Silicon Based Light Emission Devices

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OUTLINE

- **Why LEDs?**
- **Common Materials and Structure for LEDs**
- **Si-Based LEDs: Light Emission and Model for Description**
- **Quantum Confinement**
- **Preliminary Results**
- **Conclusions& Future Works**

Why LEDs?

- **Yearly global electricity consumption is 30 trillion kWh, 21% of this consumption is consumed for lighting.**

- **1% improvement of the luminous efficiency would save up to $2 billions per year.**

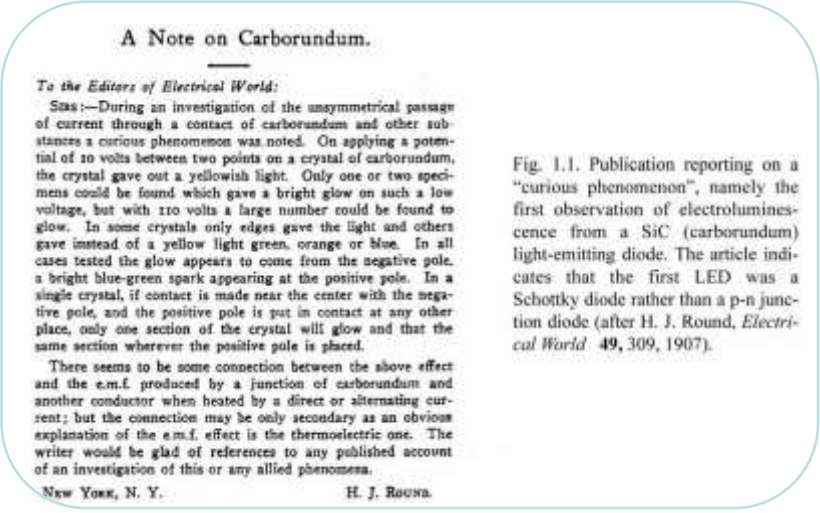
- High luminous efficiency and longer lifetimes than fluorescent or halogen lighting devices.

- Used in daily-life, as back lights in ever increasing display sizes, in illuminating wall panels, etc.

Application Areas

- Video and audio remote controls
- Large-scale display technology
- Indicator lamps
- Sources for local area communication networks
- Well-integrated into medical goggles worn by a surgeon during an operation
- Medical applications to fulfills the stringent requirements of high-quality color rendition
- Automotive headlights

Common Materials used in LEDs



A Note on Carborundum.

To the Editors of Electrical World:

SIRS:—During an investigation of the unsymmetrical passage of current through a contact of carborundum and other substances a curious phenomenon was noted. On applying a potential of 10 volts between two points on a crystal of carborundum, the crystal gave out a yellowish light. Only one or two specimens could be found which gave a bright glow on such a low voltage, but with 110 volts a large number could be found to glow. In some crystals only edges gave the light and others gave instead of a yellow light green, orange or blue. In all cases tested the glow appears to come from the negative pole, a bright blue-green spark appearing at the positive pole. In a single crystal, if contact is made near the center with the negative pole, and the positive pole is put in contact at any other place, only one section of the crystal will glow and that the same section wherever the positive pole is placed.

There seems to be some connection between the above effect and the e.m.f. produced by a junction of carborundum and another conductor when heated by a direct or alternating current; but the connection may be only secondary as an obvious explanation of the e.m.f. effect is the thermoelectric one. The writer would be glad of references to any published account of an investigation of this or any allied phenomena.

NEW YORK, N. Y. H. J. ROUND.

Fig. 1.1. Publication reporting on a "curious phenomenon", namely the first observation of electroluminescence from a SiC (carborundum) light-emitting diode. The article indicates that the first LED was a Schottky diode rather than a p-n junction diode (after H. J. Round, *Electrical World* **49**, 309, 1907).

LED had been born when Round noticed that light was emitted from a SiC crystallite as used for sand paper abrasive.

The era of III–V compound semiconductors started in the early 1950s

III-V Semiconductors

IIIa	IVa	Va
B	C	N
Al	Si	P
Ga	Ge	As
In	Sn	Sb
Tl	Pb	Bi

III-V compound SCs obtained by combining group-III with group-V element; **GaAs**, **InP**, **GaP, GaN**, etc.

Perfect light emitters but complex synthes and device fabrication.
Another issue is availability of rare elements like In,Ga

Higher Cost!

