Colloidal Quantum Dot Photodetectors on Silicon for Short-wave Infrared applications

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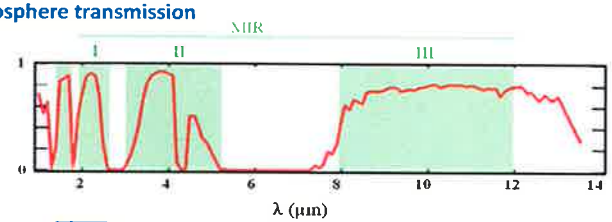
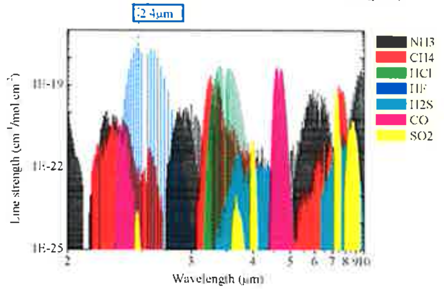
Why mid-infrared?

Atmosphere transmission



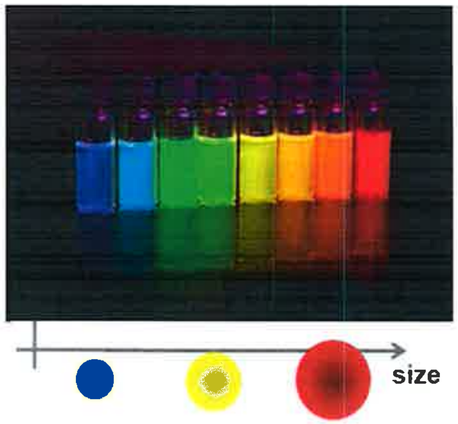


MIR Applications:

Spectroscopy
Environment
Gas analysis
Imaging
Free space communication
Defense
Security...

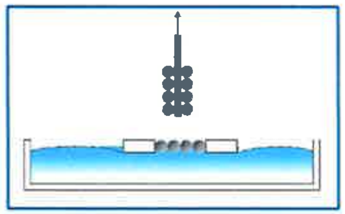
Cheap and spectrally tunable!

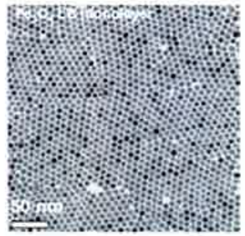
Hot injection chemical synthesis



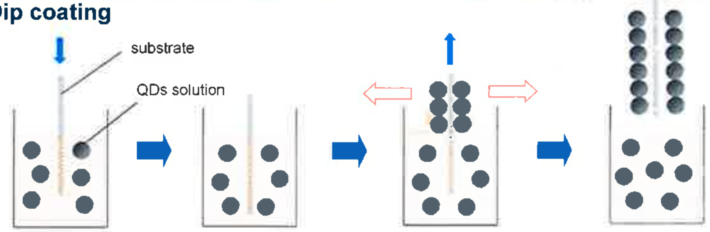
Easy heterogeneous integration on Si/SOI

- Langmuir-Blodgett deposition yields large area NC monolayers





- Dip coating

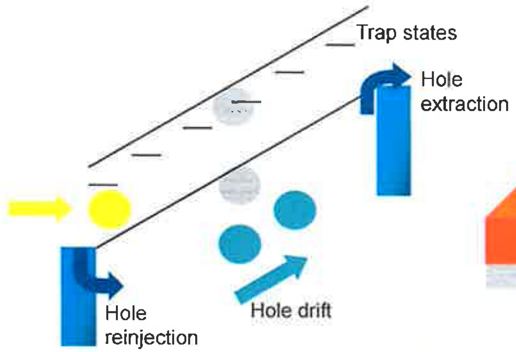


Outline

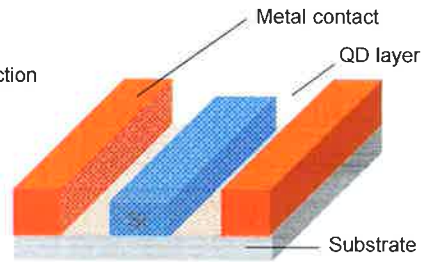
- Introduction
- SWIR/MWIR colloidal quantum dot photodetectors
- Measurement results
- Conclusion and future work

How to realize photodetection

Interband transition



Integrated MIR QD Photodetectors

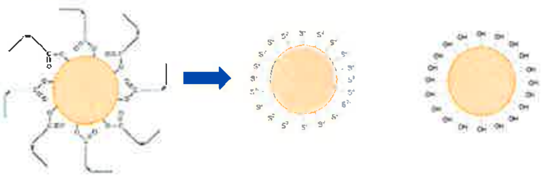


Gain = carrier lifetime / carrier transit time

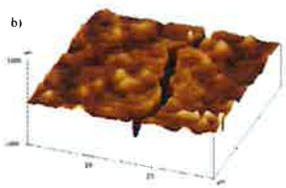
Filling of trap states reduces responsivity at higher input power

Challenges of integration?

