Symposium on Light emission and Photonics of Group IV semiconductor Nanostructures (LPGN)

Venue: Noyori Hall, Nagoya University

December 14th (Thursday)

Scope/objectives: The symposium aims at presenting and discussing the state of the art and potential for applications of group IV semiconductor nanostructures, in the field of light emission and associated photonic functions. More precisely, discussions will involve various types of silicon nanostructures, such as individual nanocrystals, porous silicon, nanodot assemblies, and nanostructures of some group IV elements (Si, Ge, Sn). The potential of such nanostructures in diverse multidisciplinary fields, such as electronics, photonics, plasmonics, biology, or medicine, will be considered. The symposium will also aim at (i) estimating the most promising fields and routes for applications of silicon nanostructures in society, as well as (ii) identifying the fundamental aspects that still need to be clarified and ways to clear them.

PROGRAM

13:00-13:05 Opening (B. Gelloz)

13:05-14:05 Keynote presentation by L.T. Canham, Univ. of Birmingham.
"Efficient Visible Photoluminescence of Silicon-Based Nanostructures"

A variety of silicon-based nanostructures with dimensions in the range 1-5nm have now been shown to emit efficient photoluminescence (PL) spanning the visible range. Achievement of high photoluminescence quantum efficiency (PLQY) relies critically on surface chemistry passivation of non-radiative processes. Two distinct PL bands will be discussed. The "S Band" has red-green emission with slow microsecond decay rates. Its efficiency (PLQY) steadily improved from ~3% in 1990 to 65% by 2017. The "F Band" has blue to yellow emission with fast nanosecond decay rates. Reported PLQY values have risen from 0.1% in 1994 to as high as 90% in 2016. The vast literature on both bands has been surveyed (1) and some conclusions drawn on the likely distinct origins of these two PL bands. Potential applications will also be covered.

(1) L.Canham. Faraday Discussions 222, 10-81 (2020)

14:05-14:40 Invited presentation by N. Koshida, Tokyo Univ. Agr.&Tech. / Quantum 14 Co. Ltd.
"Diverse Functions of Nano-structured Si"

Some topics of research and development studies on Si nanostructures are presented in relation to their varied functions. The emphasis is laid on the unique features of nano-Si systems regarding luminescent Si quantum dots (Si-QDs), nano-textures, and functional applications. The contents of each subject are as follows.

(a) Si-QDs: Efficient formation of colloidal sample, Combination with solar cell

(b) Textures: Hetero epitaxy of ceramic films, Pore filling and nanocomposites
(c) Functional applications: Ballistic electrons, Thermo-acoustics, Phononics
Along with continuing pursuit of scaling merits in LSI toward the atomic scale, the role of nano-Si as a sustainable platform is extending to whole technology area including medicine.

14:40-15:15 Invited presentation by M. Fujii, Kobe Univ.
"Silicon Nanoparticle Nanoantenna for the Enhancement of Light-matter Interaction"
A nanoantenna is a device that manipulates light propagation and enhances light-matter interaction at the nanoscale. Integration of an emitter into a nanoantenna enhances the excitation rate and the spontaneous emission rate (Purcell effect), and modifies the spectral shape. The most widely studied nanoantennas for the Purcell enhancement are plasmonic nanoantennas made from gold or silver nanostructures supporting localized surface plasmon resonances. Recently, high refractive index dielectric nanostructures are attracting attention as a new type of nanoantenna having several advantages compared to traditional plasmonic nanoantennas. Silicon is considered to be the most suitable material for dielectric nanoantennas. We have been developing silicon nanospheres having the lowest order Mie resonances in the visible to near infrared ranges as a new type of nanoantennas that can enhance not only the electric dipole transitions of a molecule but also the magnetic dipole transitions due to the low-loss magnetic-type Mie resonances at the optical frequency. In the presentation, we will briefly introduce Mie resonances of silicon nanospheres and show some experimental results on the enhancement of light-matter interactions by silicon nanosphere nanoantennas.