Main Challenge

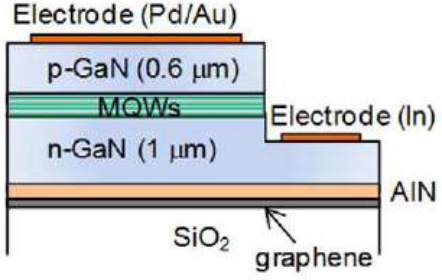
To produce low cost, large-area LEDs

How ?

- Replace single-crystal substrates with low-cost, large-area materials such as glass, metal, various oxides.

Recently: Full-color LEDs are fabricated on amorphous substrates, It could be possible to fabricate large-area LED displays on glass.

Shon, Jeong Woo, et al. "Fabrication of full-color InGaN-based light-emitting diodes on amorphous substrates by pulsed sputtering." **Scientific Reports** 4 (2014).



- Change production technique which requires high temp. (MOCVD)

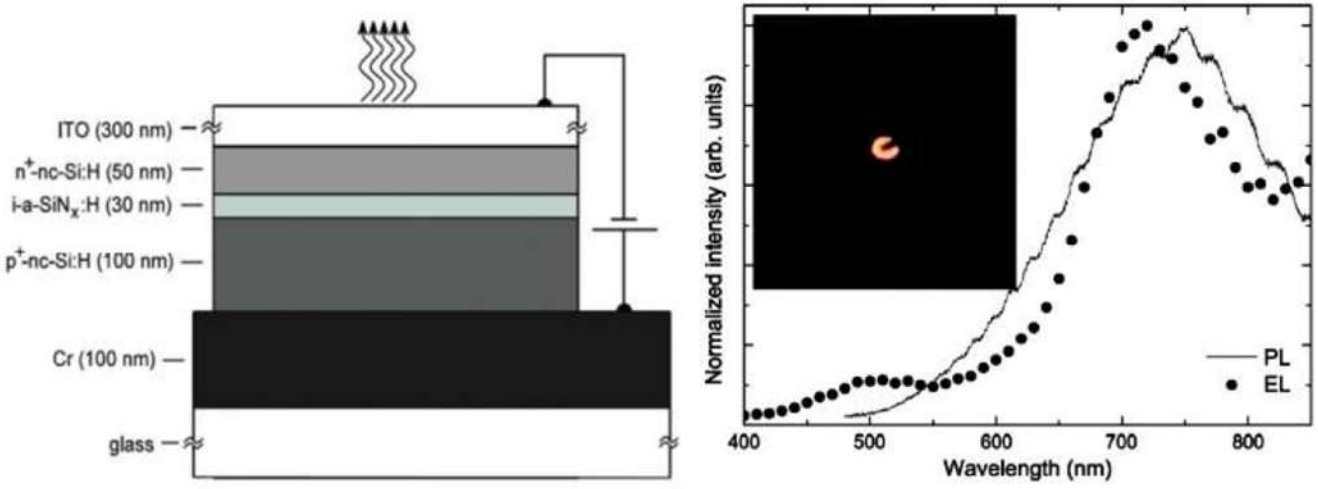
Recently : Successful fabrication of InGaN LEDs by PSD at a maximum process temperature of 480 °C has been reported.

Nakamura, Eiji, et al. "Dramatic reduction in process temperature of InGaN-based light-emitting diodes by pulsed sputtering growth technique." **Applied Physics Letters** 104.5 (2014):

Is it also possible to get light emission from Silicon ?

Proof of Concept

- a-SiNx:H-based p-i-n diode has been realized.
- The EL efficiency of the diode was very poor, but it has been improved 30-fold with high forward E-field, joule-heating assisted forming process
- Orange-red emission becomes easily perceptible by the human-eye



M. Anutgan, et al., Electroforming of amorphous silicon nitride heterojunction p-i-n diode, **IEEE Transactions on Electron Devices** *58 (2011)*

Si-Based LEDs

- Emission occurs when an e^- recombines with a h^+ to produce a photon.
  - If both e^- and h^+ are located at the same point in the brillouin zone, radiative lifetime (τ_{rad}) is short .
- For indirect SCs radiative recombination requires the phonon, longer τ_{rad}

$$\eta_{in} = \frac{\tau_{non-rad}}{\tau_{non-rad} + \tau_{rad}} (x100\%)$$

- η_{in} can be very large for direct-band material $\tau_{non-rad} > \tau_{rad}$ (10-100%).
  - For indirect-band material the $\tau_{non-rad} < \tau_{rad}$, lower η_{in} (10^{-4}-10^{-5}%).

