Reliability Prediction of Gate Dielectrics Based on Percolation Models using Fractal Structure

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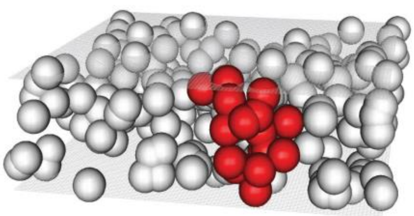
1. Introduction

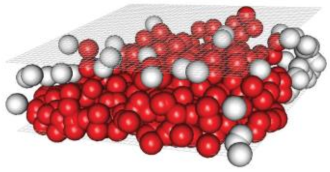
The needs for continuous size reduction of metal-oxide-semiconductor field effect transistor (MOSFET) devices can cause serious reliability concerns. Gate oxide breakdown is a key mechanism concerning the lifetimes of MOSFET devices. In this paper, several spatial point processes are employed to represent general patterns of defect generation in gate oxide. By defining oxide breakdown as a creation of conduction path connecting two oxide interfaces by overlapped defects, percolation models are discussed to predict reliability of MOSFET devices in terms of critical defect density. We propose a new method to evaluate lifetimes of area-scaled gate oxides in MOSFET devices mainly through their fractal structure based on a percolation model. The method suggests an easy way to predict the lifetimes of the devices with area-scaled gate oxides by examining their fractal structure through a fractal dimension without involving breakdown distributions of gate oxides with different areas.

2. Experiments

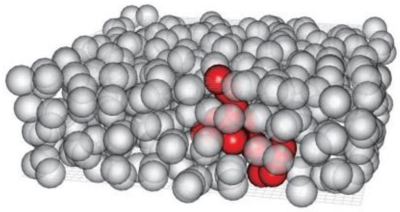
In context of percolation model, oxide breakdown occurs when a percolation path is created from the bottom to the top of the oxide layer. In order to investigate the impact of spatially distributed defects and oxide thickness dependence on the statistics of oxide breakdown, a variety of simulations are executed based on the percolation models. sphere-based and cube-based percolation models are used in this experiment. The fractal structure of oxide breakdown according to oxide area is evaluated in terms of percolation conduction path via spatially generated defects.



(a) The Homogeneous Poisson Point Process



(b) The Nonhomogeneous Poisson Point Process



(c) The Pair-potential Markov Point Process
Fig.1 Simulated spherical defects with radius r=0.45

3. Conclusion

To accurately predict reliability of newly developed MOSFET devices with ultra-thin gate oxide, spatial patterns of defects generated inside the oxide, as well as defect generation mechanisms, must be explicitly reflected in reliability model. We discussed several percolation models by envisioning oxide failure as creation of a percolation path connecting two oxide interfaces by overlapped defects. It was observed that the Weibull distribution successfully fits the breakdown data caused by creation of a percolation path connecting two oxide interfaces. However, simulation results showed that the shape parameter in the Weibull distribution depends on oxide area, hence existing area-scaling model may provide biased prediction results by assuming common shape parameter regardless of oxide areas. As an alternative, we proposed a new method to evaluate lifetimes of area-scaled gate oxides of MOSFET devices mainly through their fractal structure. We observed that defects in gate oxide can be modeled via fractal structure, and they have same fractal structure at identical oxide thickness.