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13. ABSTRACT (Maximum 200 words)

The aim of the proposed project is to realize a novel optoelectronic device that completely and instantaneously measures the incident light's polarization for a narrow wavelength band in a single physical pixel. The device uses interference among many light paths to encode in four photocurrents four values that completely describe the polarization state of the incident light at a given wavelength. It is to be emphasized that the polarization information will be both "simultaneous and co-located". This could be used for applications that involve snap shot imaging with a narrowband active illumination.

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Period: May 2007-Nov 2010

By

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# 1. Overview

The goal of this project was to realize a single pixel that could characterize all the Stokes vectors by measuring the various polarizations in a single pixel. This was a very high risk project and we have made reasonable progress towards meeting the goal.

The proposed Polarimeter-in-a-pixel is conceptualized to resolve the 4 Stokes parameters. The detail of our initial concept has been explained in the earlier reports. The four stack structure was proposed by *Mario Serna (US Patent: 6906800 B2)* is shown in Fig.1.

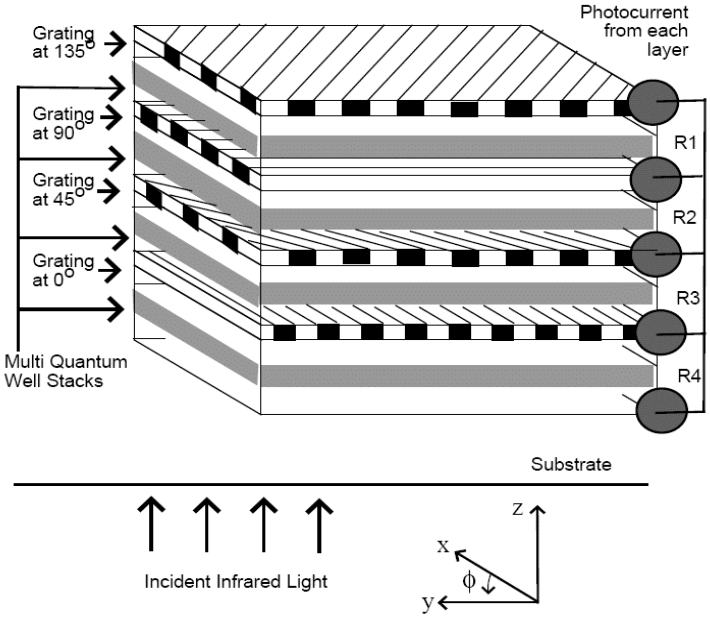


*Fig.1: Structure of an Infrared Single pixel Quantum Well Polarimeter.*

Our goal has been to demonstrate a proof-of-concept device consisting of two layers instead of four. But the above shown structure posed various fabrication complexities and hence this year we re-modified the structure in an effort to realize the device. The details of this modification and fabrication techniques have been laid out in this report along with our plans for the next coming year.

# 2. Progress at the end of third year

## 2.1. Modified Structure

Our modified structure for fabrication is shown as a 1-D representation in Fig.2. It essentially consists of two layers of Quantum Well Infrared Photo-detector (QWIP) with gratings at different angles.