- **Isolating organics**



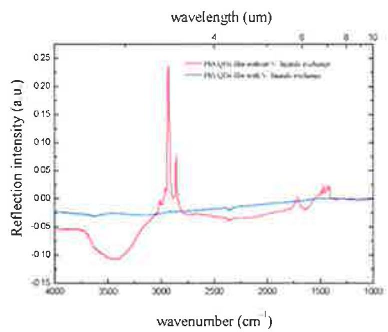
- **Film cracking due to significant volume loss during ligand exchange**



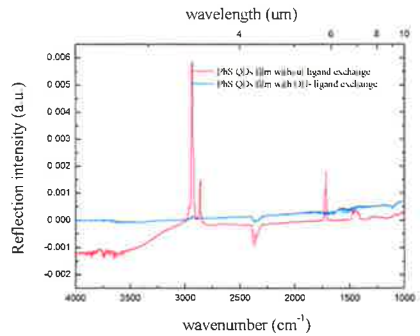
- **Patterning of colloidal QD film**

FTIR measurement: ligand exchange

S^{2-} ligand exchange

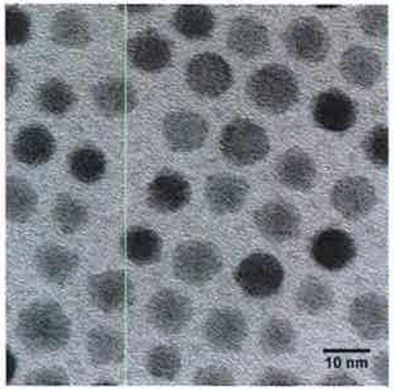


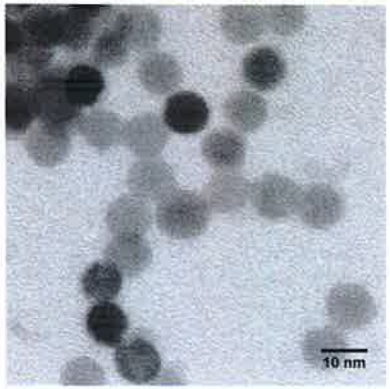
OH^- ligand exchange



- Peaks around 3010 cm^{-1}: C=C stretching; 2920 cm^{-1}: CH_2 asymmetric stretching; 2850 cm^{-1}: CH_3 symmetric stretching.
- After ligand exchange, most of the organics are removed

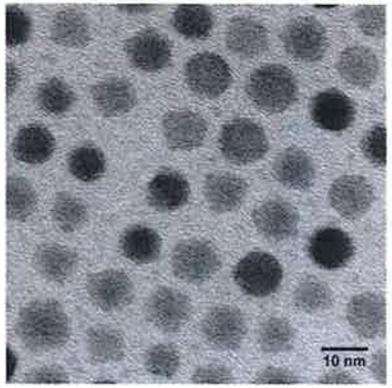
TEM: PbS/S^{2-} ligand exchange

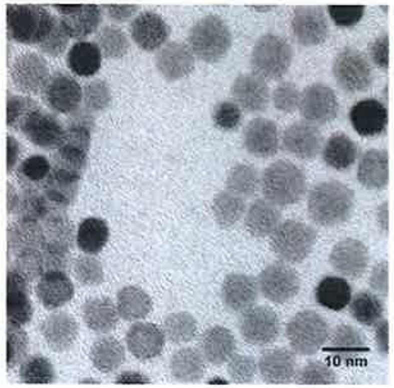




TEM images comfirm the distance between dots is decreased after ligand exchange

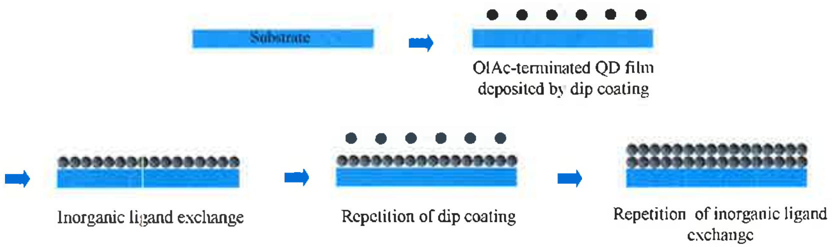
TEM: PbS/OH^- ligand exchange



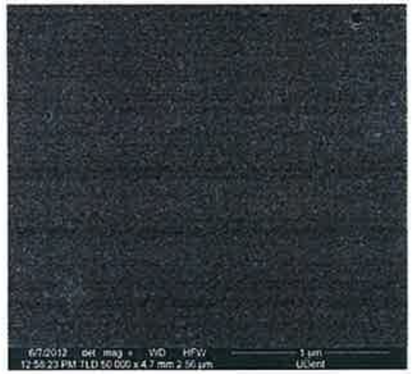


TEM images illustrate after KOH/FA ligand exchange, the distance between QDs decreases!

