Influence of the Arsenic flux on the performance of infrared photodetectors based on InAs submonolayer quantum dots.

*A. Alzeidan [a], T.F. Cantalice [a], K.D. Vallejo [b], R.S.R. Gajjela [c], A.L. Hendriks [c], P.J. Simmonds [b]
P.M. Koenraad [c] and A.A. Quivy [a]

[a] Institute of Physics, University of São Paulo, São Paulo 05508-090, SP, Brazil.
[b] Micron School of Materials Science and Engineering, Boise State University, Boise, ID, USA.
[c] Department of Applied Physics, Eindhoven University of Technology, Eindhoven 5612 AZ, The Netherlands.

Universidade de São Paulo

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1 - Abstract

Submonolayer-quantum-dot infrared photodetectors (SML-QDIPs) have emerged as a new technology for detecting infrared radiation. When compared to more conventional photodetectors based on Stranski-Krastanov quantum dots (SK-QDIPs), their advantages originate from their narrower base, better size control, and absence of a wetting layer. InAs/GaAs SML-QDs can be obtained by cyclic deposition of a fraction of a monolayer of InAs followed by a few monolayers of GaAs to cover the 2D InAs islands. Due to the strain field, the 2D islands of consecutive InAs layers will vertically allign, forming quantum dots with on-demand height. In the present work, three SML-QDIPs were grown with a different As flux to investigate its influence on the growth of InAs/GaAs SML-QDs and how they perform in devices.

2 – Sample growth:

Three SML-QDIPs having exactly the same structure were grown by MBE (Fig. 1), the only difference being the As_2 flux. Sample A was grown with a very low As_2 flux and a (2×4) surface reconstruction, sample B was grown with a slightly higher As_2 flux and a c(4×4) reconstruction (close to the (2×4) to c(4×4) transition), and sample C was also grown with a c(4×4) reconstruction but with the much higher As_2 flux generally used for SK-QDs.

After growth, we processed the samples into small squared mesas using conventional lithography techniques, wet etching, and electron-beam metallization. Then we checked their optical and electrical properties.

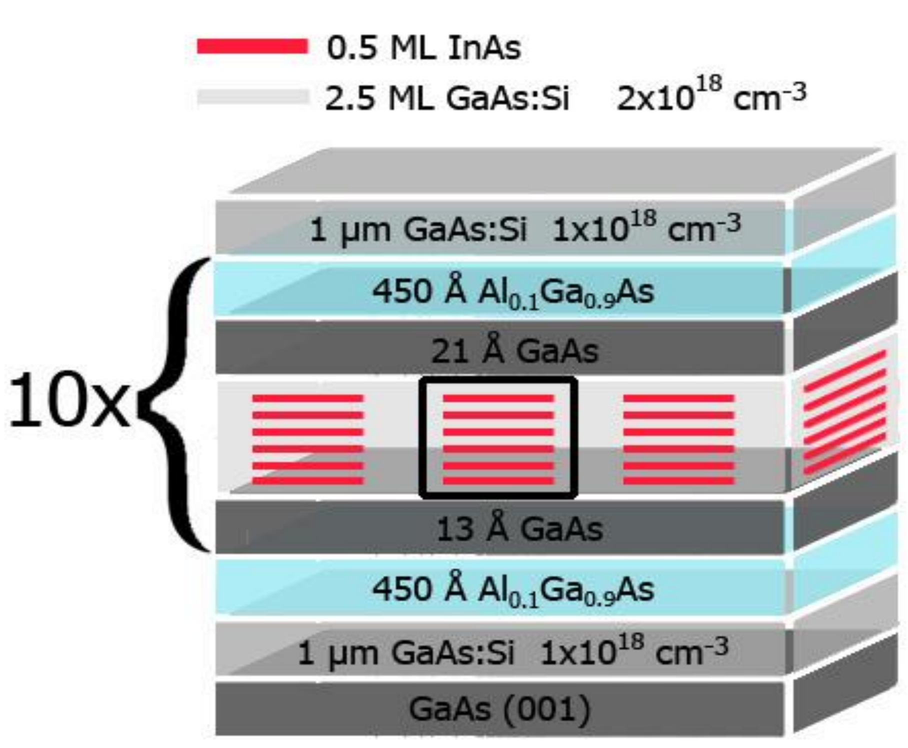

Fig. 1: Structure of SML-QDIPs A, B, and C. The black rectangle shows a single SML-QD formed by repeating six times the deposition of 0.5 ML of InAs followed by 2.5 MLs of GaAs:Si.