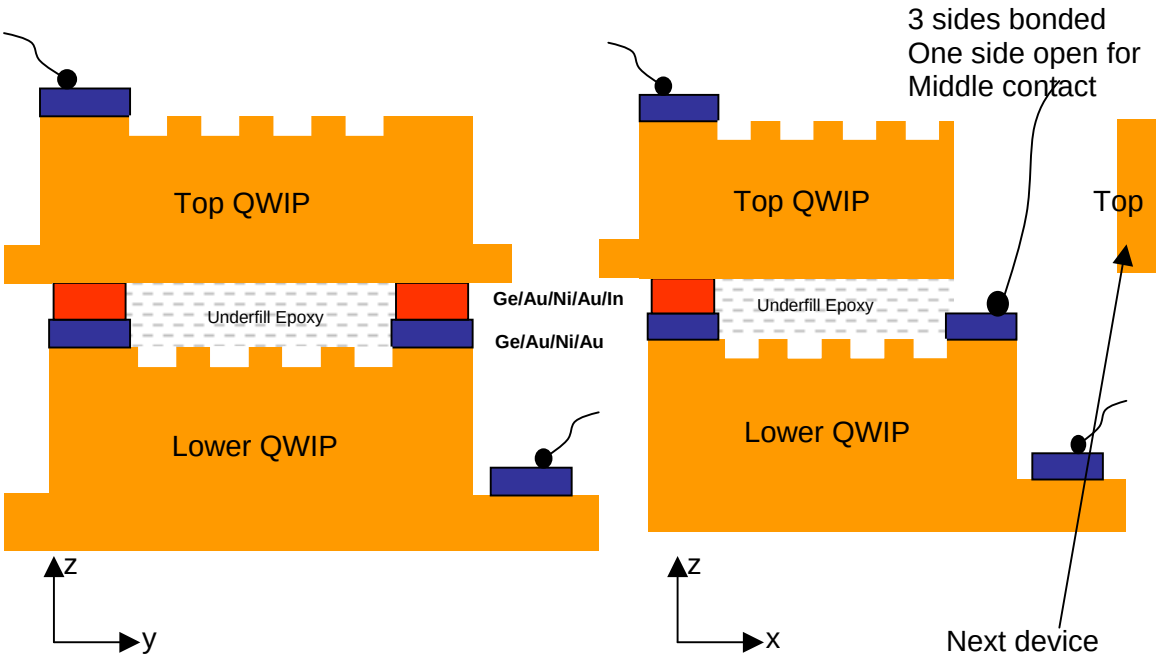


*Fig.2: 1-D Representation of modified structure of a single pixel QWIP Polarimeter.*

## 2.2. Growth of Structure

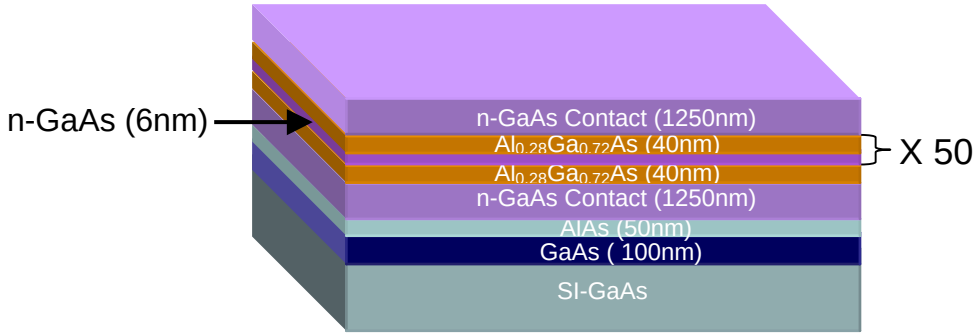


*Fig.3 Schematic showing the structure of QWIP.*

## 2.3. Modified Fabrication

To realize the structure in Fig.2, we propose two routes.

### Path 1: Nano-membrane Lift-off Technique

We propose to utilize a unique technique described as a nano-transfer printing which was implemented by Sun et al (Nano Lett., Vol.4, No.10, 2004) for transferring Nano/Micro wires onto plastic substrates.

The ultimate outcome of this procedure is that we are able to remove the substrate from an epitaxially grown and post fabricated device. The following steps detail the fabrication of a single pixel Polarimeter utilizing the nano-membrane lift-off technique:

**Stage 1: Processing Lower QWIP**

Step.1: Photoresist (PR) patterning and ICP etching of Mesa to define device dimensions.

Step.2: PR patterning and deposition of bottom and top contact metal

Step.3: PR patterning and ICP etching of semiconductor gratings

**Stage 2: Processing Top QWIP**

Step.4: PR patterning and ICP etching of Mesa to define device dimensions.

Step.5: PR patterning and deposition of bottom and top contact metal

Step.6: PR patterning and ICP etching of semiconductor gratings

Step.7: PR patterning and deposition of metal over gratings

**Stage 3: Nano-membrane Transfer Technique**

Step.8: Pattern and ICP etch outer Mesa into AlAs in the Top QWIP

Step.9: Pattern and wet etch AlAs. Due to lateral etching an under cut is formed

Step.10: Spin on a conformable elastomeric transfer element such as the poly (di-methyl-siloxane) or PDMS over the top QWIP.

Step: 11: The PDMS forms strong bonds with underlying semiconductor once the PDMS is cured. These bonds along with a large undercut facilitate in the removal of the substrate as the PDMS is peeled off.

Step.12: Rest of the underlying AlAs is completely removed by a repeated wet etch.

Step.13: The bonding metal of Ge/Au/Ni/Au/In is now patterned and deposited on the underside of the Top QWIP.

**Stage 4: Bonding the QWIPs**

Step 14: Using a flip chip bonder, the above processed Top QWIP is bonded to the bottom QWIP from Stage.1.