Layer-by-layer assembly method



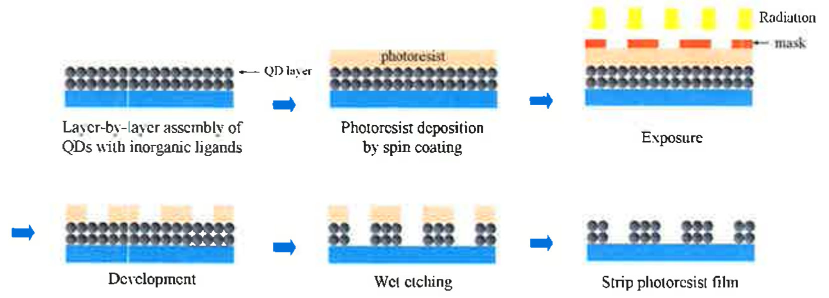
SEM: PbS/S^{2-} and PbS/OH^- film



- Left: PbS/S^{2-} film formed by 6 times layer-by-layer deposition.
- Right: PbS/OH^- film formed by 6 times layer-by-layer deposition.

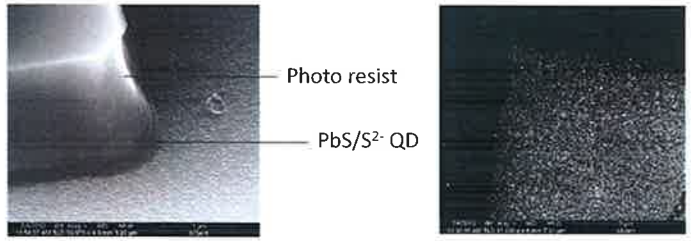
Patterning of nanocrystal film by wet etching

Process flow:



Patterning of PbS nanocrystal film

HCl/H_3PO_4 mixture



Patterning of PbS nanocrystal film on photodetector

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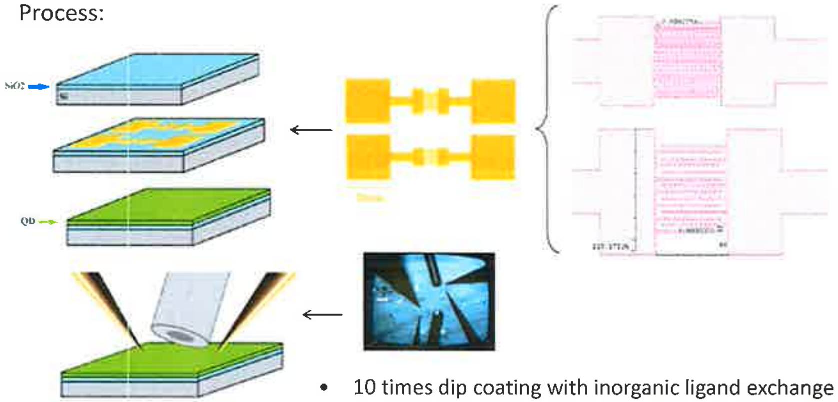
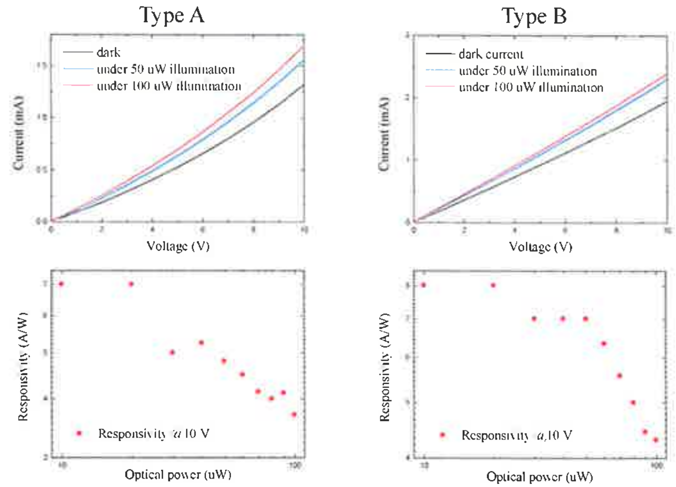
Fabrication of PbS/S2-, PbS/OH- photodetector

Process:



