CHAPTER 1

Introduction

1.1 Histories for Silicon-implanted Silicon dioxide ($SiO_2:Si^+$)

1.1.1 Silicon lasers start to take shape

One-quarter of the Earth is silicon. Devices made from silicon dominated the microelectronics industry, so silicon should be the material of choice for anyone designing new electronic devices that will be integrated with microelectronic circuits. This also applies to the optoelectronic devices that act as gateways between the electronic realm and the worlds of photonics and optical communications. Most optoelectronic components-such as waveguides and modulators-can be made from silicon, but a completely silicon-based system has remained elusive because there is a crucial missing link: a silicon light source.

A silicon laser made using “conventional” silicon-manufacturing technologies would be a disruptive new technology that could have a massive impact on the future of the semiconductor, IT and telecommunications industries. However, the electronic structure of silicon means that it is not good at amplifying light- a key characteristic of any laser medium. Now Lorenzo Pavesi of the University of Trento in Italy, and colleagues at Trento and the University of Catania, have taken a significant step towards a silicon laser by demonstrating light amplification in silicon [1]. However, several technical challenges must be overcome before this breakthrough can be transformed into a practical silicon laser.

Microelectronic systems have now reached the stage where their performance depends on the connections between the different chips and devices, rather than in the chips and devices themselves. Industry experts believe that within a decade the same problem will apply at the level of single chips. As semiconductor systems get ever smaller, the metal tracks currently used to connect the different components on a single chip will suffer increasingly from problems such as lack of speed and unacceptable levels of power dissipation.

Optical connections are an attractive because they promise to eliminate these potential problems. However, the practical implementation of optical connections presents a major challenge, and the key problem has always been the lack of a semiconductor laser that is fully compatible with silicon microelectronic.

The electronic structure of silicon does not allow it to emit light readily. In a so-called direct-band-gap semiconductor, such as gallium arsenide, a photon is emitted when an electron from the conduction band falls into the valance band and ”recombines” with a positive hole. The wavelength of the photon is determined by the energy difference or “band gap” between the conduction and valence bands.

Silicon, however, has an “indirect” band gap” this means that the minimum in the energy if the conduction band and the maximum in the energy of the valence band occur at different moment. Therefore, electrons and holes can only recombine if a lattice vibration-known as a photon-with the correct momentum is available. This makes the emission if a photo much less likely.

One way to force silicon to emit light is to illuminate it with a separate light source: this excites electrons from the valence band into the conduction band, from where they fall back down to the valence band-sometimes emitting photos in the process. This phenomenon is known as photoluminescence. Bulk silicon has a photoluminescence efficiency of much less than 0.01%. Moreover, the light is emitted at only one wavelength in the infrared part of the spectrum.

In 1990 Leigh Canham at the DRA Malvern laboratory in the UK showed that, under certain conditions, silicon can emit light efficiently, even in the visible part if the spectrum [2]. This was first achieved using porous silicon, which has a band structure that is slightly different from bulk silicon. Today we know that very efficient (i.e. above 1%) photoluminescence can be achieved in many materials if they incorporate quantum dots or wires made of silicon.

Measuring just a few nanometers, there structures are known as nanocrystals and they have unusual electronic properties because their band gaps are wider than those of the materials from which they are made. In particular, electrons and holes become "localized" inside the nanocrystals, which increases the chance that they will recombine and emit photons.

Competing recombination processes that do not result in the emission of light can also be suppressed by passivating the surface.

Now Pavesi and colleagues have produced optical gain in silicon nanocrystals made by implanting silicon in thin silicon-dioxide layers grown on silicon wafer. The nanocrystals, which measured about 3 nm across, are embedded in a crude in a crude waveguide. A laser then excites the structure, generating electrons and holes in nanocrystals that recombine to emit light with a wavelength of 800 nm, which lies between the visible and infrared regions of spectrum. They reported amplification factors or "net modal gains" of 100 per centimeter in their structure. This means that spontaneous emission in the device is amplified by a factor of $[l/(g-a)](e^{(g-a)l}-1)$, where l is the distance over which amplification occurs and g-a is the net modal gain.

In a different experiment, the "material gain" the gain or amplification that would be measured if all of the beam passed through the gain region-reached 10000 per centimeter. This is comparable with the best results for indium arsenide and other quantum-dot system. This totally unexpected result is due to the very large concentration of nanocrystals, which more than offsets the smaller gain cross-section of each nanocrystal.

1.1.2 Characteristics of the Si nanocrystals

Quantum confinement of carriers in Si wires was the first model proposed to explain luminescence [2]. Afterwards, many other alternative explanations have been proposed [3]. The various models can be grouped in six different categories, as illustrated in the scheme in Fig. 1-1. Except for the quantum confinement model, all the others assume an extrinsic origin for the luminescence.

1. Quantum confinement model (Fig. 1-1a)

Quantum confinement in crystalline Si was the first model proposed to explain the efficient photoluminescence of nc-Si [2]. Quantum confinement effects result in an enlargement of the band gap, in a relaxation of the momentum-conserving rule, and in a size dependence of PL energy that naturally explains the efficient luminescence, the up-shift and the tunability of PL band in nc-Si.

2. Hydrogenated amorphous silicon model (Fig. 1-1b)

It has been proposed that luminescence is due to a hydrogenated amorphous phase (a-Si:H) which is formed during anodization.

3. Surface hydrides model (Fig. 1-1c)

Since the luminescence decreases dramatically if the hydrogen on the surface is thermally desorbed.

