In-line copper contamination monitoring using non-contact Q-V-SPV techniques

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In present-day semiconductor manufacturing, copper is considered as a major unintentional impurity due to its ubiquitous occurrence and highly detrimental effect on electronic devices[1]. In particular, the introduction of copper interconnect-based devices requires the implementation and effective supervision of stringent copper-specific protocols to prevent any cross-contamination from copper-dedicated to virtually metal-free production areas.

In recent years, minority carrier lifetime (MCLT) measurements have been established as a fast and convenient technique for contamination monitoring of semiconductor production lines[2]. Preferentially p-type silicon (p-Si) is used for routine supervision because for boron-doped substrates trace amounts of iron can be sensitively detected and moreover quantified by MCLT measurements[3]. However, in standard MCLT measurements the limit of detection for copper (Cu) in p-type silicon is poor[4] and insufficient for present-day device fabrication[1].

We report on a novel strategy for sensitive detection and unequivocal identification of trace amounts of copper introduced into p-type silicon and its oxide during high-temperature processes. Non-contact, quasi-static Q-V-SPV measurements (surface voltage V, surface photovoltage SPV versus biasing charge Q) and time-dependent SPV measurements were used to characterize the impact of copper on distinct silicon and oxide properties. Emphasis is put on the qualification of this strategy for routine furnace monitoring in a manufacturing environment.

The total oxide charge Q_{total} is established as a sensitive and fast indicator for the presence of copper in the silicon oxide (Figure 1).

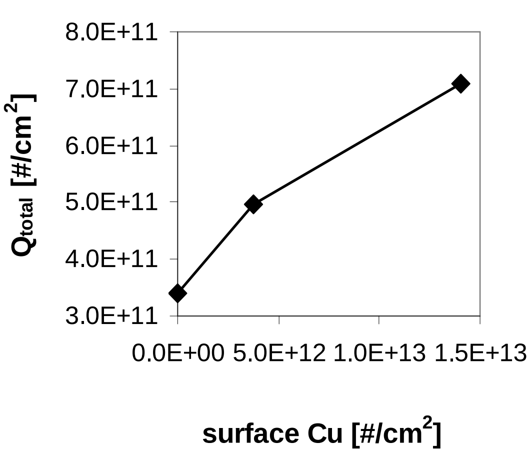

Figure 1: Total oxide charge Q_{total} versus surface Cu concentration prior to oxidation.

Once this unspecific parameter is out of control, a more detailed root cause analysis employing modified MCLT measurements yields a characteristic copper fingerprint. Upon illumination, an electrically weakly active copper species (most probably copper pairs) is transformed into an extended copper defect with high recombination activity[5]. At medium injection level the associated decrease in the recombination lifetime MI-τ_R resembles the behavior of iron-boron pairs FeB upon light-induced dissociation into interstitial iron Fe_i. Therefore, in the standard procedure for iron quantification in p-type silicon by measurement of MI-τ_R before and after illumination[3], copper exhibits a response similar to high concentrations of iron. In contrast, both metals behave drastically different if the lifetime is measured in the high injection regime: HI-τ_R decreases upon conversion of copper pairs into extended defects, while it increases in the case of transformation of FeB to Fe_i (Figure 2).

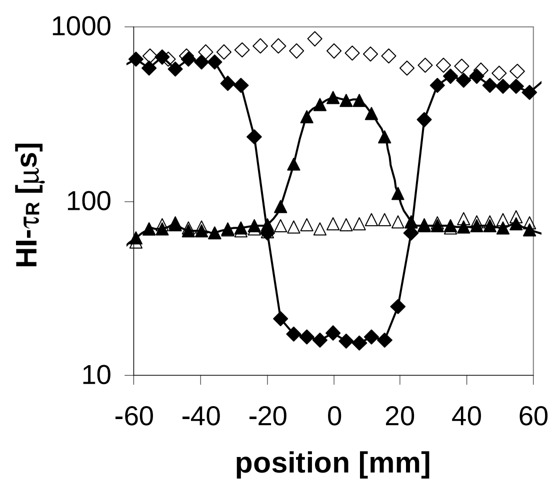

Fig. 2: Cross sections through HI-τ_R wafer maps for copper (diamonds) and iron contaminated p-Si (triangles) before (open symbols, no line) and immediately after illumination (solid line) at the wafer center.

Thus the characteristic fingerprint of copper in oxidized p-type silicon comprises an increased oxide charge and a pronounced decrease in the high and medium injection recombination lifetime upon illumination.

The efficiency of this concept is demonstrated by examples from routine furnace monitoring in a semiconductor production line.

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