An atomic layer deposition approach to ultra-shallow doping of silicon

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One criticial requirement for the boosting of silicon metal-oxide-semiconductor field-effect transistor (FET) performances in ultra large scale integration is the aggressive scaling of the source and drain extension junctions. As electronic devices are reaching sub-10 nm junction depths, the achievement of low sheet resistance becomes more challenging and raises questions about the underlying physical limitations to the electrical activation of dopant atoms in ultra-thin films. Moreover, the degradation of the junction quality by non-trivial effects related to implantation damage when an amorphization process step is used to minimize dopant channeling, poses serious difficulties to doping techniques such as beamline ion implantation. Finally, in the case of 3D devices such as multi-gate FETs, the constraint of doping conformality induces additional challenges that can not be addressed by ion implantation, which suffers from shadowing effects for patterns with high fin density. Consequently, there is a strong need of novel doping strategies for both planar and non-planar devices. On the one hand, potential alternatives such as atomic layer doping (ALD) and plasma immersion ion implantation have already shown promising results [1, 2]. On the other hand, sub-melt millisecond anneal is considered as the method of choice for dopant activation whereas classical spike rapid thermal annealing results in excessive dopant diffusion and limited electrical activation. In this work, we investigated the properties of ultra shallow junctions fabricated by the combination of ALD and sub-melt laser annealing (LA). We show that low-resistance p-type and n-type junctions compatible with current device technologies can be both manufactured using ALD and LA. In the case of ALD with boron, we demonstrate that junctions with high electrical activation level, strongly reduced diffusion tails after anneal and excellent conformality can be obtained [1, 3]. In contrast, for n-type doping, electrical deactivation of a large part of the in-diffused dopants was observed and attributed to energetically-favorable dopant-vacancy cluster formation [4, 5]. However, we found that the sheet resistance could be reduced by using an alternative capping scheme. The improvement is explained by the combination of both an epitaxial cap and the atomic dopant layer.

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