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Realization of n-type and p-type Si-Microprobe Array Using *In-Situ* Doping with Selective Vapor-Liquid-Solid (VLS) Growth Method

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1. Introduction

Vapor-liquid-solid (VLS) growth mechanism can be used to fabricate Si-probes perpendicular to the Si wafer [1-4]. Very recently the properties of the Si-microprobes have been studied to apply them as the insertion electrodes to collect the signal from the living cell [4-5], which has attractive applications in medical science. Processing of the collected signal requires the fabrication of probes with processing circuitry. Consequently, Si-microprobe electrode arrays with on chip MOSFET circuitry have been developed [6-7]. Most of the probes developed earlier were intrinsic Si-probes by Si_2H_6 gas source. The resistivity of the intrinsic Si-probe was found in the order of 10^4 Ω-cm [5]. It needs to improve the properties of the probes to make them more suitable for specific applications. Electrical properties of the probes improve if they are doped by phosphorous diffusion at 1100ºC [5]. But this high temperature is detrimental to on-chip MOSFET circuitry. Again lower temperature cannot dope the probes to the full depth. At 900ºC, the depth of doping was found 0.5 μm from the surface of the probe sidewall [7]. Under this circumstance, it requires the successful doping of Si-probes at lower temperatures to be compatible to fabricate the probes with on-chip circuitry. This paper reports about the *in-situ* doping of probes at lower temperature and successful realization of n-type and p-type Si-microprobes using VLS growth method. This also reveals the potentiality of *in-situ* doping with VLS growth method to be used to fabricate some devices like diode, transistors etc. in the vertical direction, which might be helpful in realizing high density integrated circuit.

2. Experimental details

Si (111) wafer was used since we know that the probes can be grown in the direction of <111> using the VLS growth mechanism [1]. Fig. 1 shows the schematic diagram of wafer preparation and VLS growth. The first step was the deposition of SiO_2 layer of 850 nm in thickness. Then the patterning was done by photolithography to create circular shaped window through SiO_2 mask. A thin film (120-150 nm) of gold (Au) was deposited over this pattern by evaporation method. After the lift off, Au dots left in the SiO_2 window, which dictates the size and position of the grown probes. Then the Si wafer was heated in the vacuum chamber to form the Au-Si droplets inside the window. Then molecular-beam-epitaxy (MBE) process was carried out using the mixer of gas source of Si and dopants to grow the doped probes by VLS mechanism. With Si_2H_6 as gas source of Si, PH_3 and B_2H_6 were used to realize n-type and p-type Si-probe respectively.

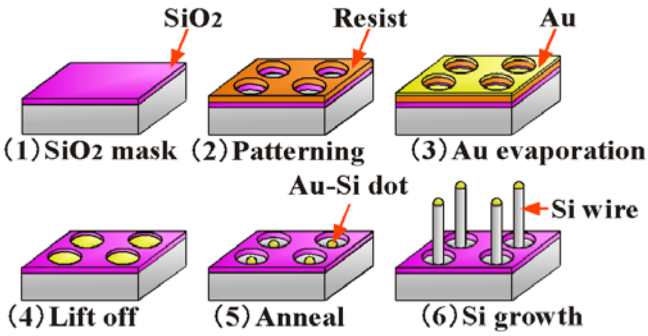

Fig. 1. Schematic diagram of wafer preparation and VLS growth of Si-probe array.

3. Results and Discussion

A mixer of PH_3 and Si_2H_6 was used to realize n-type Si-probes with the growth pressure of 3×10^{-3} ～5×10^{-3} Pa and temperature of 700ºC with the gas ratio of PH_3/Si_2H_6 varying in the range of 180～10000 ppm (fig. 2). The probes of different lengths (20～50 μm) were fabricated with different diameters (1.5～5 μm).

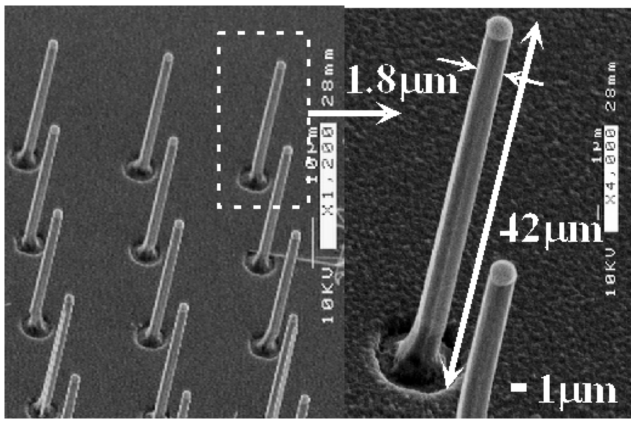

Fig. 2. SEM image of a n-type probe with diameter of 1.8 μm and length 42 μm using *in-situ* doping VLS growth (growth temp. 700ºC, press. 5×10^{-3} Pa and PH_3/Si_2H_6 ratio 180 ppm).

