## Photonic crystal for optoelectronic integrated circuits

Anri Nakajima
Associate Professor
Research Center for Nanodevices and Systems
Department of Semiconductor Electronics and Integration Science
Graduate School of Advanced Science of Matter
e-mail: nakajima@sxsys.hiroshima-u.ac.jp
http://www.rcns.hiroshima-u.ac.jp/

### ● Introduction

In this twenty-first century COE program, optoelectronic integrated circuits (OEICs) and optical interconnection are studied. The author is in charge of the development of monolithic integration technique of photonic crystal with electronic devices and of the realization of new functionality using the photonic crystal.

### ● Previous Research Achievements

The author has carried out the following researches: (1) fabrication and physics of Si single-electron device, (2) self assembled fabrication, physical properties, and device application of Si quantum dot and metal nanocrystals, (3) study of conduction mechanism and defect structures of super ionic conductor using light scattering and photoluminescence, (4) formation of gate dielectrics by atomic-layer deposition and the reliability, (5) fabrication of photonic crystal using Si related materials.

As to (1), the author has found a self-aligned fabrication method of a floating dot gate precisely on the narrow channel wire in a Si single-electron memory for the first time and realized a room temperature operation. In (2), the author has found a method of Si quantum dot formation with conventional low-pressure chemical vapor deposition for the first time. Also, the formation method of metal nanocrystals (Sn, Sb) in a thin thermal $SiO_2$ film using low-energy ion implantation has been developed. Besides, physical properties of porous Si have been examined. As to (3), there are studies of super ionic conductor such as stabilized $ZrO_2$ and doped $CeO_2$ using quasielastic light scattering. The research (4) is one of the research subject at Research Center for Nanodevices and Systems. Up to now, a self-limiting atomic-layer deposition of Si nitride has been developed and atomic-layer deposited Si-nitride/$SiO_2$ stack gate dielectrics and atomic-layer deposited Si-nitride gate dielectrics have been realized. Also, atomic-layer deposition technique of high-k gate dielectrics such as $ZrO_2$ and $HfO_2$ has been developed. Figure 1 shows the TEM micrograph of $ZrO_2$/Si-nitride stack dielectrics formed by atomic-layer deposition method.

As to (5), it is one of the research subject of this COE program. Up to now, fabrication method of three-dimensional photonic crystals made of Si related materials have been developed. Figure 2 shows the SEM micrograph of fabricated three-dimensional photonic crystal.

### ● Outline of COE Research Subject and its Impact

Photonic crystals are expected to be utilized for the appearance of new nonlinear optical phenomena due to the strong light confinement and for the fabrication of new functional device such as nanoampere laser arrays. If the photonic crystals are formed with Si related materials, there is a great impact because OEICs can be realized with extremely low cost.

In this COE program, the target devices are such as optical waveguides with sharp bends, wavelength division multiplexing devices, light emitting devices with ultra low threshold current. These devices greatly contribute to the development of the information society.

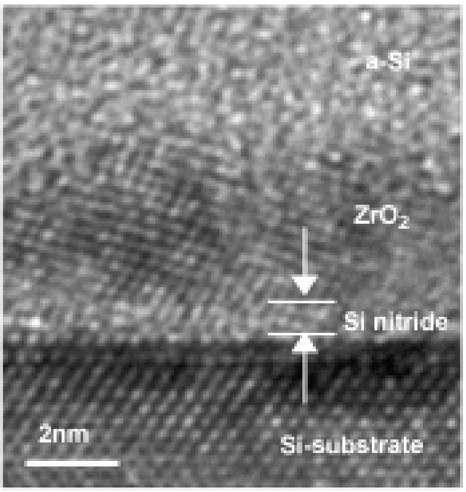


Figure 1 High-resolution cross-sectional TEM micrograph of (a) an ALD $ZrO_2$/ALD Si nitride stack film. 850 ℃ annealing was added for 3 min after the ALD to crystallize $ZrO_2$. The growth suppression of the interfacial Si oxide layer is observed. This is understood from the fact that the thickness of the interfacial anmorphous layer (~0.5 nm) coincides with that of the initially deposited ALD Si nitride.

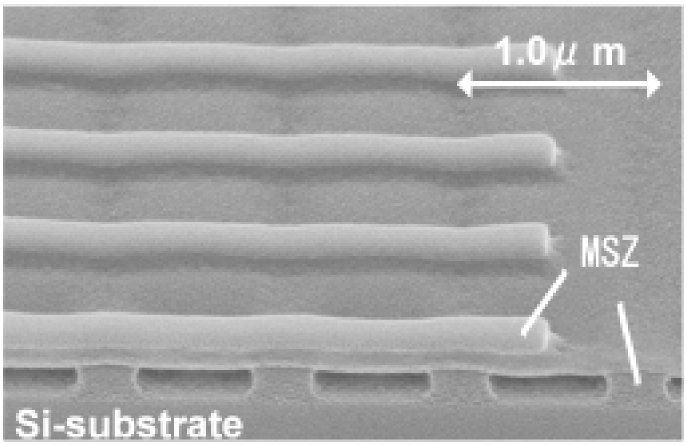


Figure 2 Bird's-eye view SEM image of the fabricated woodpile structure for photonic crystal. The stripe patterns of the stacked methylsilazane (MSZ) layer crosses over the underlying one. Utilizing the direct patterning of the photosensitive MSZ film by electron-beam lithography, the number of process steps can be reduced by about half for the fabrication of three-dimensional photonic crystals.