Optical Properties Of Si Nanowires on a Si(111) Surface

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Abstract

Large-scale simulations of silicon nanowires just several atoms in diameter have given device designers new clues about how these nanometer-scale devices will one day perform. The work provides a basis for anticipating how the quantum mechanical effects that dominate behavior of materials at this size scale will alter the operation of future generations of electronic devices. Under this project I am introducing how to find optical properties of straight silicon nanowires by means of in-situ cathodoluminescence spectroscopy in a transmission electron microscope. The nanowires grown on a Si(111) surface via step-flow growth mechanism, have no structural defects such as kink, and the diameter and growth direction are controled by varying the growth conditions. We will be able to see that the nanowires emit intence light. These lines have not been observed in other kind of Si nanostructures such as porous Si.

I. INTRODUCTION

The patterning of semiconductor surfaces on the nanometer scale has become important for a variety of applications, such as quantum wires and dots, as well as magnetoresistive sensors on sawtooth-shaped semiconductors. Due to quantum confinmenment effects, nanostructural semiconductors, such as nanowires and nanodots, are expected to show distinctive optical and electronic properties from bulk semiconductors. Various kinds of nanocrystalline semiconductors have so far been fabricated and studied their properties. Since nanocrystalline silicon emit visible light, they have been extensicvely investigated. Because of the difficulties of fabrication of the nanostructure with a simple confinment structure, their optical propertiy is still debatable.We can fabricate straight silicon nanowires in which no structural defects are introduced: the diameter and the growth direction of the nanowires can be well contolled by varying the growth conditions. We can systamatically investigate the optical properties of the silicon nanowires by means in-situ cathodoluminescence(CL) spectroscopy combined with transmission electron microscopy(TEM), which enable us to obtain simultaniously the structural data in a higher spatial resolution and luminescence spectra at the same mesoscopic location.

A. Cathodoluminescence

Cathodoluminescence is an important technical phenominon that is most widely used in modern cathode-ray-tube(CRT) based instruments, such as oscilloscope and televisions. When the energy of an electron beam is absorbed in the bulk of material, the energy is dissipated in a variety of electronic excitations. Cathodoluminescence arises from the generation and subsequent radiative recombination of electron hole pairs, the energy of which can correspond to emissions in the ultra-violet, visible, and infrared spectral range. The radiative mechanism may be intrinsic (direct band to band recombination) or may be extrinsic (involving recombination through energy levels associated with impurities, or point/extended defects).

II. EXPERIMENT

A. Sample preparation

Silicon nanowires are grown on a Si(111) surface by the step-flow growth mechanism. Stepped surfaces can serve as templates for producing one-dimensional wires or stripes by decorating the step edges in a step-flow growth mode. For such structures it is essential to start out with smooth steps. Silicon, of course, is among the preferred substrates. There have been extensive studies of steps and kinks on silicon, including their kinetics and dynamics. In particular, we want to avoid defects, such as kinks, step bunches, and multiple domains. The diameter of the nanowires range from 2 to 9nm, and the average diameter is 4.5nm. Many of the nanowires grow on a substrate along the $< 112 >$ direction as well as the $< 111 >$ direction.

FIGURES

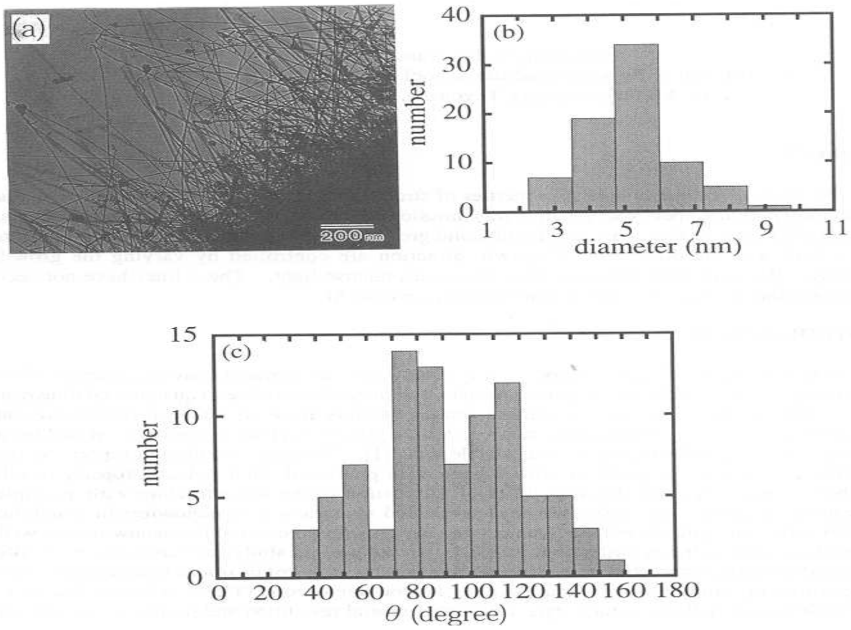

FIG. 1. (a) A TEM image of silicon nanowires on a Si(111) surface. (b,c) Histograms of the diameter and the growth directions of the nanowires. θ represents the angle between the growth direction of a nanowire and the substrate surface.

