AIP | Applied Physics Letters

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Citation: Applied Physics Letters **54**, 658 (1989); doi: 10.1063/1.100910
View online: http://dx.doi.org/10.1063/1.100910
View Table of Contents: http://scitation.aip.org/content/aip/journal/apl/54/7?ver=pdfcov
Published by the AIP Publishing

Selective epitaxial silicon growth in the 650–1100 °C range in a reduced pressure chemical vapor deposition reactor using dichlorosilane

J. L. Regolini and D. Bensahel
Centre National d'Etudes des Télécommunications, BP 98, 38243 Meylan Cedex, France

E. Scheid
Laboratoire de Physique des Composants Semiconducteurs/Centre National de la Recherche Scientifique, avenue des Martyrs, 38031 Grenoble Cedex, France

J. Mercier
Laboratoire d'Etudes des Propriétés Electroniques des Solides/Centre National de la Recherche Scientifique, avenue des Martyrs, 38042 Grenoble Cedex, France

(Received 10 October 1988; accepted for publication 2 December 1988)

Selective epitaxial silicon layers have been grown in a reduced pressure (< 2 Torr) reactor in the 650–1100 °C temperature range using only dichlorosilane (DCS) gas diluted in hydrogen. The growth rate plotted in Arrhenius coordinates (log G vs $1/T$) shows an activation energy of 59 kcal/mol in the 650–800 °C range. A comparison is made between the DCS system and our previous results concerning the $SiH_4/HCl/H_2$ system.

Low-temperature silicon epitaxy can be achieved using an ultrahigh vacuum system and "classical" chemical vapor deposition (CVD).[1] In another approach,[2] silicon epitaxy can be plasma assisted. In these two systems however, the working pressure during CVD is in the millitorr range, the gas is silane, and so far, no selectivity has been reported.

In this letter we show that epitaxial silicon layers can be selectively grown on silicon over a wide range of temperatures. The gas source is only dichlorosilane (DCS) diluted in hydrogen in a reduced pressure reactor (in the Torr range) where the temperature is obtained by a rapid lamp heating system. Two growth rate regimes are observed and discussed.

The reactor has been described elsewhere[3] and was first investigated by Gibbons *et al.*[4] and labeled LRP for limited reaction processing. For selective epitaxial studies, *p*-type (100) or (111), 2 in. wafers were oxidized to 5000 Å and patterned. The oxide was patterned by reactive ion etching followed by a 200 Å oxidation removed in buffered hydrofluoric acid. The pattern is composed by stripes aligned along the ⟨100⟩ or ⟨110⟩ directions. The ratio of oxide to silicon areas ranges from 10 to 90%. Since no loading effect has been observed when the backside of the sample is bare silicon, we will present results concerning a 10% oxide-covered surface. The epilayer thicknesses were measured by a stylus profilometer and optical reflectivity.

It is well known that cleaning prior to the epitaxial step is one of the key parameters for defect-free layers. In this letter we report a protective oxide layer created according to the RCA recipe[5] or the Ishizaka technique.[6] This oxide is removed via SiO formation under low-pressure hydrogen or "in vacuum" in less than 1 min at 800 °C or above. As an alternative the time/temperature cleaning step can also be provided by a sample peak temperature of about 1 s at 950 °C. The sample then cools down at about 100 °C/s rate to the nominal epitaxial growth temperature. This last procedure appears to be more convenient when selectivity is needed.

Selective epitaxy in the SiH_4/H_2 system (without HCl) requires temperatures of around 1000 °C.[2,7] Thus, for selective epitaxy experiments, we have used the DCS/H_2 (80:2000 in volume) system at 1.8 Torr as total pressure.

Figure 1 shows the growth rate in an Arrhenius plot for three systems: (a) SiH_4/H_2, (b) DCS/H_2, and (c) $SiH_4/HCl/H_2$. Note that as the growth rate is low, below 650 °C, this region was not investigated. These curves can be divided into two parts: above the 800–850 °C temperature range, the growth rate is almost constant which indicates that the dominant limiting mechanism is the mass transport in the gas phase. For the DCS system, in the high-temperature region, a power law fits the experimental growth rate with an exponent $\alpha = 0.9$. This figure is to be expected from the variation in the diffusion coefficient D of DCS. Indeed, according to the model we reported in Ref. 7 and assuming a

