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論文内容の要旨

Recently, large scale integrated circuit (LSI) uses electrodeposited copper thin films as an interconnect material to be further miniaturized to submicron scales for faster operation and more functionality. While those Cu films compose multilayered structures, the weak adhesion strength of interfaces between Cu and insulation layers has become one of the important issues for interconnect reliability. The weak adhesion strength not only causes delamination during the manufacturing process but also leads to poor electro-migration resistance, which sometimes brings about fatal malfunction of the device. On the other hand, since the interconnect structure in LSI typically has sub-micron dimensions, interface strength may significantly depends on locally inhomogeneous material structure. For instance, interface strength on the microscale Cu layer may be influenced by the different deformation behavior caused by different grain orientations. In addition, the plastic deformation behavior may be strongly affected by not only the size but also the microscopic structure.

In this study, firstly, a new evaluation method of interface strength was designed and applied from the viewpoint of plastic zone at the interface crack tip with different specimen size. By considering the influence of the plastic zone at the interface crack tip with the

10x10μm, 5x5μm and 1x1μm specimens by means of an elastic-plastic finite element simulation technique, interface bonding energy was evaluated and almost equal among all types of specimens. Since the average grain size of Cu lines was much smaller than the specimen dimensions, no significant difference should be expected in bonding energy. On the other hand, the fluctuation of the evaluated interface strength tends to be larger with the decreasing specimen size. The local interface strength may significantly varies depending on local grain distribution in the Cu interconnect structure. It was also concluded that an accurate estimation of the plastic zone is essential for micro-scale specimen evaluation. The new method provided an accurate evaluation tool for the reliability issues of interface strength in Cu metallization systems in LSI.

Secondly, it was successfully demonstrated that the significant fluctuation of strength of interface Cu/SiN in LSI interconnects was induced by the inhomogeneous grain structure of Cu line by comparing the result of strength distribution with that of the Cu/SiN interface on a homogeneous Cu layer. In addition, the deformation behavior of Cu line for different specimens were investigated and the results revealed that the fluctuation of interface strength was influenced by the different plastic deformation behaviors caused by different grain structure in LSI interconnect. It was demonstrated that potential fracture in LSI interconnects originate from the weak point which depends on the microscopic material structure of Cu line.

Finally, in order to remove the limitation on the freedom of grain orientation in the experiment on Cu line and further investigate the fluctuation of interface strength, bonding energy of interface between Cu and SiN was evaluated on single crystal Cu substrates with different surface orientations and in different loading directions. With the aid of computational simulation of elastic-plastic interface crack extension process, it was newly revealed that the bonding energy depends only on the surface crystal orientation of Cu and that interface strength changed in different loading direction even on the same surface orientation through the different deformation behavior of Cu substrate caused by elastic-plastic anisotropy. In addition, the fluctuation of interface strength covering the entire range of crystal orientations and loading directions was expected to obtain through the crack extension simulations in LSI.

After accumulating these new findings, this study provides not only a possibility to make a map of local strength distribution but also toward a systematic design scheme on the basis of mechanical engineering and thus to enhance the mechanical reliability brought into LSI interconnect structures.