Hybrid II-VI/III-V infrared photodetectors

Marcel S. Claro,[1] **Yasin Kaya**,[2] **Thor A. Garcia**,[1] **Candice Forrester**,[1] **Vasilios Deligiannakis**,[3] **Claire Gmachl**,[2] **Maria C. Tamargo**[1, 3 +]

[1] *Department of Chemistry, The City College of New York, CUNY and Doctoral Program in Chemistry, Graduate Center of CUNY, New York, NY 10031 USA*
[2] *Department of Electrical Engineering, Princeton University, Princeton, NJ 08544 USA*
[3] *Doctoral Program in Physics, Graduate Center of CUNY, New York, NY 10031 USA*

Despite the huge success of intersubband infrared devices based on III-V semiconductors in the past few decades, namely quantum cascade lasers (QCLs) and detectors (QCDs), and the quantum well infrared photodetectors (QWIPs), the fabrication of multi-band device is still a challenge. In the GaAs/AlAs and InGaAs/AlInAs/InP material systems, the material properties are not the optimum to cover the entire infrared (IR) range. Recently, QWIPs[1] and QCDs[2] working from 4 to 10µm were shown using ZnCdSe/ZnCdMgSe II-VI materials, and they have particularly high-detectivity in the short wavelength IR range, wherein the intersubband III-V devices lack in performance.

Aiming for a high-detectivity multi-band photodetector, we grew several structures consisting of a ZnCdSe/ZnCdMgSe QCD, designed to have peak responsivity at 5µm, stacked on top of an InGaAs/AlInAs QCD, designed to have peak responsivity at 8µm. They were grown lattice matched to InP (100) substrates. The practical integration of two devices made from these two materials in a single chip has not been yet demonstrated, and would increase the materials landscape for the design of novel advanced devices.

High-Resolution X-Ray Diffraction (HR-XRD) and Photoluminescence (PL) measurements of the hybrid structures confirm the high quality of the two materials components. Full device characterization was made on the device stack using top and bottom contacts, which means the II-VI and III-V components are connected in series, as well as using the middle contact to measure each device separately. The same characterization was performed on individual III-V and II-VI QCD devices with the same design as the hybrid. The results show that II-VI QCD devices have a much higher resistance, R_0, and higher responsivity than III-V QCD devices, and typically dominate in the hybrid responsivity spectrum. The comparison between the III-V in the hybrid stack and the pure III-V device indicates that the presence of an InGaAs/ZnCdSe interface may affect negatively the III-V device performance. Additionally, etching away of the II-VI layers in a hybrid device has also shown greatly improved performance of the underlying III-V device. Several causes are being investigated, such as built-in electric field and deep defects due to elements inter diffusion at the II-VI/III-V interface, or optical interference of the two different device structures.

The effects of modifying the interfacial layer on the hybrid devices are explored. Different device geometries are also explored to identify electrical and optical characteristics of the materials that may affect device performance.

[1] Chen, G., et al (2016). *Physica Status Solidi (c)*, *13*(7–9), 673–676.
[2] Ravikumar, A. P., et al (2014). *Applied Physics Letters*, *105*(6), 61113

[+] Author for correspondence: mtamargo@ccny.cuny.edu

Suplementary Pages

Top Contact	n+ ZnCdSe:Cl	200 nm
5 µm II-VI Active Core *repeat period 6 to 17x*	ZnCdMgSe Barriers ZnCdSe Wells	38nm per period
Middle Contact	n+ ZnCdSe:Cl	200nm
Middle Contact	n+ InGaAs:Si	600nm
8 µm III-V Active Core *repeat period 20 to 40x*	AlInAs Barriers InGaAs Wells	45nm per period
Bottom Contact	n+ InGaAs:Si	800nm
InP SI		

Figure 1 Diagram showing the layer structure of the hybrid devices analyzed.

