学位論文内容の要旨

This dissertation for the degree of doctor of engineering deals with the formation of preferentially oriented Cu[111] layer on a thin Nb diffusion barrier on SiO_2. The Cu[111] layer is applicable to Si-ULSI as a reliable interconnect material with good resistance against electromigration failure. The dissertation is comprised of six chapters. A brief overview of Cu interconnects centering the necessity of diffusion barriers and electromigration phenomena has been delineated in Chapter 1. A literature review of diffusion barriers for the Cu metallization scheme, concentrating on the formation of the [111] preferentially oriented Cu layer has been composed briefly in chapter 2. Chapters 3 and 4 contain experimental methods and results obtained, respectively. Discussions related to the obtained results belong to Chapter 5. Conclusions and suggestions for future research scopes have been pointed out in Chapter 6.

A Cu layer of [111] preferred orientation has attracted much attention as a seed layer of Cu interconnects in Si-ULSI, because a high electromigration resistance is anticipated. The most effective electromigration resistance is obtained when the closely-packed (111) plane of Cu as a fcc metal is placed in the normal direction to the current flow direction. Thus, an appropriate barrier layer, on which Cu[111] texture will be grown, is required on a field insulating layer to prevent Cu diffusion into the insulating layer on Si underneath. As a thin diffusion barrier, on which a Cu[111] texture grows, I choose Nb for the candidate, because the $[110]_{bcc}$ plane has a good epitaxial relationship matching well with the $[111]_{fcc}$.

Thus, in this dissertation, the preferentially oriented Cu[111] texture deposited on thin Nb layers in different thicknesses is characterized in thin-film stacked structure of $Cu/Nb/SiO_2/Si$ as a challenge for preparation of a Cu[111] seed layer of interconnects on an extremely thin barrier required from the recent trend toward minutuarization. For example, a 10 nm thick barrier is defined for 90 nm node technology in the International Technology Roadmap for Semiconductors.

The Cu(200~300 nm)/Nb(10~100 nm)/SiO_2/Si system was prepared by a tetrode dc-sputtering system. Crystallographic orientation between Cu and Nb layers were studied by X-ray diffraction (XRD) and transmission electron microscopy (TEM). These analyses indicate that the Nb barrier deposited on SiO_2 has a strong [110] texture, and the Cu texture grown on Nb shows a [111] single orientation. Quality of Cu[111] texture evaluated by ω-rocking curve measurements depends on the Nb barrier thickness. The ω-FWHM value of 3.04° for a Cu[111] layer deposited on a 100 nm thick Nb barrier increases to 4.36° and 6.10° for those on 20 and 10 nm thick Nb barriers, respectively. This is attributed to the microstructure of the Nb barrier. TEM observation indicates that nanocrystalline grains no larger than ~10 nm in size with rather spread [110] orientation around the substrate normal direction is characteristic for 10 nm thick Nb barrier on SiO_2, whereas, in the 100 nm thick barrier, the well oriented columnar structure of Nb[110] with ω-FWHM value of ~6° is obtained by ordering the orientation during the thickness growth of Nb film by coalescence of the initially nucleated nanocrystalline grains. On the contrary, the pronounced columnar structure of the Cu layer consisting of sufficiently larger grains is obtained on Nb layer. Cu(111) planes are almost parallel to the substrate surface, however, relatively large inclination of the lattice fringes of Cu(111) from the substrate parallel is evident on the 10 nm thick Nb layer. A very thin interlayer of 1~2 nm in thickness is seen at each interface of Cu/Nb and Nb/SiO_2, as examined by glancing incidence X-ray reflectivity measurements (GIXR). The Cu[111] orientation slightly ameliorates upon annealing. As well, the present 10 nm thick Nb barrier exhibits good barrier properties showing scarce change in morphology and texture due to annealing at 500°C for 1 h, sufficient temperature for post-metallization annealing.

The extremely thin Nb films are useful as a candidate of diffusion barrier, on which a preferentially oriented Cu[111] layer is obtained. This result will contribute to the development of Cu interconnect technology for downscaled technology nodes.

論文審査結果の要旨

本学位申請論文は、Si集積回路におけるCu配線技術に関して、微細化に伴う電流密度の増大に起因して生じるエレクトロマイグレーションへの耐性を最も高めることができるCu配線層の形成を念頭に置き、稠密面であるCu(111)面を電流方向と垂直に配置する[111]配向したCu組織を配線に不可欠なフィールド絶縁膜上に形成した拡散バリヤ上に成長させることを含めて電子材料工学の見地から検討している。Cu[111]組織を得るために、fcc金属の(111)面がbcc金属の(110)面上に成長するというエピタキシャル成長の関係に着目し、薄膜で安定なbcc相が知られている遷移金属であるNbに着目し、さらに、表面ポテンシャルが最小となるNb(110)面をフィールド酸化膜であるアモルファスSiO_2層の上に形成することを提案し、実際に実験的に可能なことを実証している。このことにより、Cu(111)/Nb(110)/SiO_2/Siという配線に応用できる薄膜積層構造の作製が可能なことを見いだしている。さらには、微細化Cu配線として、90nmノードの拡散バリヤの目標である、10nm厚さのNb膜上でのCu[111]組織の形成を実験的に検討し、バリヤ膜厚が極薄となっても、良質なCu[111]組織が形成可能なことを実験的に示し、Cu[111]配向組織を配線に用いるためのひとつの解法を示している。

これを要するに、本申請論文は、Si集積回路における配線技術に対し、材料科学の見地から、エレクトロマイグレーション耐性に優れた、Cu[111]組織の利用に大きな可能性を示しており、電子材料工学ならびに薄膜工学に寄与するところ大である。

よって、申請者は、北見工業大学博士（工学）の学位を受ける資格があるものと認める。