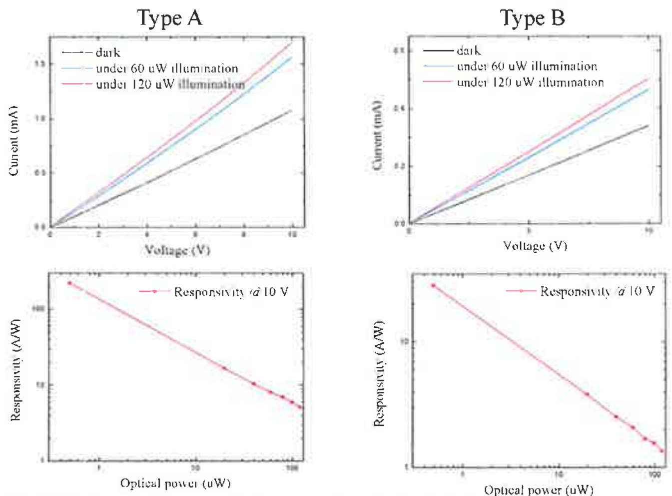
- 10 times dip coating with inorganic ligand exchange
- Band gap ~ 2.15 um
- Electrode distance: type A ~ 2 um
  type B ~ 4 um

Characterization of PbS/S^{2-} photodetector



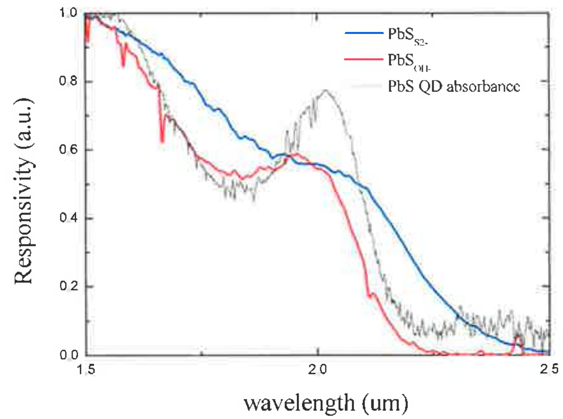
The responsivity increases corresponding to decrease of incident power

Characterization of PbS/OH^- photodetector



High responsivity 200A/W @ 500nW is realized

Detector characterization with FTIR



Spectral response curves nearly match the quantum-confined absorption spectrum

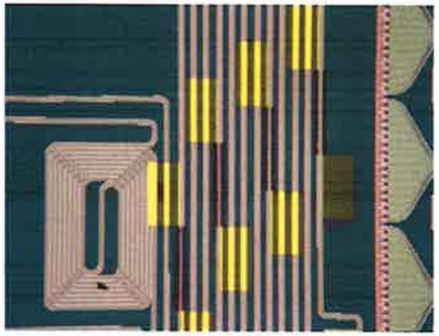
Conclusion

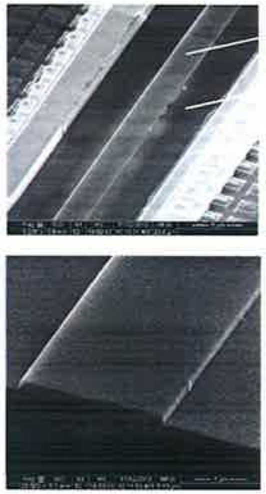
- A crack-free, homogeneous nanocrystal film can be realized
- QD film can be patterned with optical lithography and wet etching
- Colloidal PbS QD photodetector on Si with high responsivity is achieved

Future work

- Integration on photonics integration circuits
- Use graphene layer to improve performance

Integrated photodetector on SOI





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PHOTONICS RESEARCH GROUP

Thank you very much for your attention!

SPRING 13: Conference

E-MRS 2013 SPRING MEETING

Technical sessions: May 27-31
Exhibit: May 28-30
Congress Center - Strasbourg, France

The 2013 Spring Meeting included 24 parallel symposia, one plenary session, one exhibition and much more.

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Scientific Program

PLENARY SESSION

Preliminary program

MATERIALS FOR ENERGY

- **A** Energy conversion applications of atomic layer deposition
- **B** Organic and hybrid interfaces in excitonic solar cells: from fundamental science to applications
- **C** Advanced thermoelectrics: from materials to devices
- **D** Advanced inorganic materials and structures for photovoltaics
- **E** Scientific basis of the nuclear fuel cycle
- **F** Nanomaterials for energy conversion and storage

ELECTRONIC AND PHOTONIC MATERIALS

- **G** Alternative approaches of SiC and related wide bandgap materials in light emitting and solar cell applications
- **H** Multifunctional binary and complex oxides films and nanostructures for microelectronic applications
- **I** The route to post-Si CMOS devices: from high mobility channels to graphene-like 2D nanosheets