A—1—3 (Invited) Epitaxial Silicide Films for Integrated Circuits and Future Devices

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INTRODUCTION Recently, as the line widths in integrated circuits get narrower, the problem of RC delay due to the sheet resistance has become more severe. Similarly, the high frequency performance of static induction transistors and other devices with buried semiconductor gate structures is considered to be limited by series resistance of the gate. Refractory metals and metal-silicides have attracted attention to solve these problems because of their low resistivities and high temperature stability. We have been studying on the epitaxial growth of silicide films onto Si substrates and found that (1) the resistivities of epitaxial silicides are lower than those of polycrystalline silicides, and (2) Si films can be grown epitaxially onto the silicide films. These properties are considered particularly suitable for the applications described above. In this paper, we present some characteristics of epitaxial silicides and discuss about usefulness of the epitaxial silicides in VLSI and future devices.

GROWTH CONDITIONS Epitaxial silicides which are used as buried metal-gate materials in Si are necessary to satisfy the following conditions; (1) matching of lattice parameters with Si, (2) high temperature stability during growth of the Si overlayer, and (3) good electrical properties. Typical silicide materials selected under these conditions are listed in Table 1. In the epitaxial growth of silicide films, low temperature processes such as the molecular beam epitaxy (MBE; simultaneous evaporation of metal and Si onto hot substrates) and the solid phase epitaxy (SPE; deposition of metal films onto Si substrates at RT and subsequent annealing) are mainly used, in order to minimize electrical and structural degradation at the silicide-silicon interface.

STRUCTURAL AND ELECTRICAL PROPERTIES The crystalline quality of the epitaxial films is estimated by the channeling minimum yield χ_{min} in Rutherford backscattering spectroscopy. The reported best values are shown in Table 1. As can be seen from the table, the crystalline quality of Pd_2Si, $NiSi_2$ and $CoSi_2$ is excellent, but the quality of $CrSi_2$ is much worse at present in spite of nearly perfect matching with Si. We can also see from the table that (1) the lowest eutectic temperatures in the Pt/Si, Pd/Si and Ni/Si systems are lower than 1000°C, (2) the resistivity of $CoSi_2$ is lowest among them, while the resistivity of $CrSi_2$ is at least 10 times higher than that of other silicides, and (3) the resistivities of epitaxial silicides are about 2/3 of those of polycrystalline ones.

RADIATION DAMAGE Studies on radiation damage in silicide films are important, since the films are often used as masks for selective ion implantation. It has been found that metal-rich silicides as Pd_2Si is stronger for radiation damage than silicon-rich silicides as $CoSi_2$. Pd_2Si does not become amorphous to a dose of $1x10^{17}$ Ar-ions/cm^2. However, it changes to the PdSi phase by subsequent furnace annealing, when the interface between Pd_2Si and Si is heavily irradiated. No phase transformation is observed in $CoSi_2$ and $NiSi_2$. The electrical resistivity of the implanted film increases by factors 10 or more, but it almost recovers to the unimplanted value by subsequent furnace annealing.

SUMMARY The growth conditions, electrical and structural properties, and radiation effects of epitaxial silicides have been presented. It is concluded that (1) $CoSi_2$ is most suitable as interconnecting and gate materials epitaxially embeded in Si and (2) $CrSi_2$ may be suitable as a stable resistive material if the crystalline quality is improved.

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Silicide		PtSi[1,2]	Pd_2Si[3]	$NiSi_2$[3,4]	$CoSi_2$[3,5,6]	$CrSi_2$[7]
Crystal Structure		Orthorhombic (B-31) (Pseudo-Hexagonal)	Hexagonal (C-22)	Cubic (C-1)	Cubic (C-1)	Hexagonal (C-40)
Si Substrate Orientations		(111)	(111)	(100) (111) (110)	(100) (111) (110)	(111)
Equivalent Lattice Mismatch with Si (%)		9.5	2.4	0.4	1.2	0.0
Melting Point (°C)		1229	1330	>1100	1326	1550
Lowest Eutectic Temperature in the Metal/Si System (°C)		830	760	964	1195	1320
χ_{min} in RBS (%)		19	6	4	2	76
Resistivity (μΩ-cm)	poly[8]	28-35	30-35	50-60	18-20	∿600
	epi.	-	25	35	10-15	-
Schottky Barrier Height for n-type Si		0.87	0.74	0.70	0.64	0.57

Table 1 Properties of epitaxial silicides