To improve η_{in} for Si;

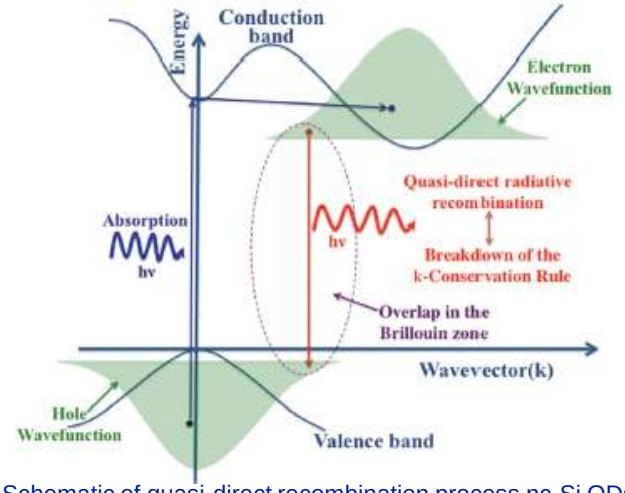
i. Suppress non-radiative recombination pathways
ii. Enhance radiative recombination rate

How rad. recombination in Si can be enhanced

Localization the electron and hole wavefunctions in the same region of space

- Using Quantum dots
- Using isoelectronic impurities
- Combining Si with another elemental semiconductor

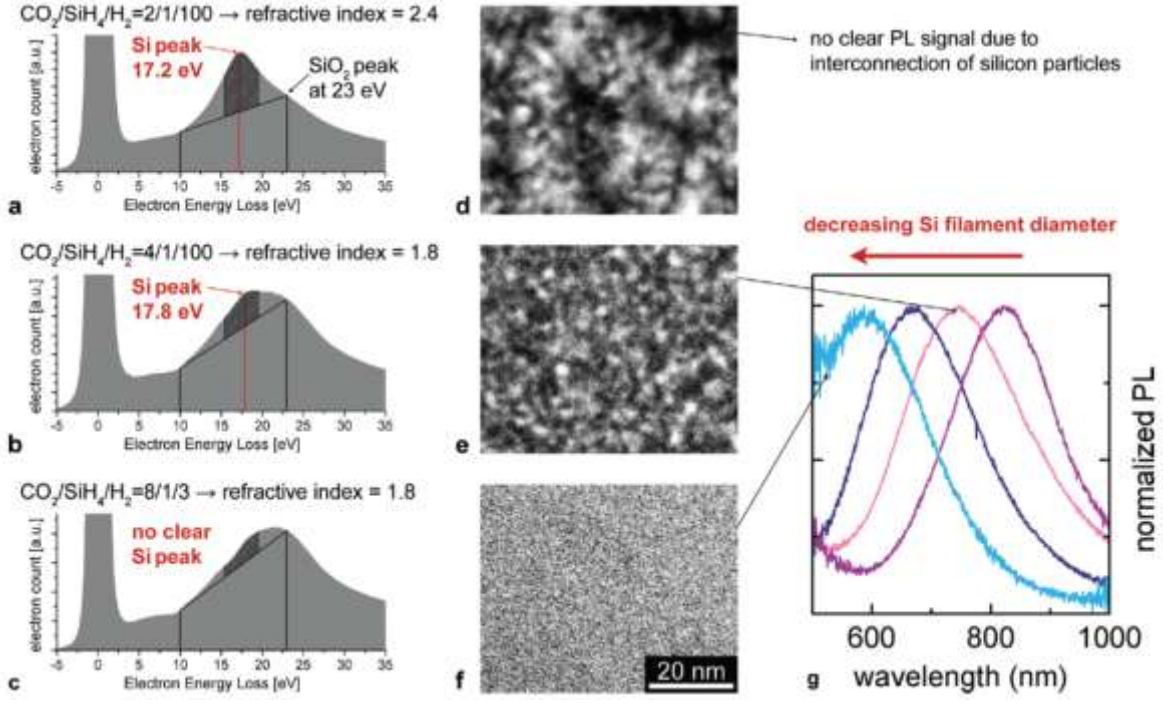
Quantum Confinement



Schematic of quasi-direct recombination process nc-Si QDs
***Phsc.Chem**.,2013,**15**,3881*

The localization of e^- and h^+ wavefunction with decreasing size increases their spread in reciprocal space, hence increase in their overlap and as a result radiative recombination rate is enhanced.