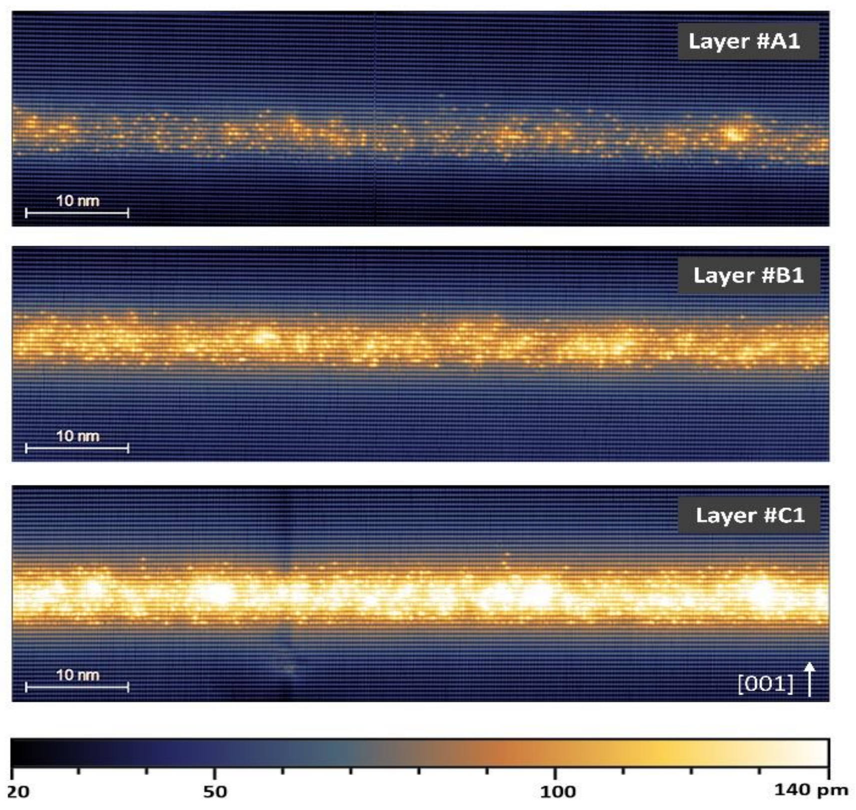

Fig. 2: X-STM images (80×25 nm^2) of the SML-QDs layers A1, B1, and C1 from sample D. The arrow indicates the growth direction [001].

3 – Experimental results

To perform a systematic structural analysis of the SML-QDs by X-STM, sample D was specifically grown on a Si-doped GaAs(001) substrate and contained SML-QDs layers A1, B1, and C1 that were deposited with the same growth parameters as the SML-QDs of samples A, B, and C, respectively.

The X-STM measurements (Fig. 2) showed that a low In incorporation and low density of nanostructures were obtained in the presence of a very low As_2 flux that yielded a (2×4) reconstruction of the GaAs(001) surface prior to deposition of the InAs material. At higher As_2 flux, the surface was c(4×4) reconstructed and the In incorporation and density of nanostructures were always higher.

