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Formation of a Double-Hetero Si/$CoSi_2$/Si Structure Using Molecular Beam and Solid Phase Epitaxies

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A monolithic semiconductor-metal-semiconductor structure is useful for high speed devices such as the metal base transistor, the permeable base transistor[1)] and the buried-metal-gate static induction transistor. In this paper, we show that this structure can be realized by epitaxial growth of single-crystal-like $CoSi_2$ films on Si(111) substrates and the growth of Si films on the Si(111)/$CoSi_2$ structure. Solid phase epitaxy (SPE) is used to grow both $CoSi_2$ and Si films. Molecular beam epitaxy (MBE:evaporation onto hot substrates) is also used to grow the top Si films. Crystalline quality of the films is characterized using backscattering and channeling measurements with 1.5 MeV He ions. TEM, SEM and reflection electron diffraction analysis are also used to check the quality and uniformity of the films.

2 to 5 Ωcm n-type (111) Si wafers were chemically cleaned using RCA solutions and etched in a HF solution. They were then loaded in a vacuum chamber equipped with ion pumps, an electron beam evaporator and a furnace with two 500 W halogen lamps and reflectors. A base pressure of the chamber was less than $3x10^{-7}$ Pa. The furnace was used to clean the surface of Si substrates by heating at high temperatures before film deposition (pre-heating) and to anneal the deposited films without breaking the vacuum (post-heating). In deposition of Co and Si films, the deposited areas were partially overlapped in order to obtain three different structures (Si/$CoSi_2$, Si/Si, Si/$CoSi_2$/Si) at the same time. Co films 18 to 100 nm thick were deposited onto the pre-heated (1050°C, 2min) Si substrates at room temperature. Pressures during the film deposition were less than $6.5x10^{-6}$ Pa. The samples were then annealed in the same vacuum for 30 min at temperatures ranging from 800 to 1000°C. Figure 1 (A) shows typical backscattering spectra for a Si(111)/$CoSi_2$ structure. The channeling minimum yield χ_{min}, which is defined as the ratio of the aligned to the random yields at a portion just behind the surface peak in the Co spectrum, is about 0.03 in this sample. From this figure, we can say that single-crystal-like $CoSi_2$ films can be grown on the pre-heated Si(111) substrates using SPE at temperatures around 900°C.

Next, Si films 100 to 400 nm thick were grown onto the Si(111)/$CoSi_2$ structure without breaking the vacuum. In MBE, the substrates were kept at temperatures ranging from 300 to 700°C, during the Si film deposition. The deposition rate was changed from 0.06 to 0.2 nm/s. It was found from the backscattering spectra that Co atoms mainly diffused into the grown Si films at substrate temperatures higher than 500°C, though the $CoSi_2$ film had been formed at temperatures around 900°C. At temperatures lower than 400°C, Co atoms did not diffuse into the grown Si film, nor into the Si substrate. Figure 1(B) shows the backscattering spectra for a Si(111)/$CoSi_2$(77nm) /Si(180nm) structure formed at 400°C. χ_{min} of the grown Si film in this sample is about 0.2. Figure 1(C) shows the spectra for a Si film grown on a Si(111) substrate under the same conditions as those in Fig.1 (B). Figure 2 shows the temperature dependence of χ_{min} and the amount of diffused Co atoms into the grown films and substrates. We can see from this figure that (1) crystalline quality of the Si films strongly depends on the deposition rate and (2) good epitaxial films containing no Co atoms are grown onto the Si(111)/$CoSi_2$ structure at temperatures around 400°C. Figure 3 shows a SEM micrograph of the cross section of a sample formed at 300°C. This figure shows that the $CoSi_2$ and the top Si films are rather uniform in a lateral direction. The reflection electron diffraction patterns for this sample showed strong single crystalline spots and weak twin spots in the top Si film and strong single crystalline spots in the $CoSi_2$ film.

In SPE, Si films were deposited onto the Si(111)/$CoSi_2$ structure at room temperature. The samples were then annealed at temperatures ranging from 800 to 1050°C for 15 min in the same vacuum. The deposited Si films were found to grow epitaxially on the $CoSi_2$ films at temperatures around 1000°C. The backscattering and channeling analysis shows that (1) the best value of χ_{min} in the grown Si film is about 0.3 and (2) no Co atoms diffuse into the grown Si film at 1000°C, but they diffuse into the Si substrate. The reason why Co atoms mainly diffuse into the Si substrate is not clear at present.

In summary, a double hetero-structure of Si/$CoSi_2$/Si was formed using the molecular beam and solid phase epitaxies. Good Si films containing no Co atoms can be epitaxially grown on the Si/$CoSi_2$ structure by MBE at temperatures around 400°C or by SPE at temperatures around 1000°C. Liquid phase epitaxy of the top Si film is also being investigated using the Q-switched pulse laser.

[Reference]

1) C.O.Bozler, G.D.Alley, R.A.Murphy, D.C.Flanders and W.T.Lindley; Technical Digest of Intern. Electron Device Meeting, 16.2 (1979)

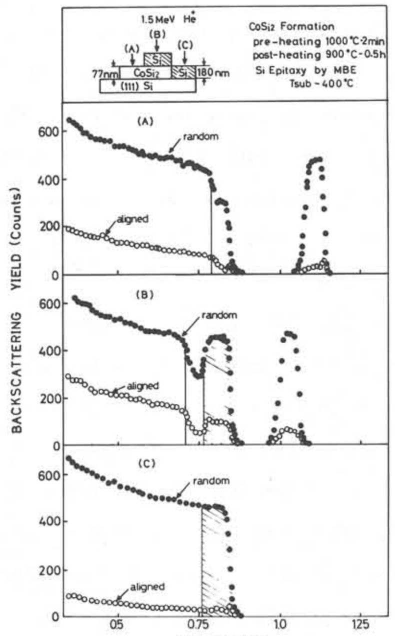

Fig.1

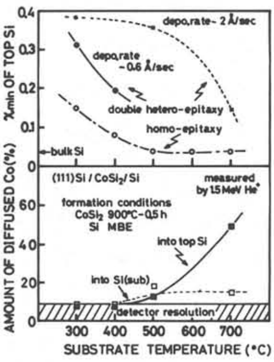

Fig.2

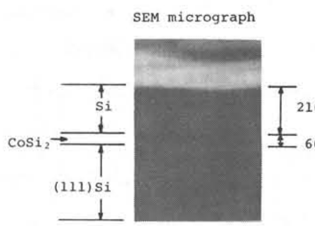

Fig.3