A CRYSTALLOGRAPHIC OPTIMIZATION STUDY IN TA/TAN BI-LAYER SPUTTERING TO REDUCE SEMICONDUCTOR MANUFACTURING QUEUE TIME CONSTRAINT.

ANUAR FADZIL BIN AHMAD

DOCTOR OF ENGINEERING

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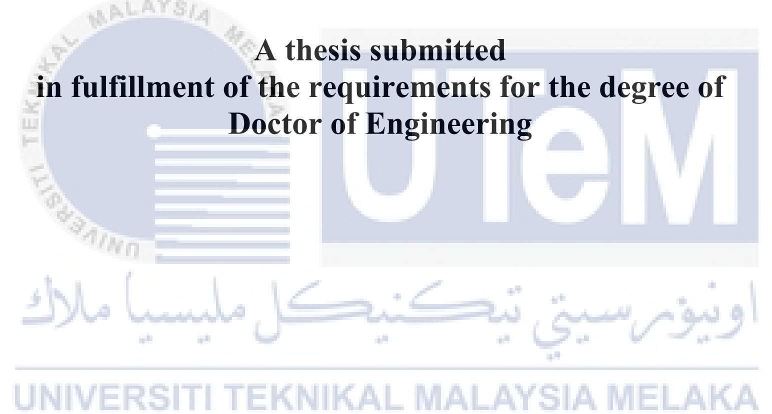

A thesis submitted
in fulfillment of the requirements for the degree of
Doctor of Engineering

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

DECLARATION

I declare that this thesis entitled "Manufacturing Constraint Mitigation through Improvement of Cu barrier seed Film Ageing Characteristics Using DOE Approaches" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Signature : ------------------------------------

Name: : Anuar Fadzil Bin Ahmad

Date : 5 February 2022

APPROVAL

I hereby declare that I have read this thesis and in my opinion, this thesis is sufficient in terms of scope and quality for the award of Doctor of Engineering.

Signature :

Supervisor's Name: : MD NIZAM BIN ABD RAHMAD

Date : 5/2/2022

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DEDICATIONS

All praise belongs to Allah.

To all Silterrans and the great company we are associated with and to my beloved family for your support patience and understanding

ABSTRACT

The Physical Vapor Deposition (PVD) magnetron sputtering method is the most extensively used technique for depositing metallic thin film in the semiconductor wafer fabrication industry. The PVD equipment manufacturer has specified stringent control, in this case, a queue time restriction between the Copper (Cu) barrier seed layer and the following Cu electroplating layer deposition processes. This restriction is formed without providing detailed data or reasoning. This is applied as a condition to safeguard the interconnect quality and performance from functionality and reliability performance failures. Consequently, the queue time has imposed plenty of manufacturing challenges. In cases when the PVD and electroplating processes have to be stopped, the queue time cannot be exceeded and this creates constraints that lead to evasive steps that can create a capacity bottleneck that risks failure in the on-time delivery. The objective of this research is to investigate the film characteristics change in Cu electroplating film against queue time impact in order to verify the need to uphold queue time requirement recommended by the tool manufacturer. In pursuit of this, baseline film ageing characteristics that include sheet resistance and microstructure studies over an ageing period are planned out and compared to the peer studies. The comparisons prompted improvement in Ta bi-layer α-Ta crystal texture content which is shown to result in higher Cu (111) crystal texture and promoted sheet resistance (Rs) stability in the interconnect stack. In order to improve the metal film stability, a screening analysis of variance (ANOVA) experiment was conducted. A fractional factorial experiment was planned out to study the impact of TaN bias power, nitrogen flow rate, Cu bias power, and re-sputter layer on both the Cu barrier seed layer and the Cu electroplating stacked on Cu barrier seed layer. The impact study is primarily on film Rs ageing properties. A statistically significant parameter that influences the Rs stability for both layers is re-sputter treatment layer. Microstructural x-ray diffraction (XRD) analysis is done to understand the ageing mechanism. Next, selected screening experiment parameter settings, along with control, have been used in a wide range of queue time intervals between Cu barrier seed and Cu electroplating processes to understand the impact of the queue time on Cu Electroplating film Rs stability. The results show a stable Rs to an interval of 40 hours. It is also learnt that the cell with re-sputter done on TaN layer has stability up to almost four times compares to the standard manufacturing process cell. The application of TaN layer re-sputter has also shown a higher level of α-Ta ratio content with respect to β-Ta which in turn produces more, of the preferred Cu (111) grains. This research went a step further to have a prediction model to minimize Rs mean and non-uniformity changes during ageing by using the TaN re-sputter process in an RSM experiment. TaN re-sputter impact has again shown its dominance over other modeled parameters causing an insignificant model fit for mean Rs. Additionally, a prediction model is successfully generated for Rs non-uniformity at 48 hours ageing period.