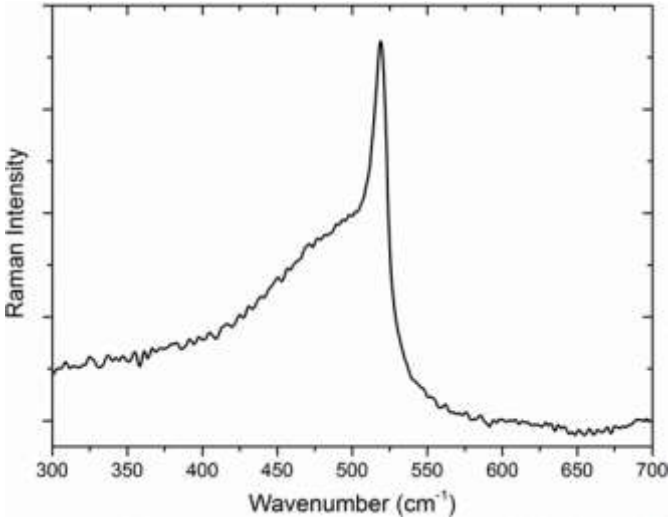
Quantum Confinement Model



- Quantum confinement is confirmed by the PL of mixed-phase Si/SiOx films, PL peak position is shifting to lower wavelengths for decreasing diameters of the silicon filaments

P. Cuony, et. all. *Silicon filaments in silicon oxide for next-generation photovoltaics* **Advanced Materials** 2012; 24.

Preliminary Results

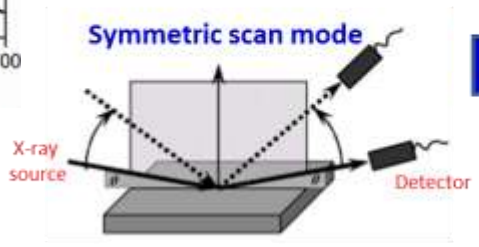


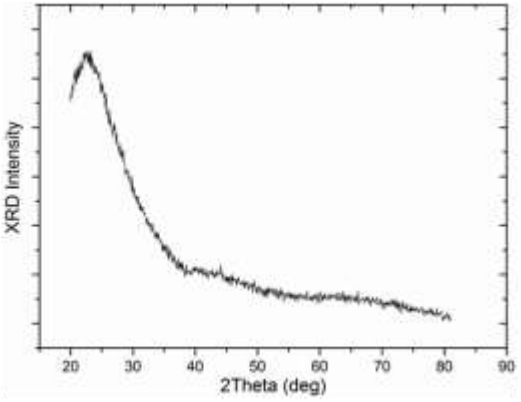
Deposition parameters (PECVD)

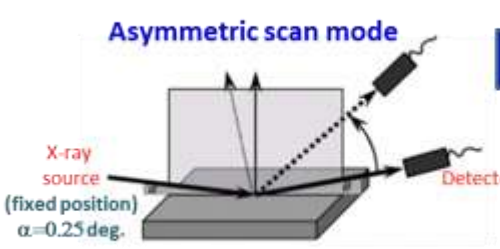
4mbar; 65W; H_2/SiH_4=250

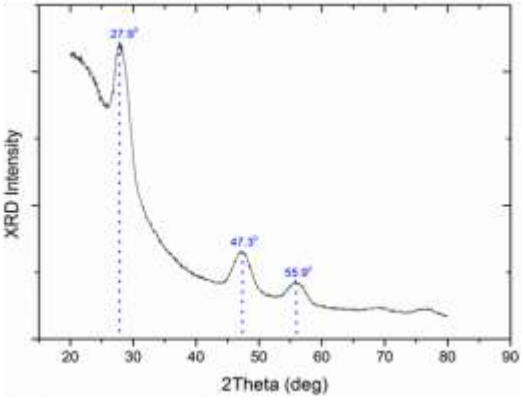
Thickness~150nm ;Raman Crystallinity ~ 63%

For structural characterization Raman and XRD techniques are used. To get an reliable XRD spectra asymmetric scan mode has been used with 0.25^0 grazing angle





