Local-Loading Effects for Pure-Boron-Layer Chemical-Vapor Deposition

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The chemical-vapor deposition of pure boron (PureB) has been used very successfully as a means of fabricating extremely shallow, less than 10-nm deep, silicon p-n junction diodes. In this technology a nm-thin amorphous boron layer is deposited selectively on silicon through openings in an oxide isolation layer at temperature from 400°C - 700°C, in all cases creating an effective p+ layer at the interface. For the application as photodiode devices, particularly performance improvements have been achieved for the detection of low penetration-depth beams for which purpose 2-nm-thick PureB-layers are reliably implemented as the front-entrance window [1]. Ideal low-leakage diode characteristics are achieved at low temperatures, which together with the fact that the deposition is conformal and highly selective to Si, also makes PureB technology an attractive candidate for creating junctions on silicon nanowires and advanced CMOS transistors including source/drain in p-type FinFETs [2]. In the latter applications, sub-3-nm thick layers are required to avoid excess series resistance through the high-resistivity boron layer. Moreover, for the photodiode application any thickness variations even in the range of angstrom can have a large impact on the responsivity to beams that only penetrate a few nm into the Si such as VUV light and less than 1 keV electrons. Therefore, a very good control of the layer thickness is crucial.

The PureB deposition is susceptible to loading effects [3] the kinetics of which are investigated in this paper in order to achieve better control of the layer thickness on patterned wafers. For this purpose an analytical model is proposed that takes many of the important factors into account: the diffusion mechanism of the diborane species through the stationary boundary layer over the wafer, the gas phase processes and the related surface reactions by applying the actual parabolic gas velocity and temperature gradient profiles in the reactor to describe the deposition kinetics and the deposition chamber characteristics that determine the deposition rate over the non-rotating bare silicon wafer [4]. During the PureB deposition, there are two boron source components (vertical and lateral) that contribute incoming reactant molecules during the PureB deposition, (b) boron concentration distribution over a patterned wafer indicating the differences occurring due to the differences in the width of the Si windows and the oxide areas.

$\frac{dC}{dx} = \frac{0.692C_0}{e^{\frac{2.52D}{hU_0}}}$

The lateral component is a so-called local-loading effect that occurs because the boron is not deposited on oxide but will diffuse along the surface of the oxide. The importance of this component will depend on the pattern of the wafer and the boron diffusion lengths on the oxide and silicon, respectively. This is studied here by measuring the PureB-layer thickness of a die in the center of the wafer as a reference Si opening of width, $W_{Si}$, that is surrounded by a ring of oxide of width $W_{ox}$ and then a ring of isolating open silicon as shown schematically in the inset of Fig. 2. The overall oxide coverage ratio is also important as described in [3]. Here we define the local-oxide ratio (LOR) as the ratio of $W_{ox}$ to $W_{Si}$, and the local-oxide ratio is varied by changing the width of the oxide, $W_{ox}$.

Fig. 2 shows the PureB deposition rate versus local-oxide ratio. As described in the figure text, three regions can be distinguished. An empirical model has been developed to describe this behavior and it can be seen that all three regions are well described by the empirical formula. This formula can be used to model the lateral diffusion component of the boron atoms and to develop a comprehensive model to predict the PureB deposition rate on any 2-D uniform or non-uniformly patterned wafer. Examples will be given in the final paper of the impact of the local-loading effect on the performance of specific devices such as, for example, low-energy electron-beam detectors made up of different photodiode areas.