I-V characteristics of the grown probes were measured by tungsten (W) needles mounted on micromanipulator system for tip and base contacting. Each of the probes showed the conductive nature as like that of conductors and exhibits I-V characteristics more or less as in fig. 3. The resistivity and the impurity concentration of the probes were also estimated

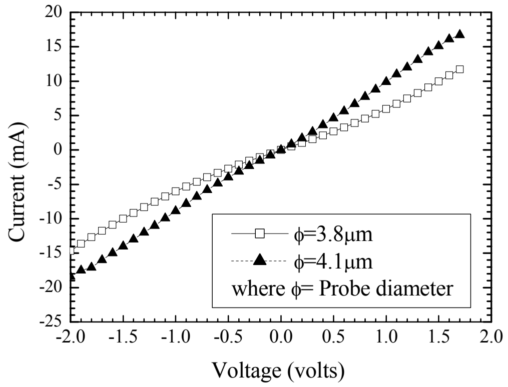

Fig. 3. I-V characteristics of n-type probe of length 30 μm grown with temp. 700ºC, pressure 3×10^{-3} Pa and PH_3/Si_2H_6 ratio 10^4 ppm.

The resistivity of the probes decreases from 1.8 Ω–cm to 5.7×10^{-3} Ω–cm and the impurity concentration increases from 2.5×10^{15} cm^{-3} to 1.8×10^{19} cm^{-3} as PH_3/Si_2H_6 ratio increases from 180 ppm to 10^4 ppm as shown in fig. 4.

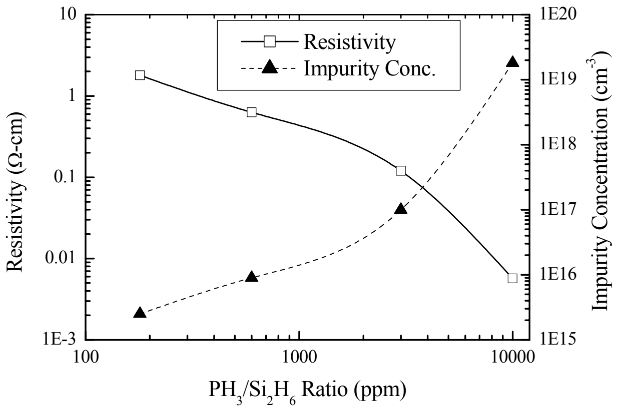

Fig. 4. Resistivity and impurity concentration of n-type Si-probe as a function of gas ratio of PH_3/Si_2H_6 (ppm).

We find the n-type probe successfully realized using gas ratio (PH_3/Si_2H_6) of 10^4 ppm at 700ºC gives the resistivity of 5.7×10^{-3} Ω–cm which was lower than that previously reported by kawano *et. al* [5].

Similarly, a mixer of B_2H_6 and Si_2H_6 was used to realize p-type silicon probes and the successful p-type probe grown with B_2H_6/Si_2H_6 ratio of 5000 ppm, growth pressure $\sim3\times10^{-3}$ Pa and temperature 700ºC gives the resistivity of 0.81Ω–cm and impurity concentration of 2.0×10^{16} cm^{-3}

4. Potential Applications

In-situ doping with VLS growth system can be used to realize the probes with much lower resistivity in the order of $\sim10^{-3}$ Ω–cm at the temp. less than 700ºC. But the conventional way of doping by diffusion required higher temperature (1100ºC) to obtain fully doped probes with the resistivity in the order of $\sim10^{-2}$ Ω–cm [5]. So, *in-situ* doping is compatible with the realization of much more conductive probes with on-chip circuitry avoiding the deviation of the characteristics of on-chip devices due to high temperature.

Again it would be possible to apply the technique of realizing n-type and p-type probes using *in-situ* doping VLS growth to fabricate p-n junction in Si probes. This probe like p-n junction diode might be configured to use in sensor applications.

4. Conclusions

VLS growth method using the gas source of Si_2H_6 gives intrinsic Si-probes with resistivity $\sim10^4$ Ω-cm. In order to make the probes more conductive to be suitable for using as insertion electrodes for collecting the signal from living cell, P-diffusion at 1100ºC was carried out that made the probes n-type with resistivity $\sim10^{-2}$ Ω–cm [5]. Since high temperature is detrimental to the device characteristics, doping by diffusion is a barrier to realize highly conductive probes with on-chip signal processing circuitry. But VLS system using mixer of PH_3 and Si_2H_6 was used to realize n-type probes at lower temperature (700ºC) with the resistivity in the order of $\sim10^{-3}$ Ω–cm. So, *in-situ* doping system eliminates the high temperature problem to realize highly conductive probes with on-chip circuitry.

The impurity concentration of n-type probes varied in the range of 10^{15} cm^{-3} $\sim10^{19}$ cm^{-3} that indicates that *in-situ* doping system can be used to realize not only n-type probe but n+-type also. Again p-type probes with the resistivity of 0.81 Ω–cm were realized at 700ºC using the mixer of B_2H_6 and Si_2H_6. Since both n-type and p-type probes can be grown by *in-situ* doping with VLS growth mechanism, it would be possible to realize p-n junction in the probes and use them in some applications.

Acknowledgement

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