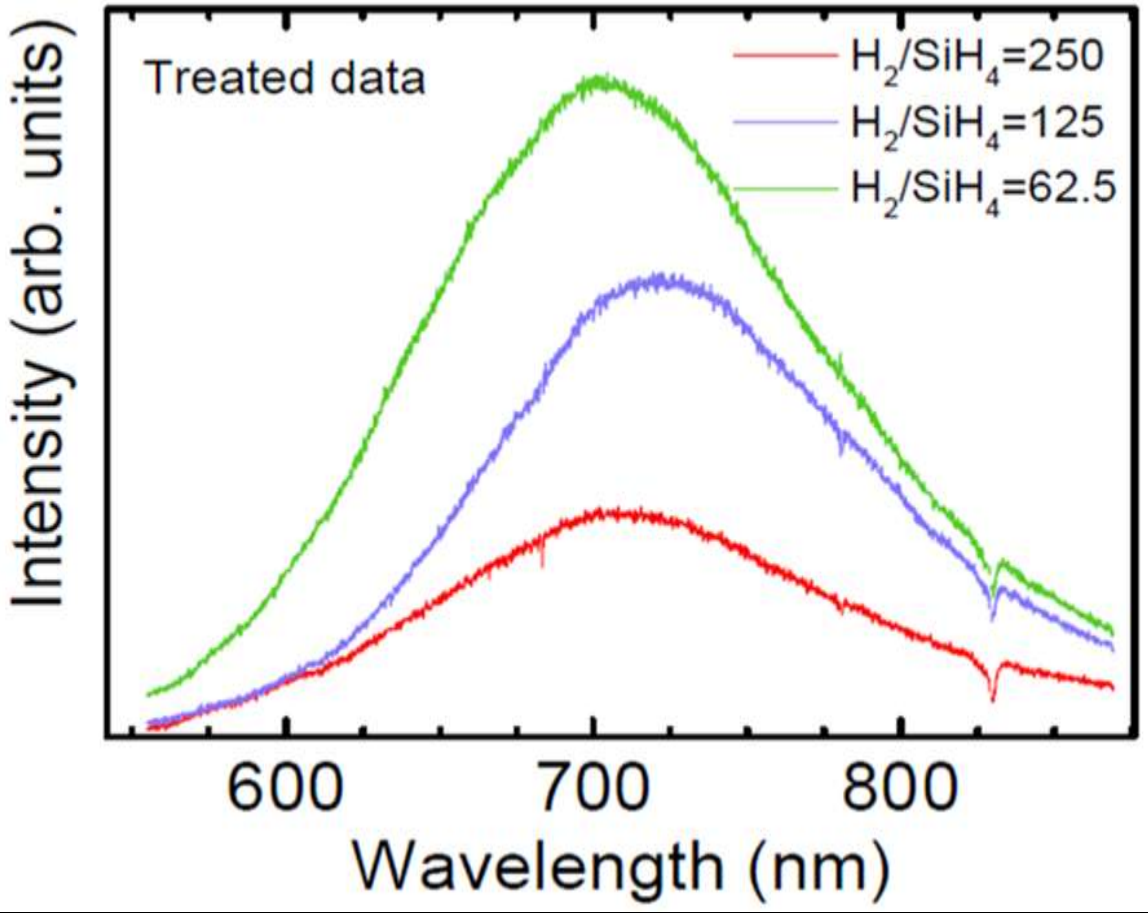




Preliminary Results (PL)

Deposition parameters;
4mbar; 65W; CO_2/SiH_4=3.5
Thickness~150nm;