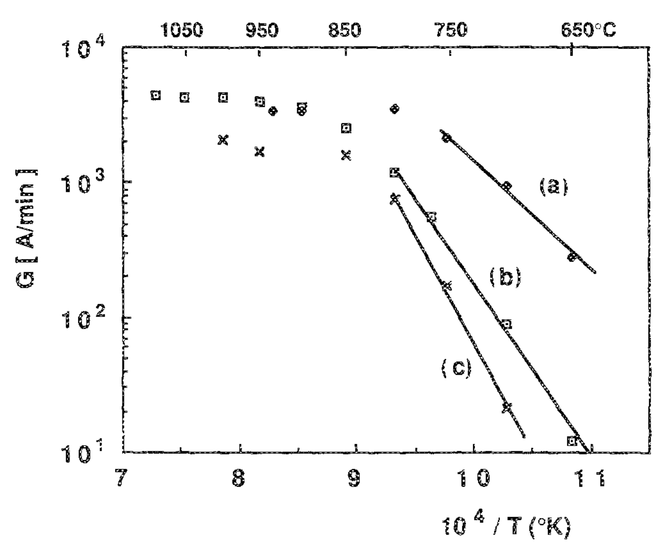

FIG. 1. Growth rate G is plotted as a function of the reciprocal absolute temperature and for 2 slm of H_2. Curve (a) is for 40 sccm of SiH_4 and we measure $Ea = 38$ kcal/mol. Curve (b) is for 80 sccm of DCS and $Ea = 59$ kcal/mol. Curve (c) is for 20 sccm of SiH_4 and 2 sccm of HCl and we obtain $Ea = 74$ kcal/mol.

growth rate limitation by the gas mass transport, its variation with temperature is primarily that of the diffusion coefficient. In addition a rough calculation along the lines of that model gives a value of $D_0 = 0.25$ cm^2/s from the general expression for D: $D = D_0 (P_0/P)(T/T_0)^\alpha$ where $T_0 = 273$ K and $P_0 = 760$ Torr. This value for D_0 is close to that given in Ref. 8. It has also been found that in that temperature region the influence of the crystalline orientation of the silicon substrate ($\langle 111 \rangle$ or $\langle 100 \rangle$) is very weak.

For temperatures lower than 850 °C, from curve 1(b), and assuming $G = G_0 \exp(-Ea/kT)$ where G is the growth rate, G_0 is in principle a constant, k is the Boltzmann constant, and T the absolute temperature, the apparent activation energy Ea calculated is about 59 kcal/mol. This value is high compared to that generally reported which is in the 40 kcal/mol range.[9] Although at this time no model can be put forward, we can safely assume a surface reaction rate limiting process. A dissociation reaction such as $SiH_2Cl_2 \rightarrow SiHCl + HCl$ (Ref. 10) can give a figure compatible with our result since the corresponding dissociation energy is 60 kcal/mol.

Full selectivity is obtained throughout the whole temperature range (from 1100 to 650 °C) when using DCS/H_2. The surface morphology of the epilayers observed by optical microscopy is always specular and shiny. No defects such as dislocations or stacking faults are present according to preliminary observations by transmission electron microscopy on layers grown at 650 °C.

As a comparison, we show in Fig. 1(a) the G values corresponding to the SiH_4/H_2 system. Selectivity is only obtained over 950 °C and the low-temperature activation energy of 38 kcal/mol compares fairly well with previous results.[11] But this system is not selective in the low-temperature region. Thus, to obtain selectivity as in the DCS system, a low amount of HCl is needed during the epigrowth. The HCl concentration needed is about 10% of the silane concentration. In this case the curve 1(a) is transformed into 1(c) (for the low-temperature region only); the activation energy is now 74 kcal/mol and full selectivity up to 650 °C is obtained.

Two ways are then reported in order to obtain selective epitaxial growth between 1100 and 650 °C: the first includes DCS/H_2 without the addition of HCl, the second is the $SiH_4/HCl/H_2$ system where the amount of HCl is just a few percent of the SiH_4 concentration. These are the main characteristics of our system working in the Torr pressure regime. This is in contrast with previous publications where the addition of HCl is needed even when using DCS/H_2.[12,13] It should be pointed out that in these published systems silicon epitaxy is achieved in the 20–100 Torr regime. Thus in our system the etching of silicon by the presence of HCl is enhanced by the reduced pressure which is in the Torr region. More details concerning this HCl behavior will be reported in a full paper.

In summary, we have shown for the first time that silicon selective epilayers can be grown using only DCS diluted in hydrogen at temperatures as low as 650 °C. Results obtained with the system $SiH_4/HCl/H_2$ show equivalent and consistent results.

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