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High resistivity Czochralski-grown silicon single crystals for power devices

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Abstract Floating zone, neutron transmutation-doped and magnetic Czochralski silicon crystals are being widely used for fabrication power devices. To improve the quality of these devices and to decrease their production cost, it is necessary to use large-diameter wafers with high and uniform resistivity. Recent developments in the crystal growth technology of Czochralski silicon have enable to produce Czochralski silicon wafers with sufficient resistivity and with well-controlled, suitable concentration of oxygen. In addition, using Czochralski silicon for substrate materials may offer economical benefits. First, Czochralski silicon wafers might be cheaper than standard floating zone silicon wafers. Second, Czochralski wafers are available up to diameter of 300 mm. Thus, very large area devices could be manufactured, which would entail significant saving in the costs. In this work, the conventional Czochralski silicon crystals were grown with higher oxygen concentrations using high pure polysilicon crystals. The silicon wafers were annealed by several steps in order to obtain saturated oxygen precipitation. In those wafers high resistivity over 5,000 Ω·cm is kept even after thermal donor formation annealing.

Key words High resistivity, Czochralski, Silicon, Power devices, Oxygen precipitation

1. Introduction

Power devices are semiconductor switches which contain mobile charge carriers in the on-state and have to represent a potential barrier for carriers in the off-state. The thyristor, for example, is a three-terminal four-layer device, in which current flow starts only if a current is fed into the gate terminal [1]. This device operates in three modes: the reverse blocking mode, the forward blocking mode and the on-state. To achieve high breakdown voltages, power devices generally require a thick n-type silicon layer with high resistivity.

Floating zone (FZ), neutron transmutation-doped (NTD) and magnetic Czochralski (MCZ) silicon crystals are being widely used for fabrication power devices (diodes, thyristors and transistors). To improve the quality of these devices and to decrease their production cost, it is necessary to use large-diameter wafers with high and uniform resistivity [2-6]. The main drawbacks of the above methods are as follows: poor axial and radial uniformities of resistivity (FZ); a serious difficulty in growing large-diameter crystals (FZ, NTD); expensive equipment (NTD, MCZ) and relatively high production cost (FZ, NTD, MCZ).

Silicon wafers grown by Czochralski (CZ) method intrinsically contain high level of oxygen, typically 10^{17}~10^{18} cm^{-3}. Using the Czochralski silicon (CZ-Si) for power devices may offer economical benefits. CZ-Si wafers are available up to the diameter of 300 mm. It results in significant savings in the costs. In this paper, it is shown that high resistivity in CZ crystals with higher oxygen concentration is obtained using multiple step annealing.

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2. Experiments

<100> 150 mm diameter wafers with 3 different oxygen concentrations (16, 14 and 13 ppma) were grown using polycrystals with low boron and phosphorus concentrations and high purity quartz crucible. The crystal was grown with conventional CZ at fully vacancy rich region. 3 step (65°C/1.5 hrs + 800°C/4 hrs + 1000°C/15 hrs). The ambients are as follows. Nitrogen was used for 650°C and 800°C and dry oxygen for 1000°C. Normal thermal donor killing process was used.

The resistivity measurements were done by a four point probe and a spreading resistance for radial profile and depth profiles, respectively. The oxygen concentrations before and after annealing were measured by FT-IR.

3. Results and Discussion

The resistivity (ρ) attained by 3 step annealing which

Table 1
The resistivity measured by 4 point probe at center position of the wafers

Sample	After Donor Killing		After 3 Step Annealing		After 450°C/16 hrs	
	[Oi] (ppma)	ρ (Ω·cm)	[Oi] (ppma)	ρ (Ω·cm)	[Oi] (ppma)	ρ (Ω·cm)
A	16	80	4.5	9500	4.3	8600
B	14	150	10.8	5800	10.5	5200
C	13	148	6.1	9800	5.9	9200