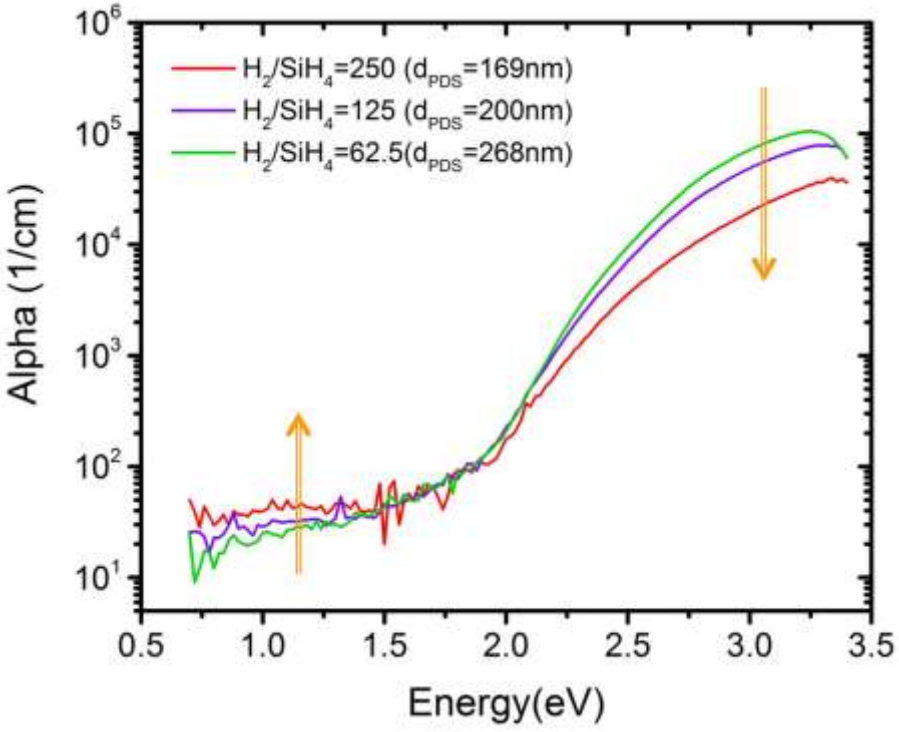
- Laser power 270uW
- Excitation wavelength 488nm

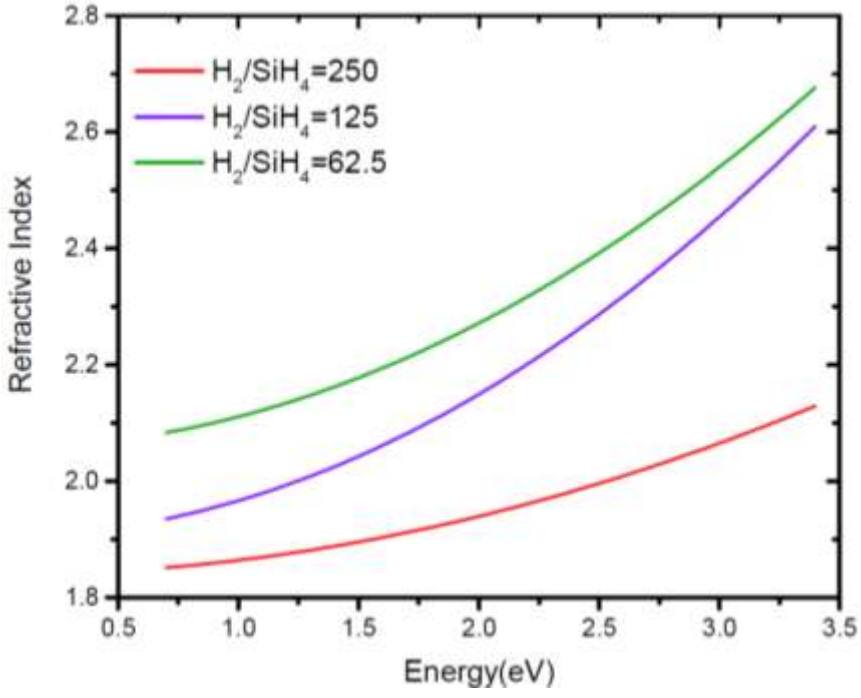


- Increasing hydrogen dilution causes a reduction in the light emission

Preliminary Results (PDS&SE)

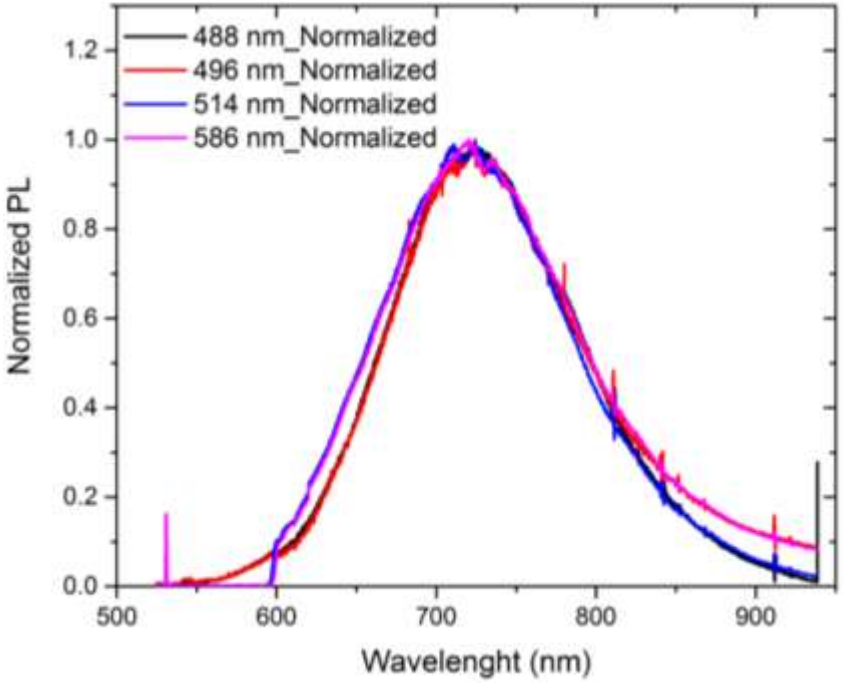
Some additional optical measurements have been performed for better understanding of the emission spectra.