KAJIAN PENGOPTIMUMAN KRISTALOGRAFI PADA LOGAM TA/TAN DWI-LAPISAN UNTUK MENGURANGKAN KEKANGAN MASA MENUNGGU DALAM PEMBUATAN SEMIKONDUKTOR

ABSTRAK

Kaedah pelapisan secara magnetron PVD adalah paling banyak digunakan untuk penyaduran filem logam nipis dalam pembuatan wafer semikonduktor. Pengeluar peralatan PVD telah menetapkan kawalan ketat dalam peruntukan sekatan waktu menunggu di antara proses pelapisan benih penghalang kuprum dan proses pelapisan elektrolisis kuprum tanpa memberikan data dan sebab. Ini dianggap perlu untuk melindungi kualiti dan prestasi lapisan logam daripada kegagalan fungsi dan ketahanan. Ini telah memberi cabaran dalam proses pembuatan. Apabila proses PVD dan elektrolisis perlu dihentikan, masa pemberhentian tidak boleh dianjali dan ini mewujudkan kekangan yang boleh mengakibatkan kegagalan penghantaran produk kepada pelanggan.Objektif penyelidikan ini adalah untuk menyelidik kesan tempoh menunggu bagi menentukan keperluan mematuhi kekangan tempoh menunggu. Untuk ini, penyelidikan sifat penuaan filem yang merangkumi perubahan rintagan logam nipis dan mikrostruktur logam sepanjang tempoh penuaan telah dianjurkan. Ia mengambil kira maklumat penyelidikan setara. Ini mendorong kepada peningkatan α–Ta dalam logam Ta dwi-lapisan dan tekstur kristal Cu(111) yang telah menggalakkan kestabilan rintangan logam. Bagi lebih meningkatkan kestabilan filem, kaedah ANOVA digunakan bagi mengkaji kesan tahap biasan proses pelapisan Ta dwi-lapisan, kadar aliran nitrogen, tahap biasan proses pelapisan kuprum dan kakisan semula pada lapisan Ta atau TaN pada sifat penuaan rintangan lapisan logam nipis ini. Faktor yang bersignifikan tinggi didapati pada pengkakisan semula lapisan TaN pada logam Ta/TaN dwi- lapisan. Analisis mikrostruktur berkaedah XRD digunakan sebagai rujukan keputusan analisis Rs bagi memahami mekanisme kesan dan ciri-ciri penuaan. Seterusnya, parameter process dari sel-sel eksperimen yang terpilih dan dari sel kontrol telah digunakan dalam penilaian kesan waktu kepada kestabilan Rs di dalam tempoh menunggu antara process pelapisan logam Ta/TaN dwi-lapisan/kuprum dan proses elektrolisis kuprum. Keputusan menunjukkan tiada perbezaan yang ketara walaupun pada 40 jam waktu menunggu. Process terpilih yang merangkumi pengkakisan semula lapisan TaN menunjukkan kestabilan sehingga hampir empat kali ganda berbanding proses standard. Kaedah ini telah menunjukkan nisbah α–Ta dan β-Ta yang lebih tinggi yang dapat menghasilkan lebih banyak butiran Cu(111). Akhirnya, kaedah RSM telah mendapatkan model ramalan bagi meminimumkan perubahan Rs dan ketidakseragamannya semasa penuaan melalui proses pengkakisan semula TaN. Kesannya sekali lagi menunjukkan penguasaannya yang lebih berbanding faktor pemboleh ubah yang lain lalu model ini tidak sesuai untuk ramalan perubahan Rs. Ramalan model bagaimanapun berjaya dijana untuk faktor ketidakseragaman Rs pada 48 jam tempoh penuaan.

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