Polyimide Film Process Equipment Qualification

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Keywords: Non-photodefinable Polyimide, Cure, C&D Track, CascadeTek Oven, Interconnect, and GaAs.

Abstract

A variety of materials are used in the Compound Semiconductor Industry for fabricating inter-layer dielectric film for metal interconnects. These materials include BCB, Polyimide, and Silicon dielectrics. In this paper we discuss a polyimide film process qualification on new processing equipment at the BAE Systems Microelectronics Center (MEC) Fabrication Facility. The work includes qualification of a new Coat Track for Polyimide coating and a new Cure Oven to cure polyimide coated films.

INTRODUCTION

Polyimide films have a low dielectric constant, a high modulus, and a relatively high thermal, chemical, and mechanical resistance[1, 2]. These properties make them an attractive candidate for numerous semiconductor and microelectronics processing applications. Some of these applications include the use of polyimide films as passivation layers in flip-chip packaging, as a substrate for printed circuit boards, in multichip module deposited dielectric packages, as dielectric interlayers in multilevel metallic interconnections, etc.[3] This paper discusses the use of a polyimide film for metallic interconnections due to its low dielectric constant for a reduced parasitic capacitance.

Metallic interconnections electrically connect various parts of an Integrated Circuit (IC). Interconnect structures are essential for modern day IC manufacturing. Figure 1 shows a cross section of a typical interconnect structure. Interconnections are fabricated with alternating metal and dielectric layers. These layers are patterned to form electrical pathways connecting various components of a circuit[1, 2, 4].

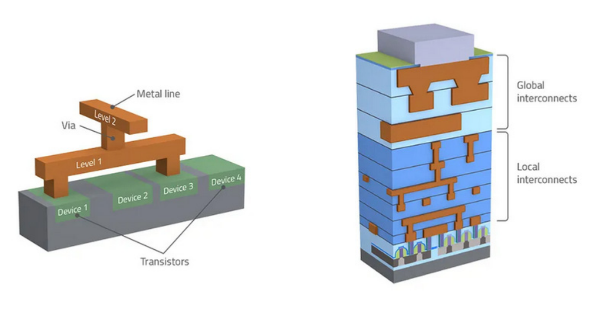

Fig. 1. Cross section of a typical interconnect structure[4].

At the Richard Reed Microelectronic AMP Center (MEC), a Non-photodefinable Polyimide (NPPI) film is used as an interlayer dielectric layer for metal interconnections in various active and passive RF MMIC circuits. This process reduces the overall footprint on the wafer and allows complex integration without affecting device performance.

Fabrication steps for a typical NPPI film processing are as follows:

1) Wafer Surface Preparation and Adhesion Promoter Dispense: The wafer surface can be prepared by a dehydration bake. Before an adhesion promoter dispense, the surface should be free of particles and contamination. For select NPPI film processing, VM651 or VM652 must be used as an adhesion promoter.
2) Polymer Spin Coat: The polymer dispense should follow a typical thick photoresist dispense process. The polymer dispense should be close to the substrate to avoid bubble formation. Dispense and cast should be performed only after all bubbles in the polymer solution are dissipated. An uncured film dissolves in n-methyl-2-pyrrolidone (NMP) based solvents. A NMP based solvent is effective for a backside rinse and an edge bead removal (EBR) process.
3) Soft Bake: A soft bake temperature between 130°C-200°C for 90s-180s in contact or proximity mode on a hotplate should be applied to substrates. For a contact soft bake, the backside of wafers should be clean or it could lead to breakage of wafers or deposition of organic residues on hotplate.
4) Cure: Curing is one of the most important steps in polyimide film processing. It controls the final film's stress, electrical, mechanical properties, etc[5]. With the application of heat, spin coated Polyamic acid precursor converts into a fully aromatic polyimide film. This conversion process is accompanied by a NMP solvent carrier dry off. The curing process crosslinks polymer chains and increases film density. A polyimide film curing process can be split into two or three steps with an increasing temperature setpoint for each subsequent step. Typically, for the curing process, an elevated temperature of up to 350°C with a slow ramp rate of up to 4°C/min in an inert environment is employed. A programmable oven should be used for the simultaneous processing of multiple wafers. This helps with a throughput increase, and an improvement in solvent dry off

uniformity, temperature uniformity, temperature control, and stress uniformity[5].