Step 15: Once bonded, the PDMS can be removed.

Step.16: We now fill the gaps between with Underfill epoxy to strengthen the 2-layered device structure.

Step.17: The contacts are wire bonded for measurements. The final structure is illustrated in Fig.4.

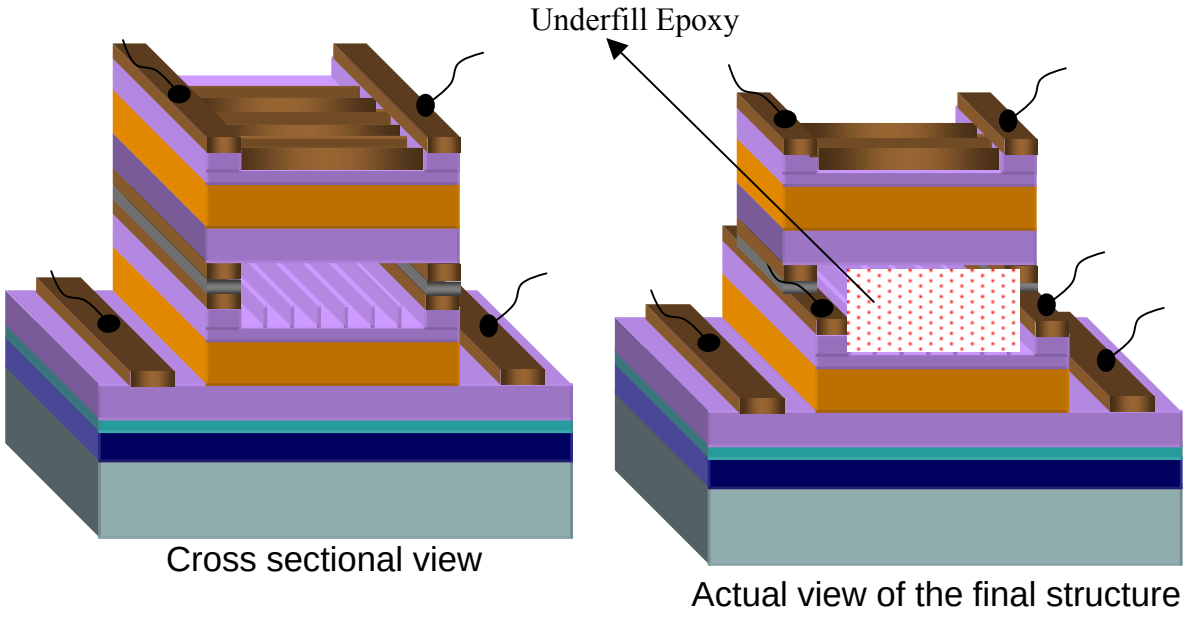


Fig.4: Schematic of the two-layer Polarimeter.

## Path 2: Polishing Technique

The alternate method to process the structure is by removing the substrate by polishing and wet etching. The procedure for this technique is laid out below:

**Stage 1: Processing Lower QWIP**

Step.1: Photoresist (PR) patterning and ICP etching of Mesa to define device dimensions.

Step.2: PR patterning and deposition of bottom and top contact metal

Step.3: PR patterning and ICP etching of semiconductor gratings

**Stage 2: Processing Top QWIP**

Step.4: PR patterning and ICP etching of Mesa to define device dimensions.

Step.5: PR patterning and deposition of bottom and top contact metal

Step.6: PR patterning and ICP etching of semiconductor gratings

Step.7: PR patterning and deposition of metal over gratings

**Stage 3: Bonding the QWIPs**

Step 8: The bonding metal of Ge/Au/Ni/Au/In is now patterned and deposited on the underside of the Top QWIP.

Step.9: Using a flip chip bonder, the above processed Top QWIP is bonded to the bottom QWIP from Stage.1.

Step.10: We now fill the gaps between with Underfill epoxy to strengthen the 2-layered device structure.

**Stage 4: Substrate Removal**

Step.11: Pattern and ICP etch outer Mesa into AlAs in the Top QWIP

Step.12: Polish the substrate to about a final thickness of ~150um

Step.13: Wet etch with Citric Acid: $H_2O_2$: $H_2O$ to remove the rest of the substrate.

Step.14: Rest of the underlying AlAs is completely removed by a repeated wet etch. The final structure will be the same as in Fig.4.