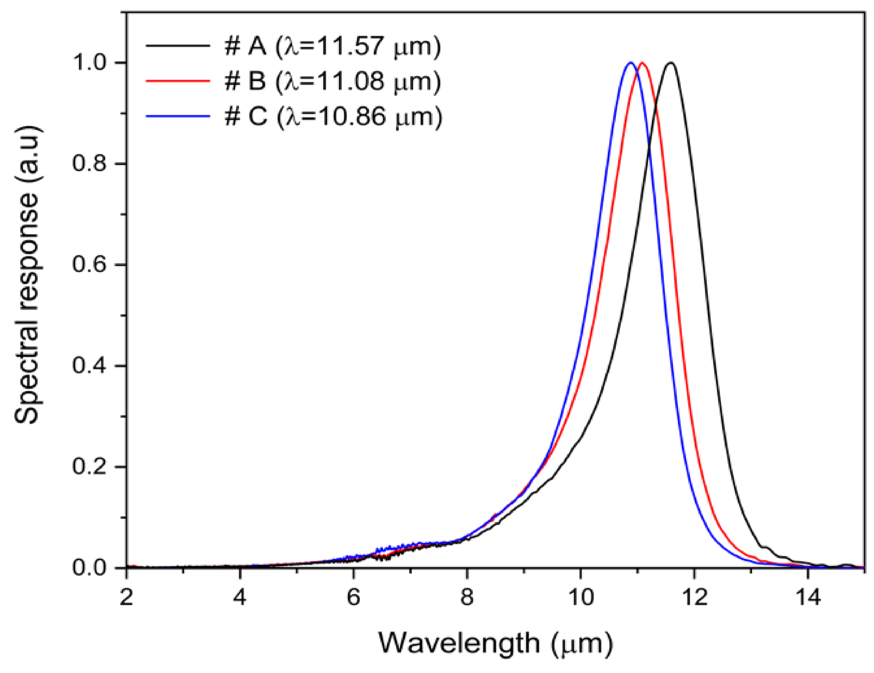

Fig. 3: Normalized spectral response of the SML-QDIPs obtained by FTIR in normal incidence at 12 K with a bias of +1.1 V.

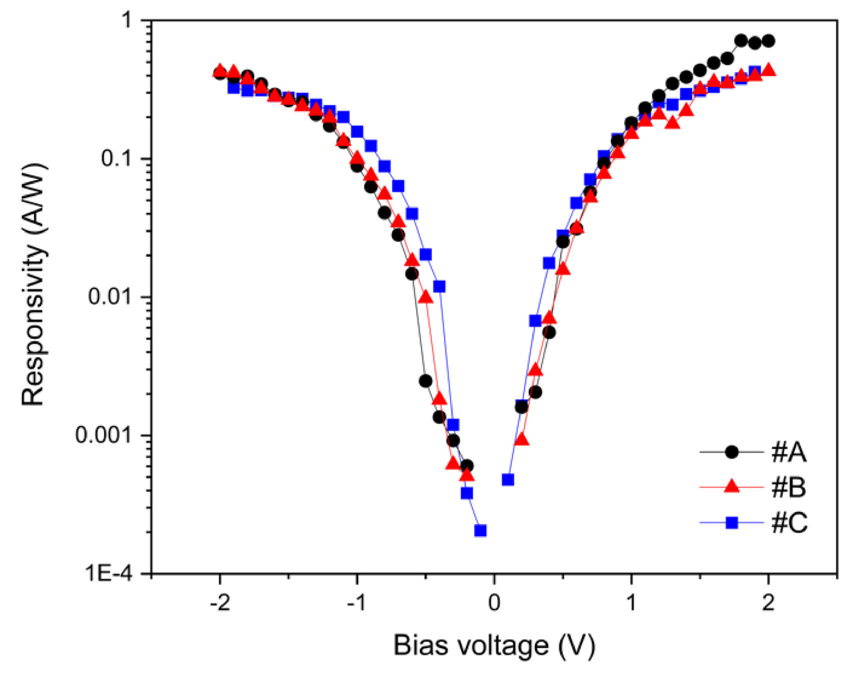

Fig. 4: Black-body responsivity of the three SML-QDIPs under normal incidence as a function of bias at 12K

