

Hybrid monolithic IR arrays based on colloidal quantum dots and 2D materials

V. S. Popov^{1,2}, V. P. Ponomarenko^{1,2} and S. V. Popov^{3,4}

¹ Orion R&P Association, JSC
9 Kosinskaya st., Moscow, 111538, Russia

² Moscow Institute of Physics and Technology
9 Institutskiy per., Dolgoprudny, Moscow Region, 141701, Russia

³ Shvabe Holding
176 Prospekt Mira, Moscow, 129366, Russia

⁴ Peoples' Friendship University of Russia named after Patrice Lumumba
3 Ordzhonikidze, Moscow, 115419, Russia

Received 9.11.2023; revised 20.11.2023; accepted 24.11.2023

In the last few years, the technology of hybrid monolithic arrays based on colloidal quantum dots has been intensively developing. This new technology will significantly reduce the cost of photodetectors. Current paper provided a review of advanced achievements in the field of creating array photosensors based on colloidal quantum dots and 2D materials. Parameters of commercially produced array sensors and prototypes based on colloidal quantum dots were analyzed.

Keywords: photosensor, IR array, colloidal quantum dots, CQD, graphene.

DOI: 10.51368/1996-0948-2023-6-45-53

REFERENCES

1. Rogalski A., Kopytko M., Hu W., Martyniuk. P. Infrared HOT Photodetectors: Status and Outlook / *Sensors* **23**, 7564 (2023). <https://doi.org/10.3390/s23177564>
2. Rogalski A. *Infrared and Terahertz Detectors*, Third Edition. CRC Press, 2019.
3. Acuros SWIR VISION. 2023. <https://www.swirvisionsystems.com/acuros-swir-camera/>
4. Emberion VS20 Vis-SWIR Camera Series. 2023. <https://www.emberion.com/products/vs20-vis-swir-camera/>
5. Ekimov A. I., Onushchenko A. A. Quantum size effect in three-dimensional microscopic semiconductor crystals / *JETP Lett.* **34**, 345 (1981).
6. Ekimov A. I., Efros A. L., Onushchenko A. A. Quantum size effect in semiconductor microcrystals / *Solid State Commun* **56**, 921–924 (1985). [https://doi.org/10.1016/S0038-1098\(85\)80025-9](https://doi.org/10.1016/S0038-1098(85)80025-9)
7. Rossetti R., Nakahara S., Brus L. E. Quantum size effects in the redox potentials, resonance Raman spectra, and electronic spectra of CdS crystallites in aqueous solution / *J Chem Phys.* **79**, 1086–1088 (1983). <https://doi.org/10.1063/1.445834>
8. Murray C. B., Norris D. J., Bawendi M. G. Synthesis and characterization of nearly monodisperse CdE (E = sulfur, selenium, tellurium) semiconductor nanocrystallites / *J. Am Chem Soc.* **115**, 8706–8715 (1993). <https://doi.org/10.1021/ja00072a025>
9. Lee S., Hahm D., Yoon S.-Y., et al. Quantum-dot and organic hybrid light-emitting diodes employing a blue common layer for simple fabrication of full-color displays / *Nano Res.* **15**, 6477–6482 (2022). <https://doi.org/10.1007/s12274-022-4204-y>
10. Saran R., Curry R. J. Lead sulphide nanocrystal photodetector technologies / *Nat Photonics* **10**, 81–92 (2016). <https://doi.org/10.1038/nphoton.2015.280>
11. Ponomarenko V. P., Popov V. S., Popov S. V. (2022) Photoelectronics Based on 0D Materials. *J Commun Technol Electron.* **67**, S1–S36 (2022). doi: 10.1134/S106422692213006X (Ponomarenko V .P., Popov V. S. and Popov S. V. Fotelektronika na osnove kvazinul'mernykh struktur / *Usp. Prikl. Fiz. (Advances in Applied Physics)* **9**, 25–67 (2021) [in Russian].)
12. Malinowski P., Georgitzikis E., Maes J., et al. Thin-Film Quantum Dot Photodiode for Monolithic Infrared Image Sensors / *Sensors* **17**, 2867 (2017). <https://doi.org/10.3390/s17122867>