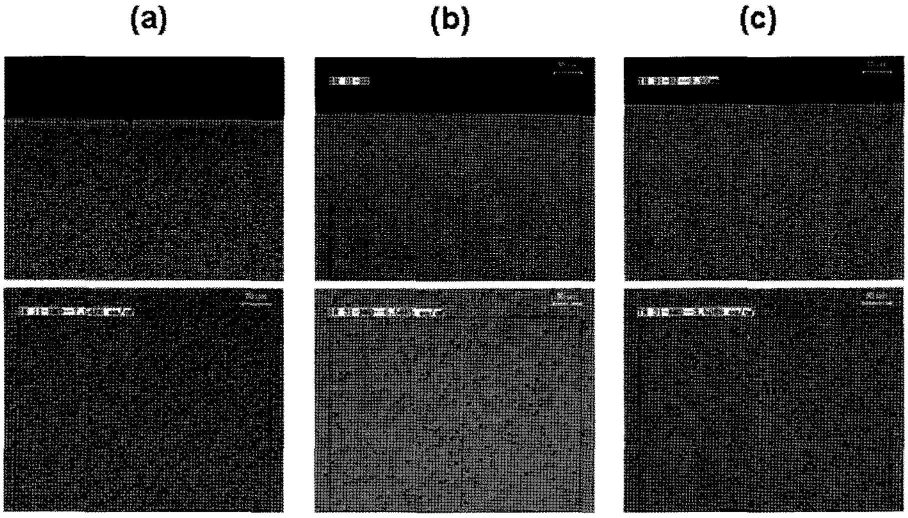

Fig. 1. BMD distribution of the wafers after 3 step and donor formation (a) Sample A (b) Sample B (c) Sample C.

are followed by the thermal donor formation at 450°C for 16 hrs are summarized in Table 1. The resistivities after donor formation annealing are kept as high as the resistivity attained by 3 step annealing. The bulk microdefects are examined to study the oxygen precipitation formation. The bulk microdefects (BMD) of 3 samples (A, B, C) are shown in Fig. 1. The wafers are annealed with 3 step and donor formation.

In VLSI/ULSI fabrication, a multizoned silicon wafer has been designed with specific structure, chemical and mechanical characteristics to support performance goals for leading-edge MOS digital circuit application [7]. This structure consists of four principal zones in the silicon wafer; device zone, denuded zone, intrinsic gettering zone and extrinsic gettering zone. Device components are physically fabricated in the device zone. This zone may be either the polished wafer front surface, that is, a part of the denuded zone. The device zone must be free of unwanted impurities, structural imperfections and wafer strain. Moreover, this zone is critical to achieve the uniform depth profile of resistivity. The resistivity depth profile of the wafer with 16 ppma oxygen concentration is shown in Fig. 2. The spreading resistance method allows microresistivity variation measurements across a specimen. The spreading resistance profiling (SRP) technique was used on angle-lapped samples. The wafer is annealed with 3 step and donor formation. The resistivity profile is almost uniform and a resistivity depletion from surface to 2~3 μm in depth. Enhancement of donor formation due to out-diffusion of oxygen atoms is related to this depletion.

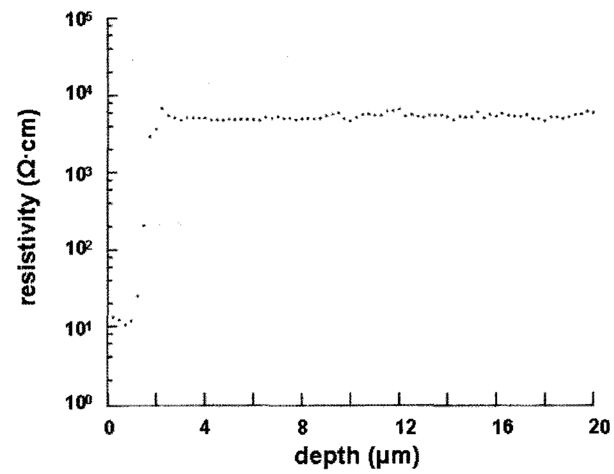

Fig. 2. The resistivity depth profile of the wafer with 16 ppma oxygen concentration after 3 step and donor formation.

4. Conclusions

Silicon crystals are grown by conventional CZ method in order to obtain high resistivity wafers with over 5000 Ω·cm. In this work, CZ silicon crystals with 13 ppma initial oxygen concentration are used. For full oxygen precipitation formation, three step annealing is studied. First is 650°C for nucleation, second is 800°C for nucleation growth and final is 1000°C for oxygen precipitation. As a results, over 5000 Ω·cm resistivity is obtained even after annealing at 450°C for 16 hrs.

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