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

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Chen Hu\textsuperscript{a,b,c}, Alban Gassen\textsuperscript{a,b}, Yolanda Justo\textsuperscript{a,c}, Zeger Hens\textsuperscript{b,c}, Günther Roelkens\textsuperscript{a,b}

\textsuperscript{a} Photonics Research Group, INTEC Department, Ghent University-IMEC, Belgium
\textsuperscript{b} Center for Nano- and Biophotonics (NB-Photonics), Ghent University, Belgium
\textsuperscript{c} Physics and Chemistry of Nanostructures, Ghent University, Belgium

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

Challenges of integration?

• Isolating organics

• Film cracking due to significant volume loss during ligand exchange

• Patterning of colloidal QD film

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

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/S²⁻ ligand exchange

TEM images confirm 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

• Substrate
• OI/AC-terminated QD film deposited by dip coating
• Inorganic ligand exchange
• Reposition of dip coating
• Reposition of inorganic ligand exchange

SEM: PbS/S²⁻ and PbS/OH⁻ film

- Left: PbS/S²⁻ 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:**
- Layer-by-layer assembly of QDs with inorganic ligands
- Photonoat deposition by spin coating
- Exposure
- Development
- Wet etching
- Strip photoresist film

**Patterning of PbS nanocrystal film**

- HCl/H₃PO₄ mixture
- Before etching
- Before removing resist
- After removing resist

- Photo resist
- PbS/S² QD

**Patterning of PbS nanocrystal film on photodetector**

- Before etching
- Before removing resist
- After removing resist

- QD layer
- Gold electrodes

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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/S2− photodetector**

Type A
- Dark current
- Under 300 W illumination
- Under 500 W illumination

Type B
- Dark current
- Under 300 W illumination
- Under 500 W illumination

The responsivity increases corresponding to decrease of incident power.

**Characterization of PbS/OH− photodetector**

Type A
- Dark
- Under 600 W illumination
- Under 1200 W illumination

Type B
- Dark
- Under 600 W illumination
- Under 1200 W illumination

**Detector characterization with FTIR**

High responsivity 200A/W @ 500nW is realized.

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

Acknowledgement

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.

Conference Chairpersons:

Alain CLAVERIE
CEMES/CNRS
29, rue Jeanne Marvig
BP 94347
31055 Toulouse Cedex 4
France
Phone: +33 (0)5 62 25 78 00
Fax: +33 (0)5 62 25 79 99
claverie@cemes.fr

Arnulf JAEGGER-WALDAU
European Commission
DG JRC - Institute for Energy
Via Enrico Fermi TP 45
21027 Ispra (VA)
Italy
Phone: +39 0332 789119
Fax: +39 0332 789268
arnulf.jaeger-waldau@ec.europa.eu

Francesco PRIOLO
INFM - Universitá di Catania
Dipt. di Fisica e Astronomia
Via S. Sofia 64
95123 Catania
Italy
Phone: +39 095 378 5401
priolo@ct.infn.it

Anke WEIDENKAFF
Empa
Ueberlandstrasse 129
CH-8600 Duebendorf-Zuerich
Switzerland
Phone: +41 44 823 4131
Fax: +41 44 823 4034
anke.weidenkaff@empa.ch

Scientific Program

PLENARY SESSION

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