4. Defect models (Fig. 1-1d)

In defect models the luminescence originates from carriers localized at extrinsic centers, i.e. defects in the silicon or silicon oxide that covers the surface.

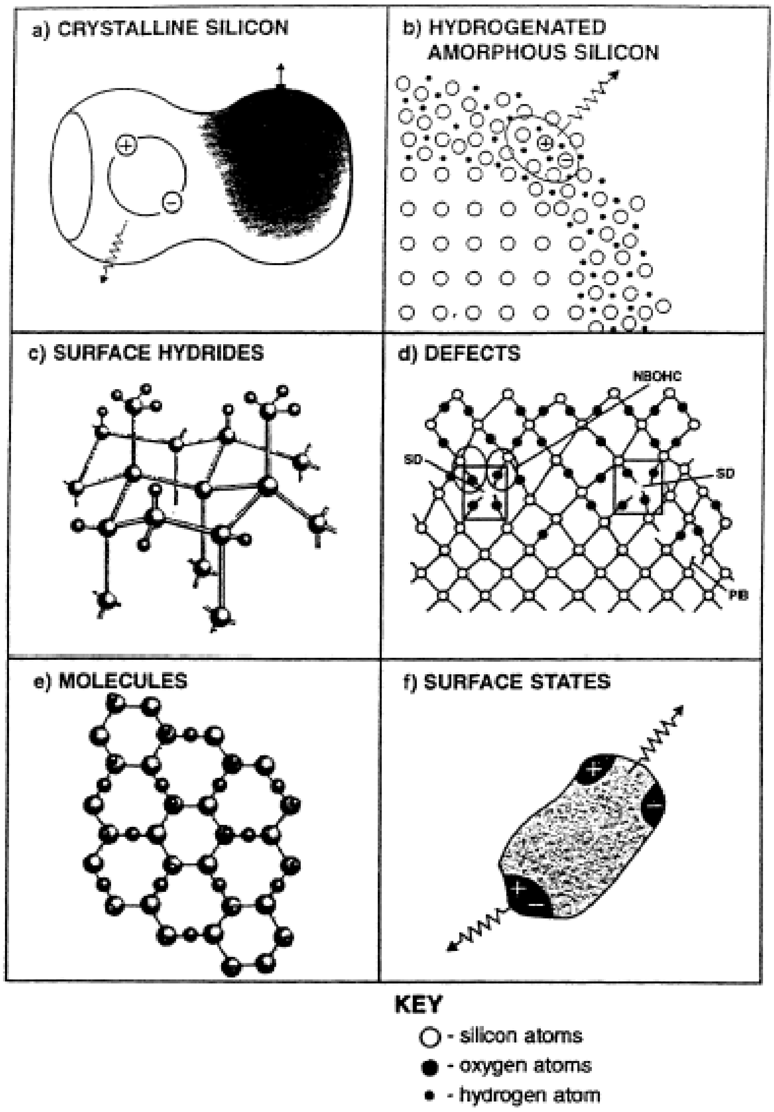

Fig. 1-1 The six groups of models proposed to explain luminescence.

5. Siloxene model (Fig. 1-1e)

Siloxene, an Si:H:O based polymer. This model is supported by the fact that the optical properties of siloxene are somehow similar to those of nc-Si. Siloxene possesses a visible-red PL band and the IR spectrum closely relates to that of aged nc-Si.

6. Surface states models (Fig. 1-1f)

The enormous inner surface of mc-Si (10% of the Si atoms are surface atoms) has led to propose that it is involved in the luminescence process [4].

1.1.2 Motivation and introduction of chapter

In chapter 2, we report the formation of nanocrystallite Si semiconductor by multi-energy implanting the silicon ions into quartz structure. The material aspects, the optical properties of the silicon-ion-implanted SiO_2 (SiO_2:Si^+) sample are characterized by using micro-photoluminescence (μ-PL). The μ-PL analyses provide information important for understanding the relationship between the annealing condition and the optical properties of SiO_2:Si^+ that depend on the local coordination. In addition, we investigate the pumping-intensity dependent μ-PL of the Si-implanted quartz prepared by multi-recipe implantation. Long-term annealed Si-implanted quartz exhibits buried nc-Si, which corresponds a red-shift in μ-PL as the pumping intensity is increased. The shifts in wavelength at various pumping intensities and durations are evaluated. The accumulating rate of surface charges and the corresponding change in the space charge field strength of the Si-implanted quartz under illumination are measured, which corroborates the effect of the electric field induced by accumulation of surface charges is more pronounced than other mechanisms.

In chapter 3, we investigate the electrical characteristics of the Al-evaporated metal contact made on the SiO_2:Si^+ by using the transmission line model (TLM), current-voltage

(I-V) analysis and capacitance-voltage (C-V) analysis. The TLM analysis was employed to investigate the dart current associated with degraded resistivity of $SiO_2:Si^+$ samples with different annealing time at temperature 1100^{o}C. We also use the TLM process to measure the electrical and opteoelectronic properties of the $SiO_2:Si^+$. The dark/photo currents of Al-contacted shottky diode made in pure quartz, as-implanted, annealing $SiO_2:Si^+$ are also determined and simulated the model of current flow mechanisms. Furthermore, we study the metal –semiconductor-metal photodiode structure (MSM-PD) in $SiO_2:Si^+$ sample. We report on the use of the characterizes of a conventional $SiO_2:Si^+$ MSM-PD operating at different wavelength.

References

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