# Chapter 1 Introduction

## 1-1. Applications of Si-based nanomaterials

In recent years, Si-based nanomaterials have been developed rapidly to be novel optoelectronic materials. In the future, Si-based optoelectronic devices will have many important applications, such as Si light emitting diodes, semiconductor lasers, and ultraviolet photodetectors etc. Computing and communicating modules [1-3] are proposed to be fabricated on silicon substrates, for reasons of practicality. Therefore, Si-based materials are compatible with standard silicon ULSI technology and cause low cost. But inefficient Si-related light emission, which is naturally limited by the indirect bandgap of silicon, is the main challenge on developing hybrid-circuits since exciting advances have already been made in other optoelectronics, such as the transmission parts of photonic crystal waveguides [1], wideband optical detectors [2] and even high-speed optical modulators [3] on silicon.

## 1-2. Properties of semiconducting nanomaterials

According to different relationship of dimension and density of state [4], semiconducting nanomaterials demarcate two-dimensional quantum wells (2D), one-dimensional quantum wires (1D), and zero-dimensional quantum dots (0D), presented in Fig. 1-1. For example, what are one-dimensional nanomaterials? In three dimensions of the material, the length of one dimension is not nanometer scale. In the same way, zero-dimensional nanomaterials are three dimensions in nanometer scale. And two-dimensional nanomaterials must be one dimension is nanometer scale. Therefore, nanomaterials must have one dimension is nanometer scale at least.

Semiconducting nanomaterials are very different from traditional semiconductors, because scale reduces greatly. Characteristics of the semiconductor often discussed are surface effect and quantum confinement effect.

Surface effect is that the ratio of surface area and volume incenses with the volume of material reducing. It not only exhibits the characteristic of area but also changes the structure of material for unstable surface energy. When the size is small, atoms on the surface increase. Those atoms are activated and unstable, so they combine with other atoms to generate new effects.

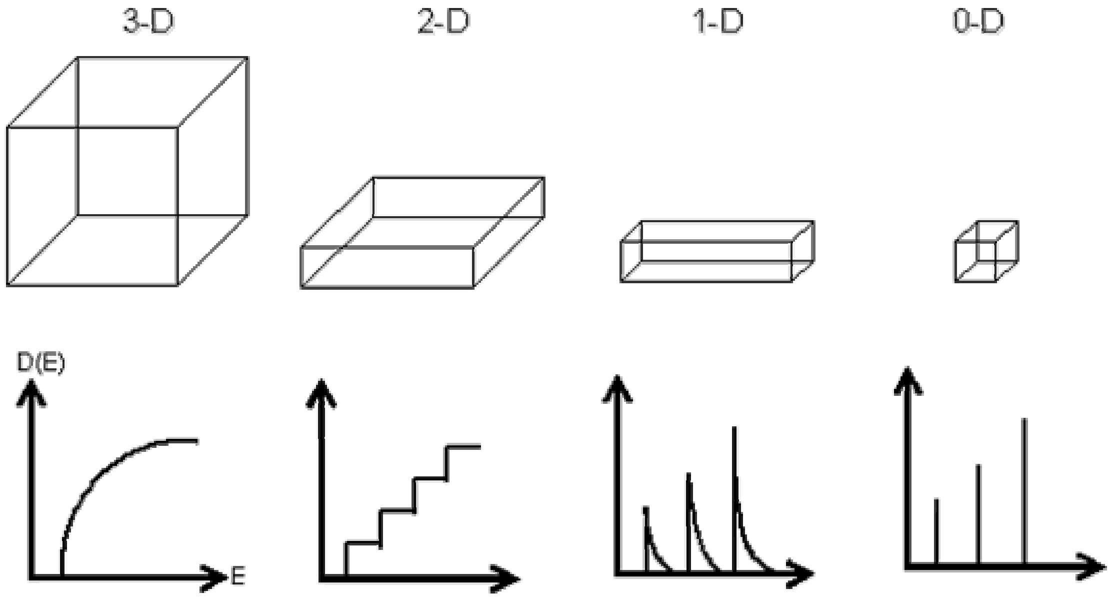

**Fig. 1-1**: Relationship of dimension and density of state

Quantum confinement effect is that energy distribution of electron structure appears dispersed energy state with particles reducing. When size reduces into nanometer scale, atoms of nanomaterials are confined and have lower conducting electrons than bulk materials. That causes intermittent phenomenon near Fermi-Level and energy bandgap is increase with size reducing. It is different from bulk materials which have infinite conducting electrons and continuous energy level.

## 1-3. Research of low dimensional Si-based materials

Many efforts have been devoted to exploit Si-related light sources. In 1990, L. T. Canham investigated porous-silicon-based devices [5]. They have demonstrated that Si wafers subjected to combined electrochemical and chemical dissolution can emit visible photoluminescence at room temperature.

In 1995, P. Mutti et al. investigated $Si^+$-implanted $SiO_2$ layers [6]. They observed room-temperature visible photoluminescence from $Si^+$ implanted $SiO_2$ that layers thermally grown on silicon substrates. In the same way, L. S. Liao et al. observed $Si^+$-implanted thermal $SiO_2$ films on crystalline Si can exhibit blue PL with a peak at

2.7 eV under the 5.0 eV excitation [7].

In 2000, P. Photopoulos et al. investigated the Si/$SiO_2$ supperlattice with post annealing [8]. Yu. D. Glinka et al. investigated mesoporous silica (MS) materials [9]. They proposed that PL from MS originates from variously surrounded NBOs, hydrogen-related species and water-carbonyl groups. L. Pavesi et al. investigated optical gain in silicon nanocrystals [10]. Their findings open a route towards the realization of a silicon-based laser.

In 2001, Wai Lek Ng et al. investigated doping impurities in Si [11]. They demonstrated the most likely candidate currently for implementing efficient light sources in silicon.

The core concept for those methods is to (1): generate electron-hole irradiative recombination centers associated with quantum-confined nanocrystals (NCs) or NCs/interfaces composites [10-11]; and (2) to densely disperse NCs within host materials to enhance luminescence efficiency [6-8].

In this study, we exploit Mesoporous silica (**MS**) film. Mesoporous silica naturally has enormous radiative recombination centers, mainly contributed from regularly distributed nanopores (2-10 nm) [12]; therefore similar to surface-oxidized silicon nanocrystals, emitting light from blue to red [9,13]. However, the reported luminescence characteristics [9,13-14] for MS materials are obtained from powder MS [9,13] or free-standing MS [14] and a few studies have addressed luminescence (or even electroluminescence (**EL**)) from MS thin films integrated with Si substrates.

## 1-4. Motivation

The dielectric constant and reliability of MS films as interlayers strongly depend on their porosity and the amount of moisture taken up [15]. In considering the number of radiative recombination centers within the MS matrix, the porosity (or pore nanostructures) determines the total area of the pore-surfaces (and, thus, the abundances of the emission centers [9,10,16-18]) and the nanoscaled surroundings, both of which influence the luminescence efficiency and spectra. The advantages of MS film are high porosity (30~75%), controllable pore diameter (2~10nm), ordering pore channel array, and providing quantum surrounding for doping nanomaterials. In this study, integrated-circuits compatible skills are employed to form various nanostructures within MS films supported on Si substrates. Photoluminescence (**PL**) from such films is investigated. Additionally, the UV to blue light photodetector fabricated from MS films is achieved.