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A Photo-Detector Having a Silicon Quantum Wire Embedded in Silicon Dioxide

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1. Introduction

Low dimensional quantum nanostructures can be used to make not just feature VLSI systems, but also new functional optical devices.

The development relates to a photo-detector, and more particular, a quantum type photo-detector in which flow and intensity of an electric current can be controlled, when light or electromagnetic wave is irradiated, by positively employing a quantum structure such as a quantum dot [1] and wire [2] on a semiconductor material so that a confinement potential barrier is locally generated from a quantum effect of a conductive channel region.

In the previous work [3], we studied transport properties of a gate-all-around silicon quantum wire transistor using silicon on insulator (SOI) technology, EB lithography, and thermal oxidation method. Here we report the detection of some photons in the wavelength range 400-1200 nm (3.10 -1.03 eV) at room temperature on the same quantum point contact (QPC) structure consisting of very narrow silicon quantum wires (QWRs) surrounded by a poly-Si gate oxide, and found that the sample has large photo responsivity of ~10^6 A/W in each absorption wavelength region.

2. Experimental

The proposed device was patterned by mix-and-match method, which used both conventional optical lithography and EB lithography on a p-type (100) SOI wafer as shown in Fig. 1 (a) and (b). Overall active regions including source and drain were patterned by optical lithography, and then the narrow channel in the open window region was defined using EB system. After pattern transfer, dry oxidation at 900 °C was performed to obtain more narrow wire than patterned channel width. As a result, the real silicon QWR with width of about 30 nm, being fully contained within silicon dioxide, was formed. The rest of the device process is similar to a standard MOSFET fabrication. Details of these processes and structures are discussed elsewhere [3].

Photo responsivity measurements were carried out by using a monochromated light source with a tungsten lamp which is an objective lens for an optical microscope and DC current measurement setup. Power of the spectrally resolved light largely changed due to using a monochromator and a high wavelength pass filter, and was less than a few hundred pW in the measured wavelength region. The light size was set at 15 x 200 μm^2 on the active QWR channel regions. Effective power obtained by taking account of the ratio between the light image size and the area size of each photo-responsive region of the device was in the order of fW. From the effective light power, we can estimate the photo responsivity by dividing measured photocurrent. Noise level of the current was in the order of sub-fA.

3. Results and Discussion

Figure 2 shows photo-responsivity through the 30 nm QPC-channel measured by a lock-in amplifier with a

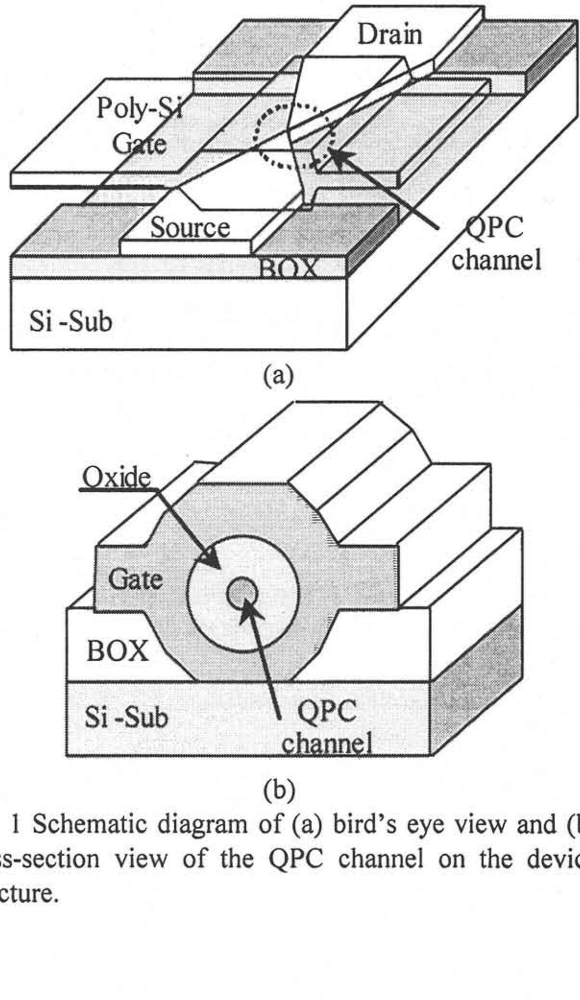

Fig. 1 Schematic diagram of (a) bird's eye view and (b) cross-section view of the QPC channel on the device structure.

