Thresholds for Effective Internal Gettering in Silicon Wafers

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It has long been known that the transition from ineffective to effective internal gettering (IG) occurs at a very small overall amount of oxygen precipitation [1]. Subsequent work [2] revealed that the critical density of developed precipitates for effective IG was around 10^7 cm^{-3}. In fact, it was shown that this was not only a threshold but that there is no need for higher densities of precipitates. A maximum density of 10^7 cm^{-3} sites actually could take part in the gettering of fast diffusing transition metals due to self-gettering effects around the precipitates, as gettering progresses during the cooling of the wafer [3]. The question that remained unclear was just what is the feature of each individual precipitate that marks the transition from a non-gettering to a metal-gettering site - at which metal silicide precipitation occurs. Studies of the onset of gettering in early stages of oxygen precipitation have been made recently [4,5]. The results have been interpreted in terms of a threshold size of the developing oxide precipitates during thermal treatments.

Recent investigations, however, indicate that the transition to the effective gettering lies not in the size of the oxygen precipitates but rather in a morphological transformation of the developing precipitates from an initially unstrained (and hence inactive) state to strained (active) platelet state. Such transformations – from initial non-strained plates of an atomic thickness to regular strained amorphous platelets - have been observed during prolonged anneals at 750°C [6].

In our study, it has been found that this morphological change does not occur all at once, in the population of growing initial precipitates, but rather proceeds at some rate within the population. Importantly, the rate of transformation is found to depend strongly on oxygen concentration, density of growing precipitates and the temperature of growth.

The transition to effective gettering occurs when a sufficiently high density (ca. 10^7 cm^{-3}) of the platelets is produced from the initial precipitates.

Extensive TEM studies were performed of the development of oxygen precipitate populations. A wide variety of total oxygen precipitate densities (10^7-10^{11} cm^{-3}) was produced by both low temperature nucleation and vacancy controlled nucleation (MDZ) in samples of a wide range of oxygen concentrations. Heat treatments to induce growth and morphological transformation of initial plates were performed at 950 and 1000°C. The transformation to the strained platelet state was observed by both the appearance of etch features and direct observations of strained oxide platelets in conventional TEM. Over time at growth temperatures, the density of the strained particles in the distribution increases steadily until the entire population of oxide plates (set by the nucleation treatment) has been converted. In this way, the rate of transformation to the strained state was determined as a function of temperature, oxygen concentration and site density.

A very strong dependence of the transformation rate was observed for both site density and oxygen concentration – especially at low oxygen concentrations where the solubility (corresponding to the initial morphological state) is approached. As such, these two parameters have a very strong effect on the transition time to effective gettering.

The dependence of the transformation rate has been successfully modeled assuming that self-interstitials participate essentially in the above morphological transformation. The self-interstitials are emitted by the primary precipitates, and are sunk at the sample surface or elsewhere. The time to set effective IG (which means: to create approximately 10^7 cm^{-3} of platelets from a given density of sites and from a given concentration of oxygen at given temperature) can be calculated. Examples of these calculations are shown in Figures 1 and 2. The results are in good agreement with observations of gettering thresholds for nickel and copper.

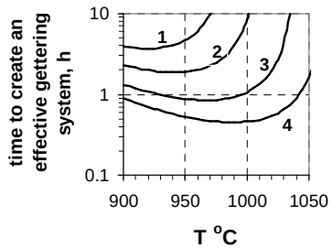

Fig 1. Temperature dependence of the annealing time required to create the gettering state from a site density of 10^{10} cm^{-3} for [Oi] = 8, 10, 13 and 16 ppma for curves 1, 2, 3 and 4 respectively.

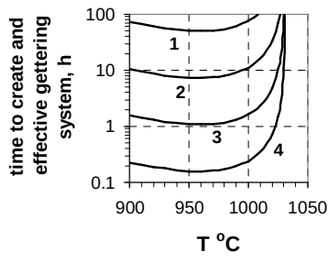

Fig 2. Temperature dependence of the annealing time required to create the gettering state from an oxygen concentration of 12 ppma with a site density of 10^8, 10^9, 10^{10} and 10^{11} cm^{-3}. (curves 1-4 respectively)

References

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