5) Patterning: For the NPPI layer, the patterning of a blanket cured film can be done by a process of dry etching or laser ablation. This is due to the issues with typical wet etching processes. A dry etch hard mask needs to be fabricated over the film. Oxygen plasma with a mixture of CF4 is typically used in RIE tools to dry etch a cured polyimide film. In certain cases, a surface descum after a full pattern etch should be performed to improve adhesion of the upcoming metallic layer.
6) Multiple Metallic Layer Processing: For the subsequent metallization of a patterned and cured polyimide film, the surface should be roughened to improve adhesion of the metal film. This roughening can be done with Oxygen plasma descum or a dehydration bake[3,5].

At the MEC, per technical guidelines, a NPPI film is spin coated and soft baked using a coat track. Polyimide film coated substrates are then cured in a programmable cure oven to dry off the solvent carrier and complete the polyimide imidization process.

This paper discusses the qualification procedure of a new polyimide spin coating track and new cure oven at the MEC. Qualification of this new equipment will increase throughput and improve reproducibility of polyimide processing at the MEC-AMP Center.

QUALIFICATION PROCEDURE AND DATA COLLECTION

The curing process hardens a polyimide on a substrate. Consequently, it is difficult to remove a cured film with conventional film stripping methods without damaging the devices on the substrate. Thus, after a polyimide film is cured, it is extremely difficult to rework. Any mishap during film processing can lead to a wafer or lot level scrap event. Hence, the qualification procedure of new equipment needs to be stringent to avoid any processing issues.

To meet the rigorous qualification standard set forth by the technical team at the MEC, the new equipment qualification process was divided into multiple phases. The results at the completion of each phase were thoroughly reviewed before proceeding to the next phase. Table I presents the qualification phases' description, parameters, and substrate.

TABLE I
DIFFERENT PHASES IN THE QUALIFICATION OF THE NEW COAT TRACK AND CURE OVEN

S. No.	**Description**	**Parameters**	**Wafers**
1	Feasibility runs	• Backside cleanliness • Pre & post cure film thickness • Frontside film coating uniformity • Frontside defects	Blank GaAs mechanical wafers
2	Coating tools split runs	• Pre and post cure thickness variation	Blank GaAs mechanical wafers
3	Cure ovens split runs	• Post cure thickness variation • Oven temperature profile	Blank GaAs mechanical wafers
4	NMP soak	• Film thickness change	Blank GaAs mechanical wafers
5	Production lot split run	• RF device performance	Production wafers

During Phase 1 of the qualification process, initial feasibility runs were performed on blank GaAs mechanical wafers. These runs were used to dial in a recipe on the new polyimide coat track and new cure oven per the specifications in the technical datasheet. A coat recipe and a cure recipe were fine-tuned in the Phase 1 runs to meet a film thickness and uniformity specification set by the design team. Multiple other process improvements were made including backside cleanliness and polyimide coat uniformity. This was achieved by making changes in polyimide dispense, arm positioning, spin speed, and cure temperature profile.

During Phase 2 of the qualification process, ten blank GaAs wafers were run in the new coat track (C&D Track) and the POR track each. Pre-cure thickness was measured on nine points on each wafer. The box plot generated during an analysis of the data is shown in Figure 2. The wafers were then cured in the POR cure oven. Post cure thickness data was compared using JMP Software. The box plot from the post cure thickness analysis is shown in Figure 3.