## 2.4. Bonding the Two Layers

We acquired out Flip Chip bonder FC150 last year. This machine can enable us to accurately align the two layers and bond them. This is in-situ operation makes the above processing a possibility.

## 2.5. Initial Measurements

For initial measurement the structure shown in Fig.2 was grown. They were then processed with the single pixel mask we presented in the last year's report. The mask layout is shown in Fig.5.

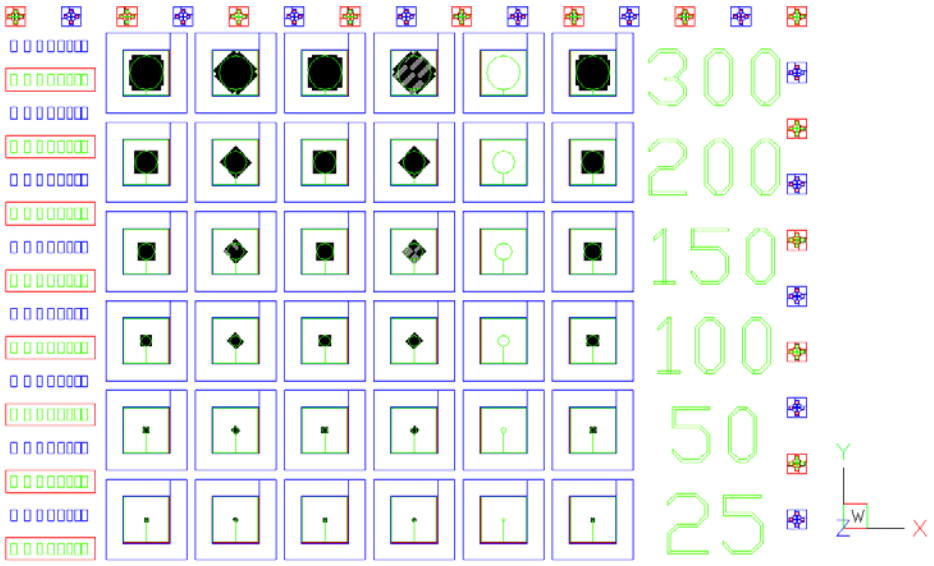


*Fig.5: Mask layout of a single die showing 36 different devices with different apertures of 300 to 25um and different grating angles of 0˚, 45˚, 90˚, 135˚, no grating, and 0˚ with reverse duty cycle devices.*
*Colors representation: Top Metal (Green), Mesa Etch (Red), Bottom Metal (blue), Gratings (Black) layers.*

For processing these single layer devices, we first define the device dimensions by performing ICP (Induced Coupled Plasma) assisted Mesa etches to reach the bottom contact layer. Then the contact metals (Ge/Au/Ni/Au) are deposited for the top and bottom contacts simultaneously. Then the contacts are annealed to form Ohmic interfaces with the semiconductor below. Finally the

gratings are etched into the top contact layer by ICP etching. Photocurrent versus wavelength plots of these devices with grating angles of 0˚, 45˚, 90˚and no gratings are shown in Figures 6, 7, 8 and 9 respectively. It has to be noted that all the measurements were taken at a temperature of 30K.

