

Application of Si nanocrystals

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Functional properties induced in quantum-sized nanocrystalline Si (nc-Si) provide various opportunities for development of silicon devices with significances different from the conventional scaling merits [1]. The technological potential has been extending into photonics, ballistic electronics, acoustics, and biology as indicated in **Table 1**. Some topics of them are presented here.

- Photonics

Surface control is critical for the characteristics of nc-Si EL device [2], microcavity [3], and optical energy transfer [4]. For enhancement of the visible luminescence, for instance, high-pressure water vapor annealing (HWA) is very effective. Under the appropriate HWA condition, the external PL quantum efficiency in the red band reaches 23% at room temperature [5]. This is attributed to a reduction of non-radiative defects at the nc-Si/SiO₂ interface and a strong localization of excitons in nc-Si dots [6]. A combination of HWA and thermal oxidation can generate efficient long-lived blue phosphorescence related to luminescence centers in oxidized nanosilicon network [7]. Observed slow transitions via triplets suggest the appearance of a molecular structure in nanosilicon system. Band gap engineering in nc-Si is also attractive from a viewpoint of photo-electronics. Actually, the nc-Si layer exhibits a highly sensitive photoconduction for blue-light incidence and avalanche multiplication of photo-carriers [8]. Related possible application is advanced photovoltaic conversion.

- Ballistic electronics

The nc-Si diode operates as a planar cold electron emitter in vacuum. This emitter is most characterized by high energies of emitted electrons. It has been supported from experimental and theoretical analyses that there is a specific ballistic transport mode in interconnected nc-Si dot chains. By arranging the ballistic emitter arrays on a glass substrate, a proto-type 7.6-inch full-color flat panel display was developed [9]. Another usefulness of energetic electron emission has been demonstrated in atmospheric-pressure gases, where negative ions are produced by electron attachment in air [10] and vacuum-violet photons are directly emitted from Xe molecules without impact ionization [11]. Besides the use as an excitation source, it was also reported that the PS ballistic emitter operates even in solutions. In water [12], the emitter plays a role as an active electrode, and then only hydrogen gas is generated through direct reduction of H₂O molecules and/or H⁺ ions at the interface with no help of counter electrodes. The availability of nc-Si cathode in solutions leads to the technique not only for hydrogen generation but also for control of electrochemical properties of liquids.

- Ultrasonics

An extremely big contrast in the thermal properties between nc-Si and c-Si makes it possible to generate an acoustic wave at the surface of metal/nc-Si/c-Si device based on efficient thermal transfer without any mechanical vibrations [13]. Due to a completely flat frequency response, contrary to the conventional piezoelectric transducers, an ideal acoustic output pulse can be generated with no lingering oscillation. This is directly applicable to a probe for object image sensing in air [14] and non-contact actuator [15]. Owing to the broad-band response, this device is useful for means of bio-acoustic communication, e.g., reproduction of mouse-pup ultrasonic vocalizations [16,17]. Further applications is development of broad-band functional digital speaker [18].

It has been made clear that nc-Si behaves as a confined semiconductor with various functions useful in photonics, electronics, acoustics, and possibly in biology. The silicon technology will be further amplified by these functions and by their combinations.

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Table 1. Possible applications of nc-Si.

Area	Applications
Photonics	Multicolor Si EL Devices Photonic Components Advanced PV & PC Cells Light-emissive Nonvolatile Memory
Ballistics	Flat-Panel Display Parallel EB Lithography Generation of H ₂ and VUV Photons High-Sensitivity Image Pick-up
Acoustics	3-D Image Sensing in Air Non-contact Actuating Digital Information Transmission Broad-Band Digital Speaker
Biology	Scaffold for Bio-Sensing Bio-medical Products Drug Delivery