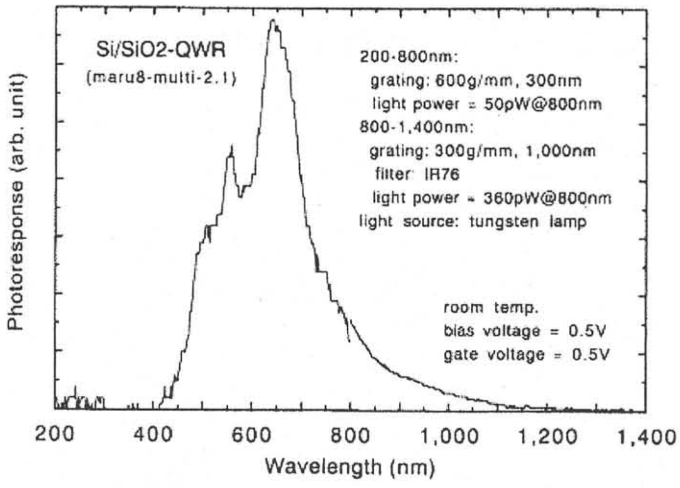

Fig. 2 Photo-responsivity of the QPC-channel as a function of wavelength of the spectral-resolved incident tungsten light source, where the bias conditions are V_g=0.5V and V_d=0.5V.

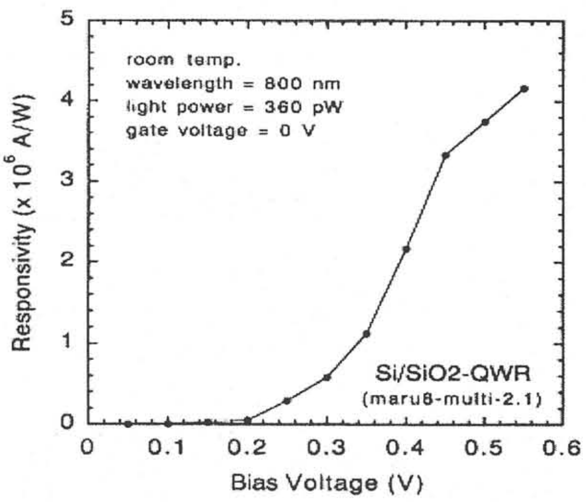

Fig. 3 Responsivity of the QPC transistor on V_g=0 V as a function of drain voltage, where wavelength and power of the light source is 800 nm and 360 pW, respectively.

modulation frequency of about 200 Hz as a function of wavelength of the spectral-resolved incident light. The high level photocurrent is absorbed in the region from visible to near infrared at room temperature. As shown in this figure, an absorption gap is seen at a wavelength of about 1100 nm, which corresponds to bandgap of Si. Therefore, it is estimated that most of the light is absorbed in the active Si-QWR, and generated holes storage into valence band of the QPC channel, which effectively reduced the random potential barrier of conduction band of the QPC so that the electrons can flow through the QPC region. On the other hand, the electrons cannot easily pass the QPC during no illumination conditions because the height of the conduction band of the channel increases on the influence of charging effect of an interface between the active Si region and the surrounded Si dioxide.

We also investigated the photosensitivity of the QPC transistor on V_g=0 V as a function of drain voltage, where wavelength and power of the spectral-resolved incident light source was 800 nm and 360 pW, respectively. A high responsivity of ~10^6 A/W was obtained by the 30 nm-width QPC transistor at room temperature as shown in Fig. 3. This super responsivity is considered to be caused from effective holes trapping in the quantum dot-like random potential well in the valence band in the QPC-channel. Here, responsivity linearly increases with increasing drain voltage maybe due to hot electron effect.

4. Conclusions

We investigated the photoresponse of Si-QPC structures and found that the device appeared phototransistor action with high sensitivity of about 10^6 A/W. We expect that this structure is desirable in a number of light detecting applications to be able to sense the receipt of individual photons, since this represents the upper limit for resolution and sensitivity. Furthermore, this application is promising for advanced optical circuits and devices such as smart pixels and a single charge CCD [4].

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