13. Thom R. D. High density infrared detector array. 1977.
14. Gréboval C., Darson D., Parahyba V., et al. Photoconductive focal plane array based on HgTe quantum dots for fast and cost-effective short-wave infrared imaging / *Nanoscale* **14**, 9359–9368 (2022). <https://doi.org/10.1039/D2NR01313D>
15. Leemans J., Pejović V., Georgitzikis E., et al. Colloidal III–V Quantum Dot Photodiodes for Short-Wave Infrared Photodetection / *Adv Sci.* **9**, 1–8 (2022). <https://doi.org/10.1002/advs.202200844>
16. Malinowski P., Pejovic V., Bentell J., et al. Augmented Vision Enabled by Imagers Based on PbS Quantum Dots. In: *Lectures. AMA Service GmbH, Von-Münchhausen-Str. 49, 31515. Wunstorf, Germany, 2023*, pp. 121–122.
17. Steckel J. S., Josse E., Pattantyus-Abraham A. G., et al. 1.62 μm Global Shutter Quantum Dot Image Sensor Optimized for Near and Shortwave Infrared. In: *2021 IEEE International Electron Devices Meeting (IEDM)*. IEEE, pp 23.4.1–23.4.4 (2021).
18. Liu J., Liu P., Chen D., et al. A near-infrared colloidal quantum dot imager with monolithically integrated readout circuitry / *Nat Electron* **5**, 443–451 (2022). <https://doi.org/10.1038/s41928-022-00779-x>
19. Luo Y., Tan Y., Bi C., et al. Megapixel large-format colloidal quantum-dot infrared imagers with resonant-cavity enhanced photoresponse / *APL Photonics* **8** (2023). <https://doi.org/10.1063/5.0145374>
20. About. SWIR Vision Systems. (2023). <https://www.swirvisionsystems.com/about/>
21. Gregory C., Hilton J. A., Violette K., et al. Colloidal quantum dot sensor bandwidth and thermal stability / *Infrared Technology and Applications XLVIII. SPIE* **12107**, 3 (2022).
22. Hilton A., Wyman S. J., Garcia C., et al. High-definition broad-band visible-SWIR sensors for laser mark detection / *Infrared Technology and Applications XLIX. SPIE* **12534**, 1253406 (2023).
23. PRESS RELEASE: New high technology company established based on leading edge research. 2016. <https://www.emberion.com/new-high-technology-company-established-based-leading-edge-research/>
24. Emberion VS20 VIS-SWIR camera launched at VISION. 2021. <https://www.emberion.com/emberion-vs20-vis-swir-camera-launched-at-vision/>
25. Hu C., Aubert T., Justo Y., et al. The micropatterning of layers of colloidal quantum dots with inorganic ligands using selective wet etching / *Nanotechnology* **25**, 175302 (2014). <https://doi.org/10.1088/0957-4484/25/17/175302>
26. Georgitzikis E., Malinowski P. E., Hagelsieb L. M., et al. NIR Sensors Based on Photolithographically Patterned PbS QD Photodiodes for CMOS Integration. In: *2018 IEEE SENSORS / IEEE*, pp. 1–4. 2018.
27. Georgitzikis E., Malinowski P. E., Li Y., et al. Integration of PbS Quantum Dot Photodiodes on Silicon for NIR Imaging / *IEEE Sens J.* **20**, 6841–6848 (2020). <https://doi.org/10.1109/JSEN.2019.2933741>
28. Pejovic V., Georgitzikis E., Lee J., et al. Infrared Colloidal Quantum Dot Image Sensors / *IEEE Trans Electron Devices* **69**, 2840–2850 (2022). <https://doi.org/10.1109/TED.2021.3133191>
29. Lee J., Georgitzikis E., Li Y., et al. Imaging in Short-Wave Infrared with 1.82 μm Pixel Pitch Quantum Dot Image Sensor. In: *2020 IEEE International Electron Devices Meeting (IEDM) / IEEE*, pp. 16.5.1–16.5.4 (2020).
30. Zeissler K Quantum dot image sensors scale up. / *Nat Electron* **4**, 861–861 (2021). <https://doi.org/10.1038/s41928-021-00701-x>