Figure 2 shows a high-resolution TEM image of a silicon nanowire, indicating that it consists of single crystaline silicon covered with an amorphous silicon oxide layer, and the growth direction is the $< 112 >$ direction.

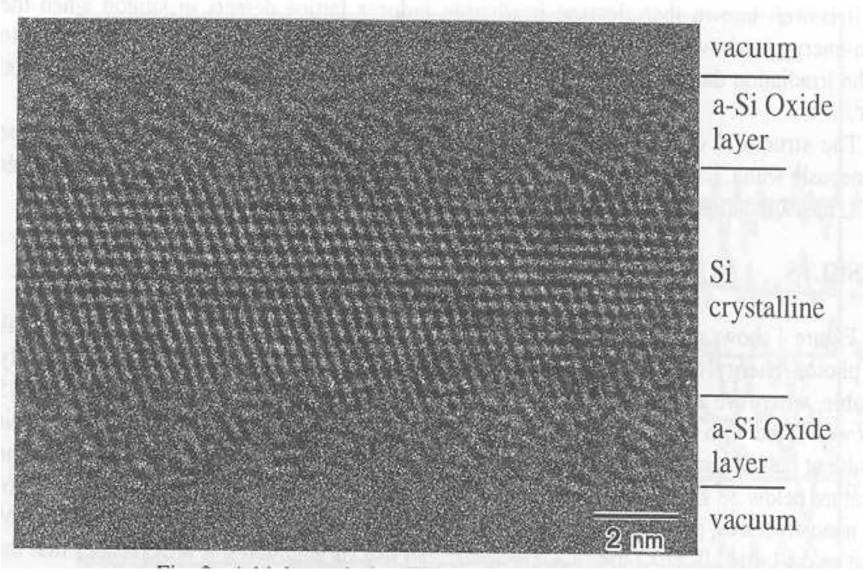

FIG. 2. A high-resolution TEM image of a silicon nanowire.

B. In-situ cathodoluminescence spectroscopy in a transmission electron microscope

The optical property of the silicon nanowires are studied by means of in-situ CL spectroscopy in a transmission electron microscope(TEM). Cathodoluminescence is the light emitted by some materials when they are subjected to electron beam irradiation. When detected within a TEM, it provides the basis of a powerful micro-characterisation technique for the analysis of the optical and electronic properties of many materials. Figure 3 shows a schematic view of an apparatus for the spectroscopy: The emitted light, excited by an electron-beam of a small size, is collected by an ellipsoidal mirror and introduced in a monochromator through the optical fiber.

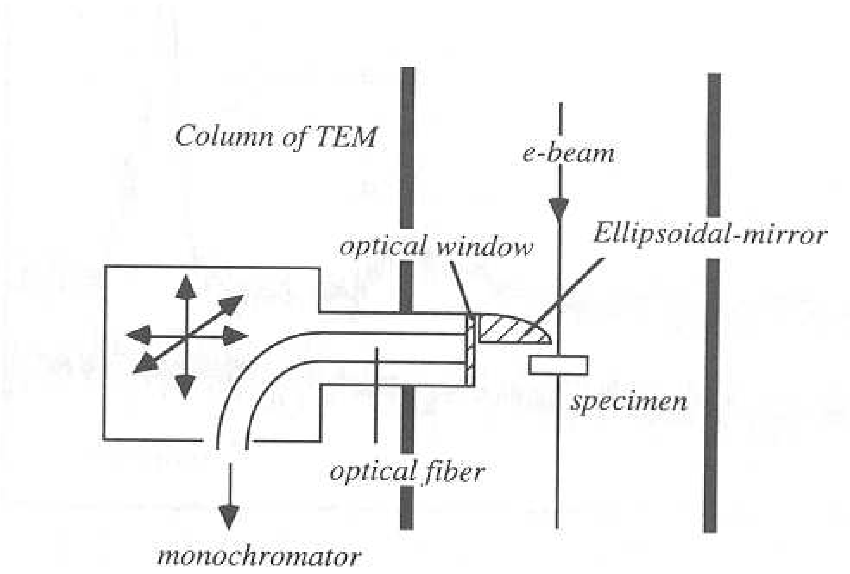

FIG. 3. A schematic view of an apparatus for in-situ CL spectroscopy in a transmission electron microscope.

