser applications. However, doping level characterization for this material remains difficult, and precise doping level tuning is required for other devices such as phototransistors. Contactless I-V measurements offer a simple and quick way of characterizing the doping level in this promising new material.

Background

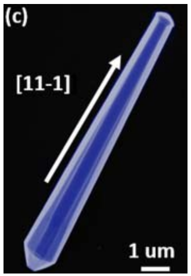


Figure 1. SEM of InP nanoneedle [5].

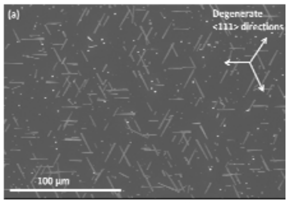


Figure 2. SEM of InP nanoneedle forest [6].

- Grown, self-aligned on Si
- Single crystal quality
- Scalable dimensions

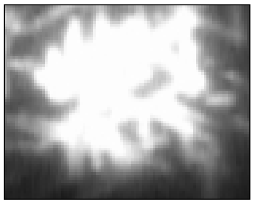
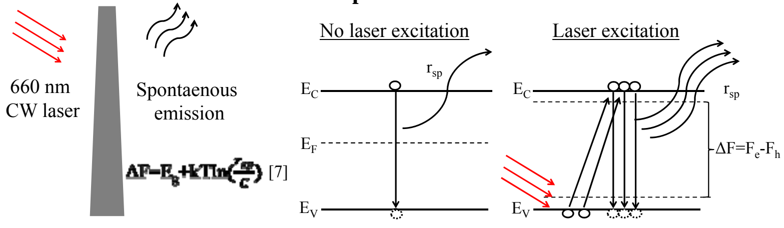


Figure 3. Image of PL signal from ensemble of InP nanopillars [6].

- Bright PL compared to other nanowire III-V materials

Methods

Experimental



660 nm CW laser

Spontaenous emission

$\Delta F = E_g + kT\ln\left(\frac{r_{sp}}{C}\right)$ [7]

No laser excitation

Laser excitation

Modeling

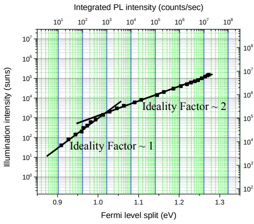
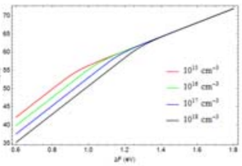
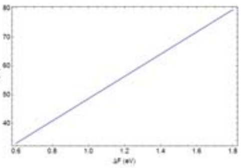


Figure 4. Contactless I-V for p-doped InP nanoneedle.

A: SRH Recombination

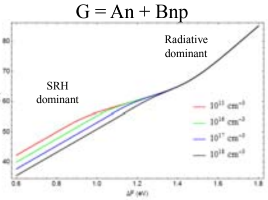


B: Radiative Recombination



Combined Model

$G = An + Bnp$



- Kink due to change in ideality factor, position changes depending on doping level
- At high power, Fermi level split increases twice as fast with power
- Combined effects of SRH and radiative recombination influence contactless I-V shape

Results

P-Doped:

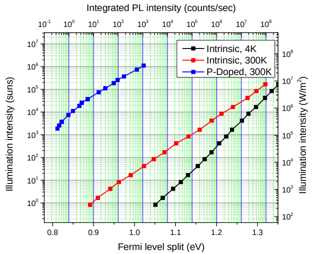


Figure 6. Contactless I-V for p-doped InP nanoneedle.

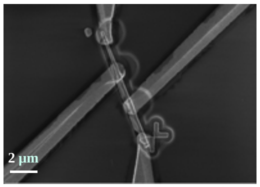


Figure 5. SEM of 4-point-probe on p-doped InP nanoneedle. Image courtesy of Indrasen Bhattacharya.

4PP	$1\text{x}10^{15}$ acceptors/cm^3
CIV	$7\text{x}10^{14}$ acceptors/cm^3

N-Doped:

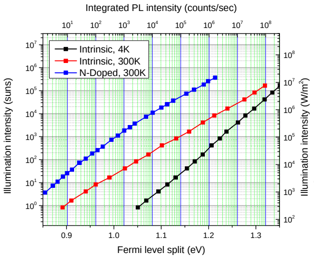


Figure 7. Contactless I-V for n-doped InP nanoneedle.

Burstein-Moss Shift Equation [8]:

$$\Delta E = \frac{16.9}{m_{eff}}\left(\frac{n}{10^{19}\,cm^{-3}}\right)^{2/3}$$

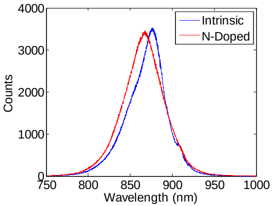


Figure 8. Emission spectra for InP nanoneedles showing Burstein-Moss shift.

BM Shift	$2\text{x}10^{17}$ donors/cm^3
CIV	$1\text{x}10^{16}$ donors/cm^3

Conclusions

The contactless I-V measurement was in good agreement with the 4-point-probe measurement for the p-doped nanoneedle sample, with an error of about 30%. However, there was a discrepancy of about an order of magnitude between the contactless I-V doping level and the doping level calculated from the Burstein-Moss shift equation. This discrepancy could have arisen partially from the error in the Burstein-Moss equation itself.

Further improvements to the fitting model could be made with the inclusion of an effective temperature variable as well as a term for Auger recombination. The contactless I-V method is promising, as it has yet to be optimized and early results indicate decent agreement with other established methods of doping level characterization.

References

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