15:15-15:35 ~ Coffee break *(1F near entrance; with drinks/snacks)*

15:35-16:10 Presentation by B. Gelloz, Nagoya Univ.
"Photoluminescence of Wet Porous Si Nanostructures: High-energy Limit and Band-filling Phenomenon"
Bernard Gelloz (Nagoya University) and Lianhua Jin (Univ. of Yamanashi)
It is well established that nanoporous Si (PSi) and Si nanostructures in general can emit visible photoluminescence (PL). Highly efficient (yields up to ~60% for nanocrystal assemblies) red/orange PL is now routinely produced by various methods. However, the same cannot be said of blue PL. Only rare reports exist for blue PL, and even for those rare cases, the emission mechanism was generally not clearly attributed to recombination of excitons in Si nanocrystals cores. Thus, the question: Is it really possible to continuously tune the emission energy from NIR to blue only by changing nanocrystal sizes and not intruding external luminescence centers? In order to shed some light into this matter, I will present the results of an experiment (PL of PSi during etching in HF) which tend to show that the PL can be shifted up to ~ 515 nm (~2.4 eV) but not any further up in energy. Our results support the idea of a critical size (~ 1.5–2 nm) below which the PL quantum efficiency vanishes, possibly because of the emergence of structural non-radiative defects below a certain size. Furthermore, the optimum PL intensity was generally obtained for a peak wavelength of ~565 nm (~2.2 eV). In a second part of the talk, I will discuss the PSi PL recovery after its quenching by electron injected from the substrate. I will show that the recovery time is compatible with escape of electrons from PSi back into the substrate by tunnelling through an energy barrier at the interface. Electrons can remain in PSi for long periods of time (minutes) without recombining.

16:10-16:45 Invited presentation by O. Nakatsuka, Nagoya Univ.

"Research and Development of GeSn-related Group-IV Semiconductor Heterostructures for Optoelectronic Applications"

Osamu Nakatsuka[1,2], Shigehisa Shibayama[1], Masashi Kurosawa[1], and Mitsuo Sakashita[1]

[1]Graduate School of Engineering, Nagoya University

[2]Institute of Materials and Systems for Sustainability, Nagoya University

GeSn and related group-IV semiconductor materials have been much attracted for next-generation nanoelectronics, optoelectronics, and thermoelectronics applications. GeSn heteroepitaxial structures promise high carrier mobility, highly efficient optoelectronic conversion, low thermal conductivity, and also low thermal budget process on Si ULSI platform. Some challenges are necessary with increasing the substitutional Sn content, improving the crystalline quality, and forming available heterostructures for practical applications. Our group have been developing epitaxy and interface engineering technologies of GeSn, GeSiSn, and SiSn semiconductor thin films using various techniques of MBE, MOCVD, and sputtering methods. We will present recent findings and achievements of group-IV heterostructure and energy band engineering from our research and development.

16:45-17:20 Invited presentation by K. Makihara, Nagoya Univ.

"Fabrication and Characterization of Ge/Si Core-Shell Quantum Dots for Light Emission Devices"

Katsunori Makihara and Seiichi Miyazaki, Graduate School of Engineering, Nagoya University

Light emission from Si/Ge based nanostructures has attracted much attention in the field of Si-based photonics because of its potential to combine photonic processing and electronic processing in a single chip. So far, we have demonstrated high density formation of quantum dots (QDs) consisting of Si clad and Ge core by controlling thermal decomposition of SiH_4 and GeH_4, alternately, on thermally grown SiO_2 and their unique charge storage characteristics associated with type II energy band alignment between the Si clad and the Ge core, that is, holes are store in the Ge core but electrons in the Si clad. And we also reported that, in the case that a single layer of QDs having a 6nm Ge-core and a 3nm-thick Si-clad in average size on SiO_2 was excited by 976nm photons, stable PL signals consisting of four Gaussian components were detected in the energy region from 0.66 to 0.88eV at room temperature, and that the components are attributable to radiative recombination through quantized states in QDs as verified from dot size dependence of PL peak energy. In this talk, our achievements on room temperature electroluminescence (EL) of the Ge/Si core-shell QDs have been reviewed.

17:20-17:30 Closing remarks (B. Gelloz).

17:30-18:00 Free discussion *(1F near entrance; with drinks/snacks)*, leave the venue.

Free of charge. Everybody is welcome. Please register by Dec. 12th at:

http://www.j-group.phys.nagoya-u.ac.jp/LPGN.html

Chair/問い合わせ：物理 J-研　Gelloz Bernard（bernard.gelloz@nagoya-u.jp）

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