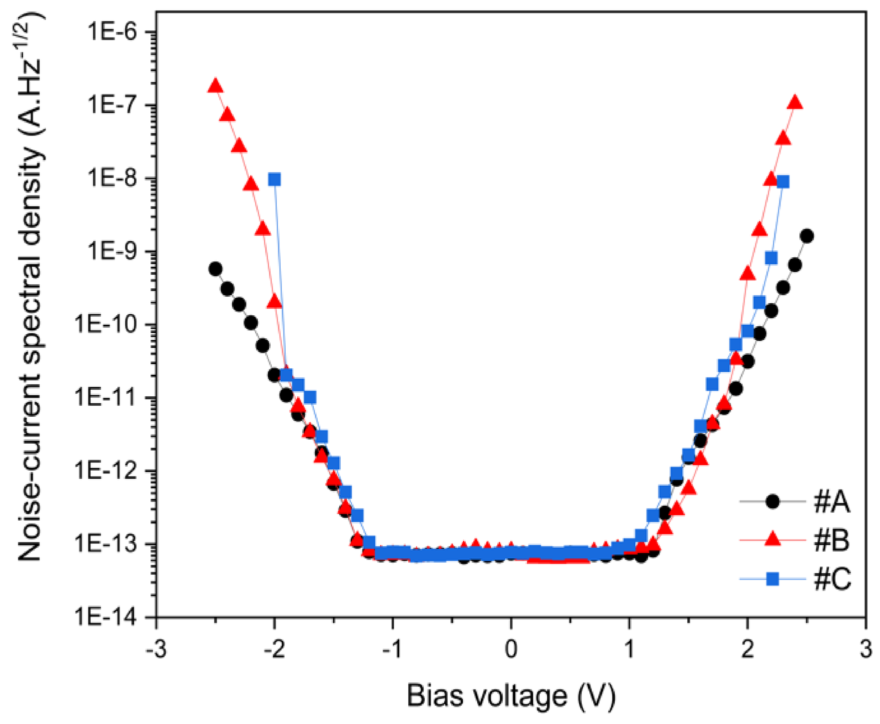

Fig. 5: Noise-current spectral density of SML-QDIPs A, B, and C as a function of bias voltage at 12K.

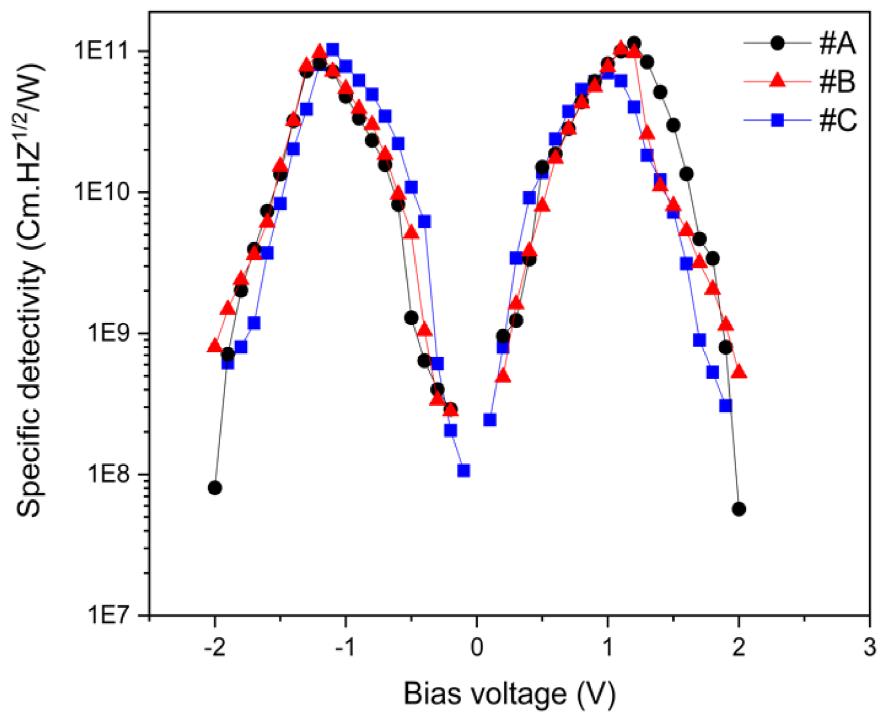

Fig. 6: Specific detectivity of SML-QDIPs A, B, and C as a function of bias voltage at 12 K.

Figures 3 to 6 show that the main figures of merit of the three SML-QDIPs are very similar, which is unexpected. Although all of them have a very high specific detectivity (above 1×10^{11} cm Hz$^{1/2}$ W^{-1}), sample C has a density of SML-QDs that is ten times larger than that of sample A. This is due to the small size and low In content of the SML-QDs which can barely confine electrons, whose wavelength can overlap the closest nanostructures, limiting thus the optical activity of samples with the highest densities. The XSTM images reveal that the SML-QDs are smaller than expected and show no internal periodicity related to the vertical alignment of 2D InAs islands. It seems that In segregation has a strong influence on the growth of SML-QDs, reduces their In content and, consequently, weakens the internal strain field that is supposed to align the 2D InAs islands, leading to irregular In-rich InGaAs clusters scattered in an InGaAs matrix.

4 - Conclusion

The performance of SML-QDIPs is much superior to that of SK-QDIPs, but SML-QDs still need to be optimized to achieve their full potential. In segregation needs to be reduced–by using for instance lower growth temperatures–to avoid the 2D InAs islands to be dissolved during capping. A (2x4) surface reconstruction should also be used as it is the only one allowing nucleation of 2D InAs islands. Only then will it be possible to obtain the expected columnar nanostructures with on-demand height.

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