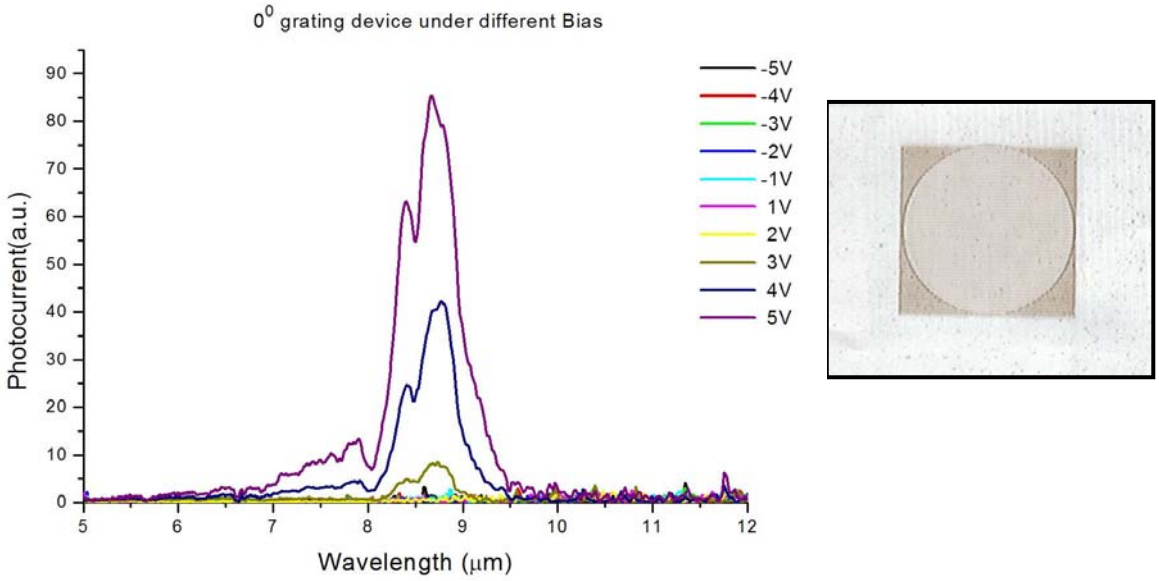


*Fig.6: Left- Spectral response of a 0˚ grating device at different bias. Right-picture of a 0˚ grating device.*

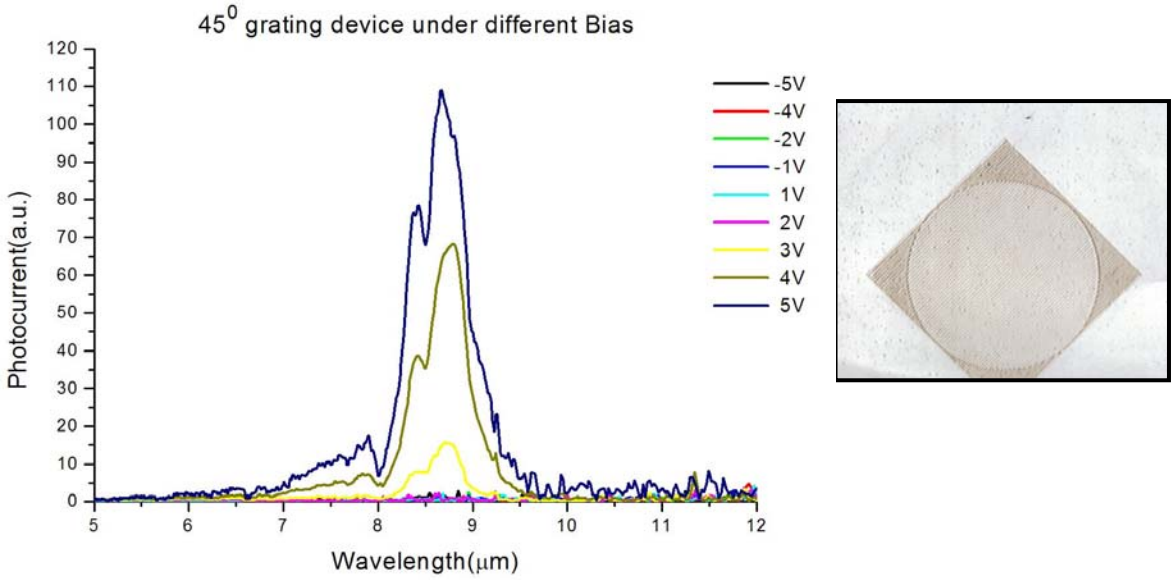


*Fig.7: Left- Spectral response of a 45˚ grating device at different bias. Right-picture of a 45˚ grating device.*