31. Vision China Show|Products. (2023). http://www.visionchinashow.net/txw_ensz/exhibit/product_list.aspx?zs=1344
32. Klem E. J. D., Gregory C. W., Cunningham G. B. et al. Planar PbS quantum dot/C60 heterojunction photovoltaic devices with 5.2 % power conversion efficiency / *Appl. Phys. Lett.* **100** (2012). <https://doi.org/10.1063/1.4707377>
33. Klem E. J. D., Gregory C., Temple D., Lewis J. PbS colloidal quantum dot photodiodes for low-cost SWIR sensing / *SPIE. Infrared Technology and Applications XLI* **9451**, 945104 (2015).
34. Allen M., Bessonov A., Ryhänen T. Graphene Enhanced QD Image Sensor Technology / *SID Symp Dig Tech Pap.* **52**, 987–990 (2021). <https://doi.org/10.1002/sdtp.14855>
35. Yang J., Sharma A., Yoon J. W., et al. Structurally Driven Ultrafast Charge Funneling in Organic Bulk Heterojunction Hole Transport Layer for Efficient Colloidal Quantum Dot Photovoltaics / *Adv Energy Mater.* **13**, 1–13 (2023). <https://doi.org/10.1002/aenm.202203749>
36. Yuan Y., Xu J.-L., Zhang J.-Y., et al. Interface Engineering for High Photoresponse in PbS Quantum-Dot Short-Wavelength Infrared Photodiodes / *IEEE Electron Device Lett.* **43**, 1275–1278 (2022). <https://doi.org/10.1109/LED.2022.3183602>
37. Vafaie M., Fan J. Z., Morteza Najarian A., et al. Colloidal quantum dot photodetectors with 10-ns response time and 80% quantum efficiency at 1.550 nm / *Matter.* **4**, 1042–1053 (2021). <https://doi.org/10.1016/j.matt.2020.12.017>
38. Shuklov I. A., Demkin D. V., Konavicheva V. A. et al. Issledovanie protsessy zameny ligandov v tonkikh sloyakh kolloidnykh kvantovykh tochek sul'fida svintsya s pomoshch'yu IK-Fur'e spektroskopii / *Applied Physics*, № 6, 35–42 (2022) [in Russian].
39. Ganeev R. A., Shuklov I. A., Zvyagin A. I. et al. Synthesis and low-order optical nonlinearities of colloidal HgSe quantum dots in the visible and near infrared ranges. *Opt Express* **29**, 16710 (2021). doi: 10.1364/OE.425549
40. Popov V. S., Ponomarenko V. P., Demkin D. V. et al. Fotochuvstvitel'nost' nanostruktur s energeticheskim bar'erom na osnove kolloidnykh kvantovykh tochek PbS / *Doklady RAN. Fizika. Tekhnicheskie nauki* **511** (1), 78–82 (2023). doi: 10.31857/S2686740023040120
41. Tang X., Ackerman M. M., Guyot-Sionnest P. Thermal Imaging with Plasmon Resonance Enhanced HgTe Colloidal Quantum Dot Photovoltaic Devices / *ACS Nano* **12**, 7362–7370 (2018). <https://doi.org/10.1021/acsnano.8b03871>
42. Zhang S., Bi C., Qin T., et al. Wafer-Scale Fabrication of CMOS-Compatible Trapping-Mode Infrared Imagers with Colloidal Quantum Dots / *ACS Photonics* **10**, 673–682 (2023). <https://doi.org/10.1021/acsp Photonics.2c01699>
43. Milenkovich T., Shuklov I. A., Mardini A. A., Popov V. S. Study of Photoresistor Fabrication Based on Mercury Chalcogenides Applying Various Ligand Exchanges. In: *IOCN 2023*. MDPI, Basel Switzerland, 2023, p. 21.