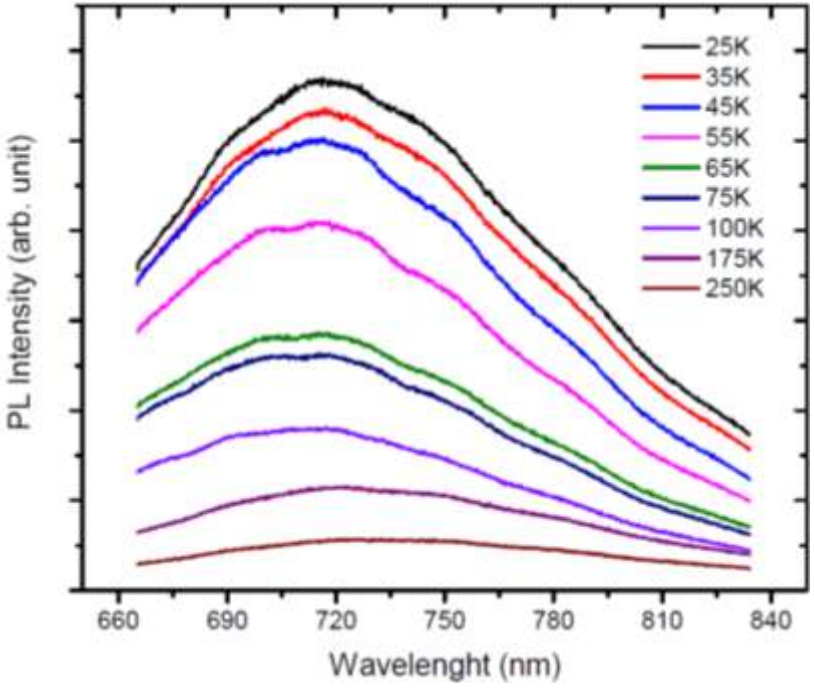


Preliminary Results

Excitation with different wavelengths at RT

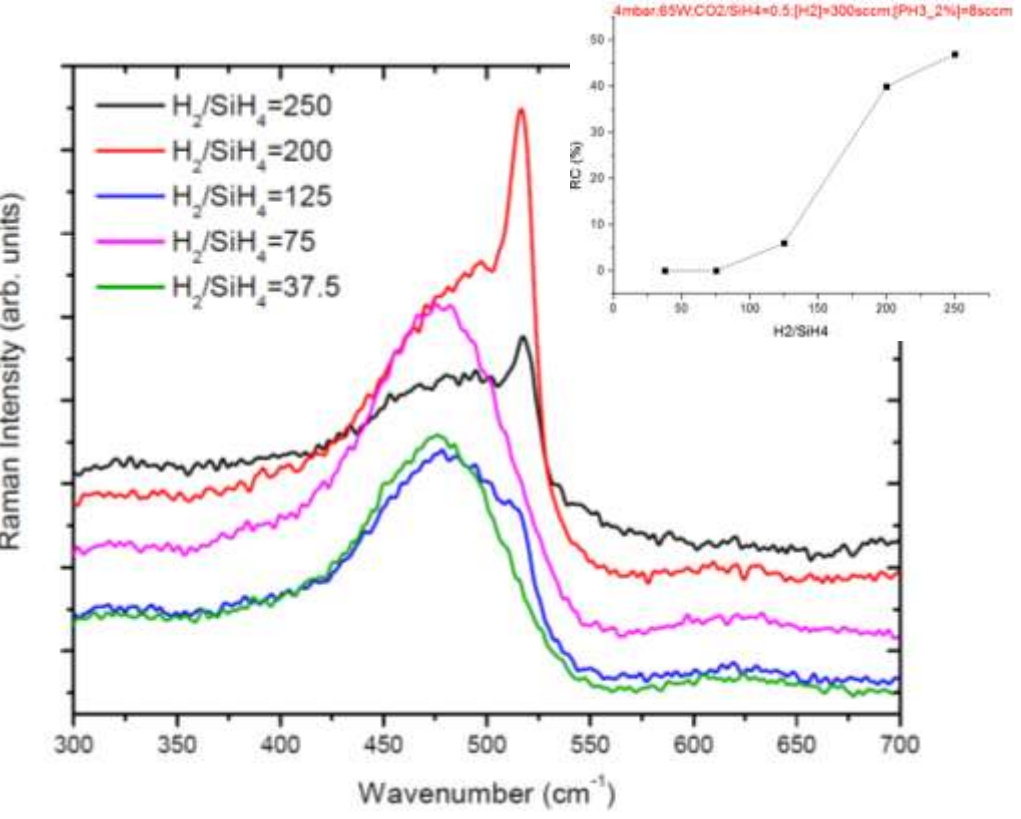


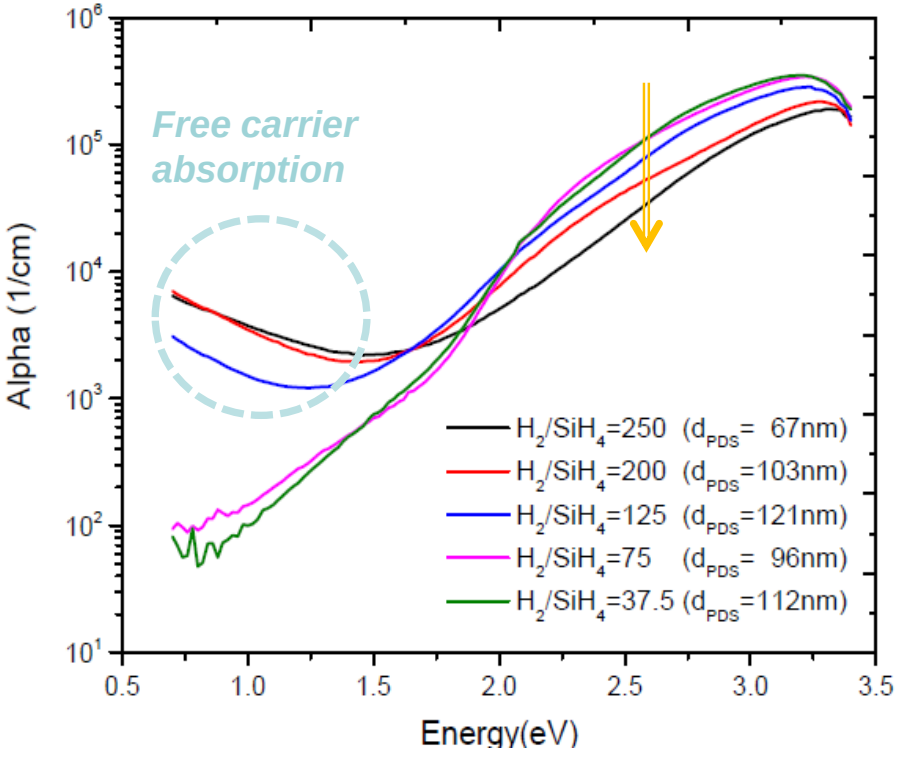
Temperature dependence Photoluminescence



Preliminary Results

PH_3_2% doped Set: H_2/SiH_4=250; 4mbar;65W;CO_2/SiH_4=0.5





SiO_x layers are also doped with PH_3 to investigate the dopant effect and it is observed that layer structure can be controlled however layers become more defective. No more PL signal.

Conclusion & Future Works

- Recent work illustrates that it is possible to realize efficient Si-based light emitters

- The preliminary PL measurements demonstrate that SiO_x layers have a clear potential for development of light emitting devices.

- Luminescence spectroscopy of semiconductors including silicon nanostructures in high band-gap matrices such as SiO_x, SiN_x, SiC_x will be investigated more in detail.

- Si-Ge nanostructures also show efficient light emission and amplification that makes them another potential material.

Acknowledgement

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Thank you for your attention!