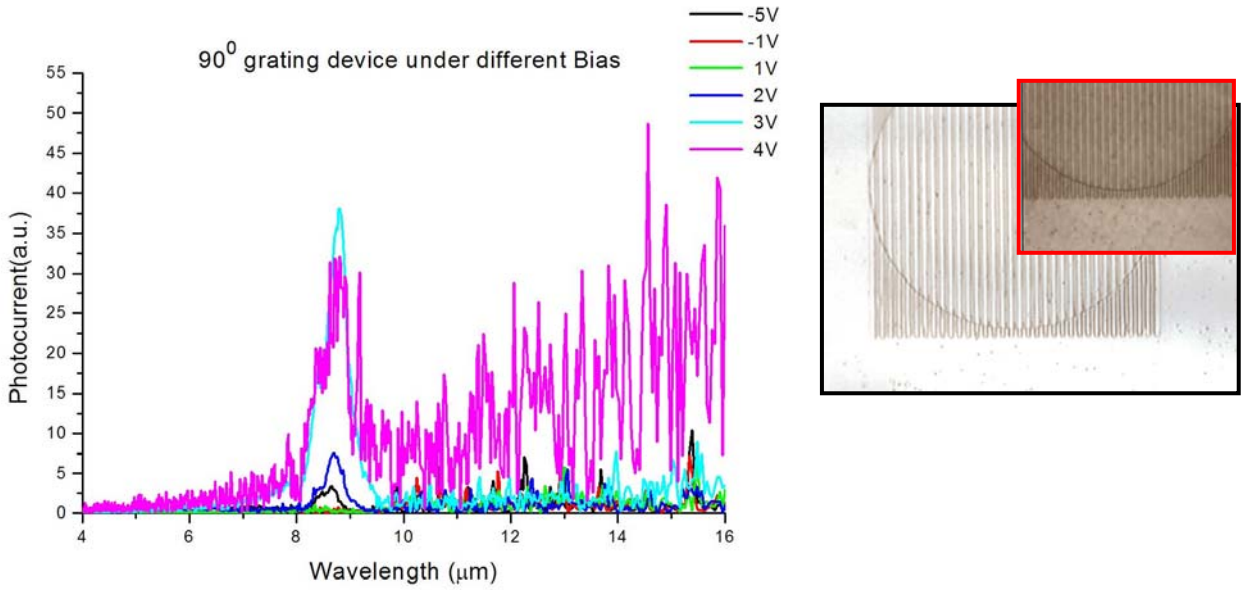


*Fig.8: Left- Spectral response of a 90˚ grating device at different bias. Right-picture of a 90˚ grating device and the inset gives closer look at the grating etched.*

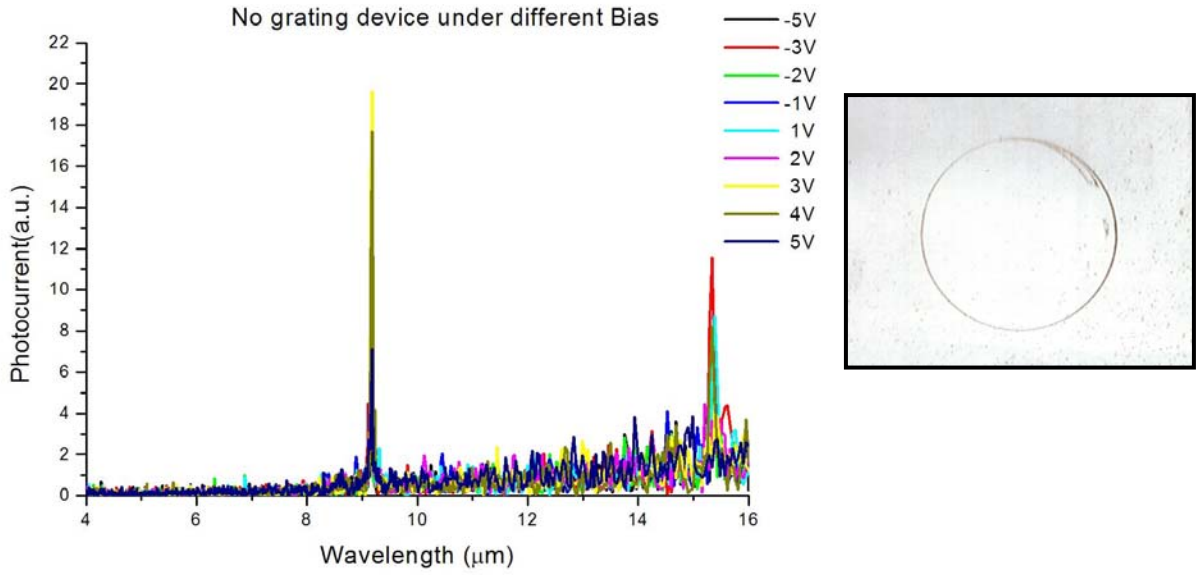


*Fig.9: Left- Spectral response of a no- grating device at different bias. Right-picture of a no-grating device.*

Studying the figures above, we can infer that the highest photocurrent intensity was seen in the 45˚ grating device which peaked at ~8.67μm with an intensity of 108.91a.u. for a 5V bias. The next highest was for the 0˚ grating which gave the

maximum photocurrent intensity of 85.29a.u for a 5V bias at 8.67μm wavelength. The 90˚ grating device peaked at 8.8μm with an intensity of 38.16a.u at 3V bias. The device with no grating gave the lowest of all measured, with an intensity of 19.66 a.u. at 3V bias and wavelength of 9.18μm. These plots shows us that having gratings does improve the performance of the device.