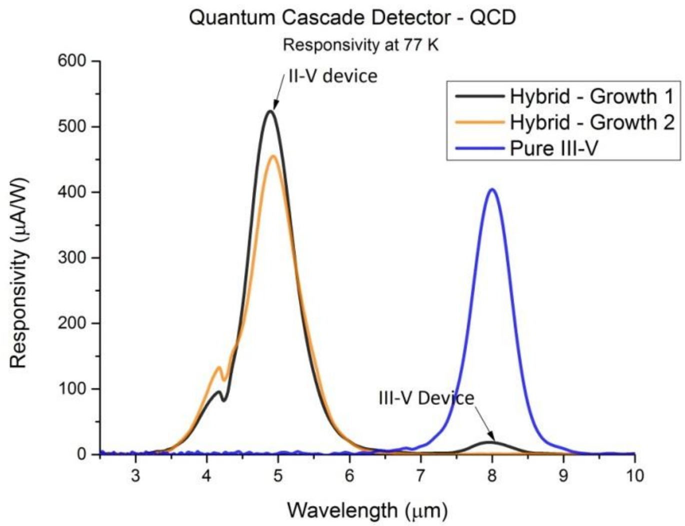

Figure 3 Responsivity spectra of two hybrid quantum cascade detectors (QCD) (Black and Orange) composed of the same ZnCdSe/ZnCdMgSe QCD structure, designed to have peak responsivity at 5µm, stacked on top of an InGaAs/InAlAs/InP QCD, designed to have peak responsivity at 8µm. A single InGaAs/InAlAs/InP QCD of the same design as the III-V component of the hybrid was also grown and fabricated (Blue).

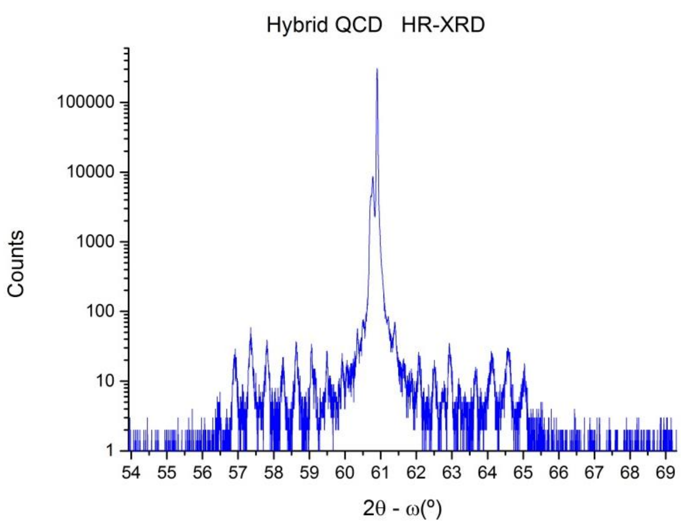

Figure 2 High-resolution X-ray diffraction of a hybrid QCD device. The data confirms the near lattice matching and high crystalline quality of the structure.

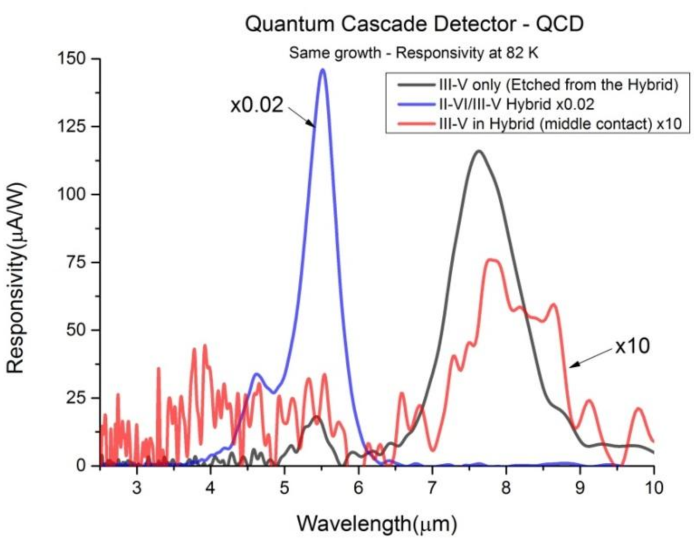

Figure 4 Comparison of the responsivity spectra of the hybrid quantum cascade detectors (QCD) when both devices are measured together in series configuration (Blue), when the III-V QCD is accessed separately using a middle contact (Red), and when the III-V QCD is accessed after the complete chemical etching of the top II-VI device (Black).