UNIVERSITI TEKNIKAL MALAYSIA MELAKA

PLASMA ETCHING PROCESS FOR ALUMINUM-COPPER METALLIZATION BY PHOTORESIST MARGIN IMPROVEMENT FOR CMOS 0.13-µm TECHNOLOGY

WAN FAIZAL MOHAMED HASSAN

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

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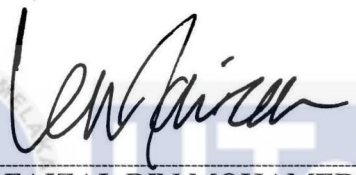
2022

DECLARATION

I declare that this thesis entitled "Plasma Etching Process for Aluminum-Copper Metallization by Photoresist Margin Improvement for CMOS 0.13-μm Technology" 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.

Signature : 

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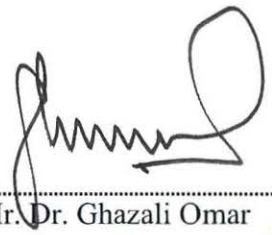
APPROVAL

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 : 

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DEDICATION

To my beloved mother, father and family. All praises to ALLAH and His blessing for the completion of this thesis.

ABSTRACT

In wafer fabrication manufacturing, the aluminum etching process is a dry plasma etching process used as the main process for construction of aluminum copper (AlCu) interconnect structures. As customer requirements changed for faster, more reliable and lower cost chips, chip manufacturers have learned to reduce the size of components on a chip in order to achieve those requirements. As the geometry of the chip is getting smaller, the width of AlCu line wiring specifications is also shrinking. To print the smaller geometry pattern requirements, the photoresist (PR) thickness in the masking process also has to be reduced for better resolution. Such a thinner resist will create a challenge during plasma etching to ensure a minimal resist loss process which will require a new type of equipment. The use of an oxide film as a hard mask has been evaluated by many other researchers. This approach does require a process integration change with full technology qualifications and will easily take many lengthy qualification procedures particularly to qualify the existing products. In SilTerra, the plasma AlCu etching process for 0.13µm High Voltage (HV) technology is qualified at the Applied Material (AMAT) DPS+ etcher system. Larger chamber volume design coupled with the use of C_2H_4 patterned passivation gas process is enabling the 0.13µm AlCu etching process to run with enough PR margin process. This limited capacity of the AMAT tools triggered SilTerra engineers to initiate process qualification works at the LAM9600PTX chamber which is an equipment designed for 0.16µm and bigger technology scale. The initial trial using SilTerra 0.13µm technology process failed to meet the process requirements on the PR remaining thickness. The insufficient margin caused deformed AlCu structure formations. This thesis evaluated the use of methane gas during AlCu etching process as an additional passivation gas to the existing nitrogen gas. The AlCu etching rate non-uniformity due to aspect ratio dependent etching (ARDE) is evaluated at a methane gas flow rate within the range of 0 to 18 standard cubic centimeters per minute (SCCM). One factor of a time experiment with comprehensive design of experiment trials is evaluated and it is found that, an addition of methane at 9 SCCM in AlCu etching step able to reduce the ARDE% from 26% to 21% with acceptable incremental of metal width critical dimension. A 60 SCCM of Cl_2 and 10 SCCM of CHF_3 gas mixture has been determined from DOE runs as a replacement gas mixture to the existing Cl_2/O_2 to address organic backside anti-refractive coating (OBARC) etching requirement for lower PR loss process. The true mean value of PR margin thickness and oxide loss margin thickness from the proposed new process conditions have been statistically determined to meet the minimum SilTerra process requirement. The electrical tests on M2B_V and RS_M2C parameters are verified on the production pre-runs and the final sort yield data are validated on the volume runs successfully. This novelty finding is successfully increasing the capacity with an additional 5,000 wafers output per month which is equivalent to USD 2.5 million and a capital expenditure avoidance of USD 5 million.

