Photodetectors with Internal Aiding Field based-on GaAs/AlGaAs Heterostructures

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OUTLINE:

Aim of this work is to exploit how reduced dimensional systems can improve the carrier transport in optoelectronic devices.

• From a HEMT heterojunction to a family of devices
• Properties of the photodetector: barrier enhancement and the internal aiding field
• Results for two AlGaAs dopings
• Conclusions and work in progress
The ‘classic’ GaAs/AlGaAs heterostructure

The two dimension electron gas concentration $n_s$ depends on AlGaAs doping
AlGaAs doping (and GaAs resistivity) also affects electric field in GaAs
• Source and drain are ohmic with 2-DEG
• Schottky controls channel conductivity through $n_s$
A Two-Dimensional Electron Gas Photoconductor (2DEG-PC)

In this gate-less HEMT $n_s$ is controlled by light
A Two-Dimensional Electron Gas Photodetector (2DEG-PD)

Vertical Profile of the $e^-$ energy

Schottky on AlGaAs: low dark current, fast (no gain)
Photogenerated electrons drifted by the internal ‘vertical’ field toward AlGaAs.

Applied bias between contact gives the ‘horizontal’ field.
SEM images of the interdigitated structure

- **Gold Pad**
- **GaAs**
- **Mesa-etching**
- **AlGaAs**

Measurements:
- 2µm
- 2µm
- 1µm
- 2µm
Photocurrent spectra for two values of AlGaAs doping

- Better collection for higher AlGaAs doping

- Absorption edge of GaAs

- Absorption edge of AlGaAs

Current (A) vs. Wavelength (nm)

- $N_d = N_d = 3 \times 10^{17}$
- $N_d = N_d = 6 \times 10^{17}$
• Higher AlGaAs doping also improves dark and light I-V
I-V (dark) at different temperatures

- Higher Activation energy for higher AlGaAs doping
Theoretical Explanation:

1. Reduced dark current is due to electron-electron cloud Interaction.
   \[ \Psi(x) = \Phi_{bn} - q/(16\pi \varepsilon_s x) - (E_m - E_e)x \]
   Anwar et al., J. Appl. Physics, vol.85, pag. 2663, 1999

2. Increase in photocurrent is due to the vertical e-field.

Both are due to 2DEG
Numerical simulations (ISE-TCAD™):

2D electric field distribution in the section of the device biased 10V

Comparison for low \(3 \times 10^{17} \text{cm}^{-3}\) and high \(6 \times 10^{17} \text{cm}^{-3}\) AlGaAs doping

- Horizontal (in GaAs near AlGaAs)
- Vertical (across GaAs/AlGaAs)
Current transient induced by femto-s laser pulses at 850nm

- After a 8-9ps pulse, a long tail...holes?
- High-doping improves peak reasponsivity and pulse width
microwave reflection coefficients
(in the range 45 MHz-40GHz using a network analyzer)

Smith Chart

Equivalent Circuit

- Equivalent circuit is useful to design the photodetector components
Conclusions

- Realized and characterized photodetectors based on HEMT structure
- These photodetectors enhance (respect to conventional ones):
  - dark (noise) response due to the interaction metal-2DEG
  - light (responsivity) response due to the internal vertical field
- Comparisons consistently show better performance for higher AlGaAs doping
- Devices operate in tens of GHz (useful for signal transmission)
- From reflection coefficient measurements extracted the equivalent circuit to design the complete photoreceiver

Work in progress:
- δ-doping instead of uniform doping
- Resonance-Cavity-Enhanced photodetectors (λ selectivity)
- Time-domain measurements with E-O conversion
Application Areas

- Wavelength Division Multiplexing
- Remote sensing
- Laser Communications in Free Space Systems
- Medical applications
- Photodetector Arrays and Low Cost Packaging