It is well known that electron irradiation induce lattice defects in silicon when the electron-energy is above 160keV. We therefore can use 80-keV electron beam in order to avoid the irradiation damage during CL measurments. The excitation density is about $100mA/cm^2$.

The structural data of the nanowires can be obtained by conventional TEM technique simultaneously with CL measurments; the diameter, lengh, and growth directions of the nanowires at the CL measured area can be also quantitatively investigated.

Figure 4 shows a typical CL spectra from silicon nanowires. The sharp and intense peak at the photon energy of 2.35eV/n, and weak peaks at 2.2eV/n, and 2.0eV/n are clearly observable, where we assume that n is equal to two.

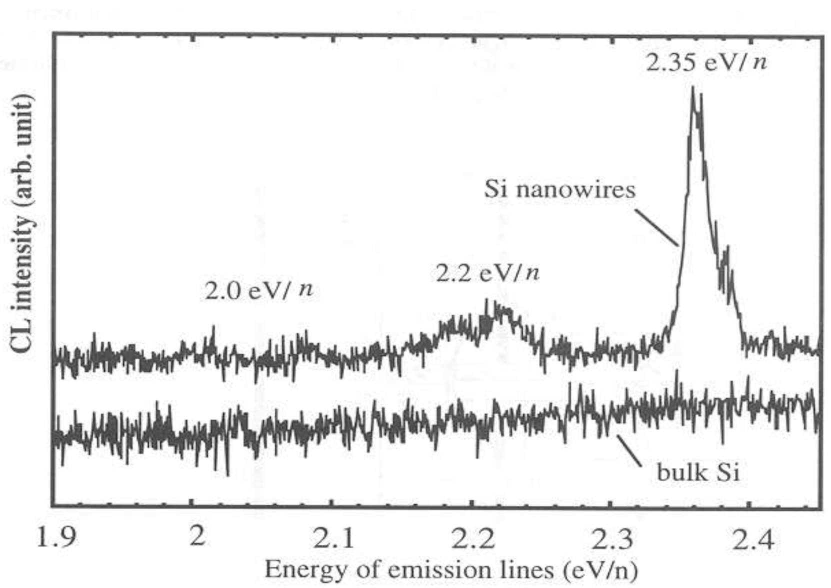

FIG. 4. CL spectra from silicon nanowires and a bulk silicon. No distinctive light emission arises from a bulk silicon.

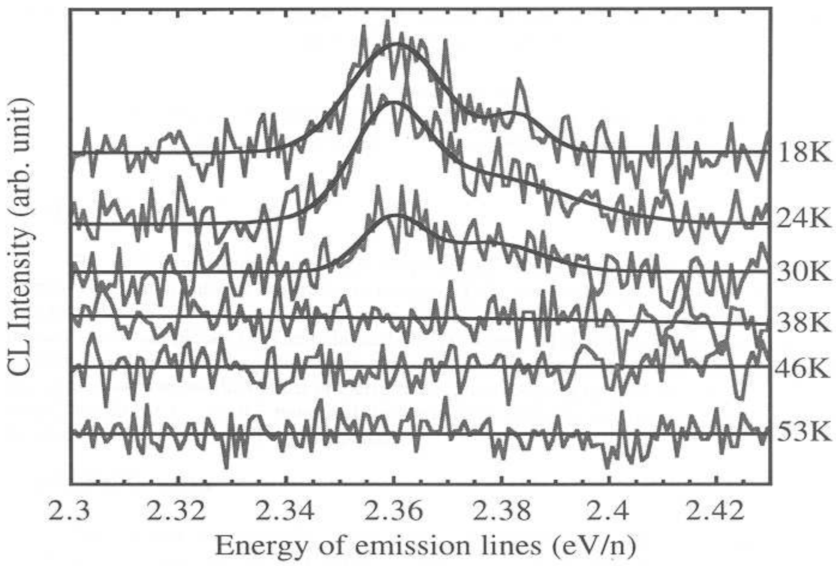

FIG. 5. CL spectra observed at various temperatures.

III. SUMMARY

Here we talked about investigating the optical properties of defect-free straight silicon nanowires whose diameter and growth direction are well controlled. The light emission from the nanowires can be measured by means of in-situ cathodoluminescence spectroscopy in a transmission electron microscope. We can see that the nanowires emit sharp and intense light in the photon-energy range from 2.0/n to 2.4/n eV. These emission lines have not been observed in other kind of silicon-based nanostructures such as porous silicon.

IV. REFERENCES

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