PROSES PUNARAN PLASMA UNTUK PELOGAMAN ALUMINIUM-TEMBAGA OLEH PERBAIKAN MARGIN FOTORINTANG UNTUK TEKNOLOGI CMOS 0.13-µm

ABSTRAK

Dalam pembuatan fabrikasi wafer, proses punaran aluminium-tembaga (AlCu) adalah proses plasma punaran kering yang digunakan sebagai proses utama untuk pembinaan struktur interkoneksi AlCu. Oleh kerana keperluan pelanggan berubah untuk cip yang lebih pantas, dan lebih pelbagai fungsi dengan kos yang lebih rendah, pengeluar cip telah mengurangkan ukuran skala struktur kepada 0.13µm pada cip untuk mencapai keperluan tersebut. Apabila geometri cip semakin kecil, lebar spesifikasi pendawaian garis AlCu juga menyusut. Untuk mencetak keperluan corak geometri yang lebih kecil, ketebalan fotorintang dalam proses pelindung juga harus dikurangkan untuk resolusi yang lebih baik. Ini akan menimbulkan cabaran semasa pengukuhan plasma untuk memastikan proses kehilangan bahan rintang yang minimum memerlukan peralatan baru. Penggunaan filem oksida sebagai topeng keras telah dinilai oleh penyelidik lain. Pendekatan ini memang memerlukan perubahan integrasi proses dan kelayakan teknologi sepenuhnya dan dengan itu prosedur kelayakan akan lebih panjang terutama untuk memenuhi syarat produk yang sedia ada. Di SilTerra, proses punaran AlCu plasma untuk teknologi 0.13µm dapat dipenuhi syaratnya dalam sistem Applied Material (AMAT) DPS +. Reka bentuk isipadu ruang yang lebih besar ditambah dengan penggunaan proses gas pasif bercorak C_2H_4 telah memungkinkan proses pengukuhan AlCu 0.13µm berjalan dengan proses margin fotorintang yang mencukupi. Kapasiti terhad alat AMAT telah mendorong para jurutera SilTerra untuk memulakan kerja kelayakan proses di peralatan LAM9600PTX yang berkeupayaan untuk skala teknologi 0.16µm dan lebih besar. Percubaan awal menggunakan proses teknologi SilTerra 0.13µm gagal memenuhi syarat proses pada ketebalan fotorintang (PR). Margin yang tidak mencukupi telah menyebabkan pembentukan struktur AlCu yang cacat. Tesis ini telah menilai penggunaan gas metana semasa proses punaran AlCu sebagai gas pasifasi tambahan kepada gas nitrogen yang ada. Kadar keseragaman proses punaran AlCu yang tidak seragam kerana kebergantungan kepada nisbah aspek (ARDE) yang dinilai pada kadar aliran gas metana dalam lingkungan 0 SCCM hingga 18 SCCM. Satu faktor eksperimen masa dengan penilaian beberapa percubaan eksperimen reka bentuk yang komprehensif telah didapati bahawa pada 9 SCCM kadar aliran metana telah dapat mengurangkan ARDE% dari 26% hingga 21% dengan terdapat peningkatan pada dimensi kritikal lebar logam. Campuran 60 SCCM Cl_2 dan 10 SCCM CHF_3 telah ditentukan daripada larian DOE sebagai campuran gas pengganti kepada Cl_2/O_2 sedia ada untuk proses punaran lapisan anti-bias belakang organik (OBARC) untuk proses kehilangan PR yang lebih rendah. Nilai min sebenar ketebalan margin PR dan ketebalan margin kehilangan oksida daripada proses punaran baharu yang dicadangkan telah ditentukan secara statistik untuk memenuhi syarat minimum bagi proses punaran logam di SilTerra. Ujian elektrik pada parameter M2B_V dan RS_M2C telah disahkan semasa pra-pengeluaran dan juga data hasil akhir telah disahkan pada pengeluaran tinggi yang berjaya dijalankan. Penemuan baru ini berjaya meningkatkan kapasiti penambahan 5,000 output wafer sebulan yang setara dengan USD 2.5 juta dan mengelakkan dari perbelanjaan modal sebanyak USD 5 juta.

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