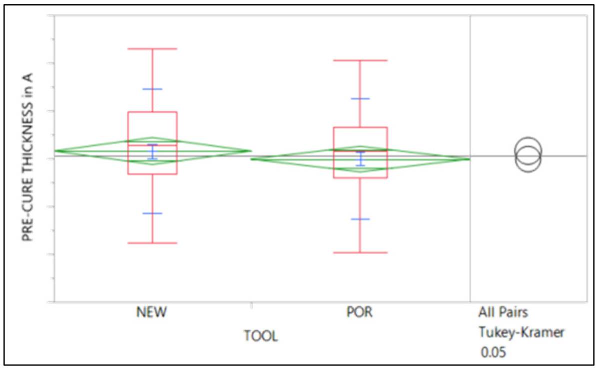

Fig. 2. A plot showing pre-cure thickness comparison between **the coating tools** (New vs POR)

During Phase 3 of the qualification process, twenty blank GaAs wafers were coated using the POR coat track. The pre-cure thickness was measured on nine points per wafer. Half of these wafers were then cured using the POR cure oven. The other half were cured using the new cure oven. Post cure thickness data was compared using JMP as shown in Figure 4. Temperature was measured and the data was plotted for the duration of the cure run in both the cure ovens as shown in Figure 5.

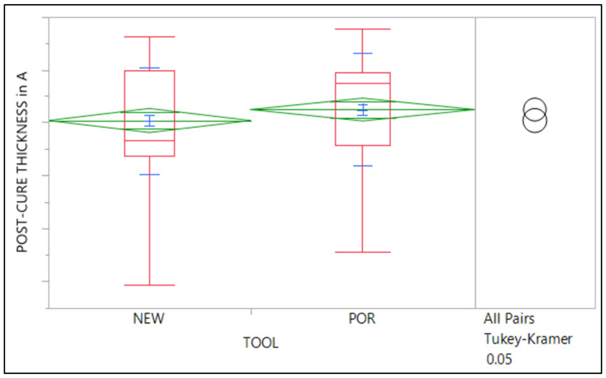

Fig. 3. A Post-cure thickness data comparison plot between **the coating tools** (New vs POR)

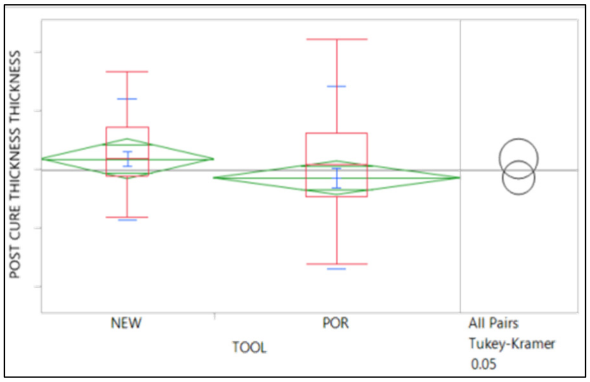

Fig. 4. A Post-cure thickness data comparison plot between **the cure ovens** (New vs POR)

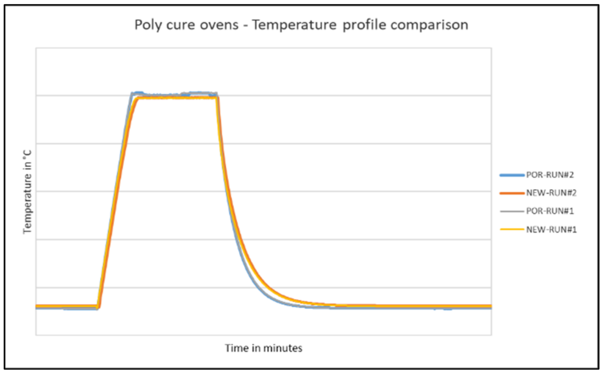

Fig. 5. A temperature profile of POR vs new cure oven

During Phase 4, an NMP soak was used as a test to evaluate if the polyimide film was fully cured. When placed in an NMP bath for an extended period of time, an uncured polyimide film dissolves. An NMP soak test was performed for cured films on wafers used in Phase 2 and Phase 3. After wafers were soaked in an NMP bath, a film thickness was measured. A difference in the film thickness was analyzed to determine if the cured film was swollen as a result of the soak. Thickness difference between post cure and post NMP soak film were not statistically significant. The thickness difference was within an error margin of the film thickness measurement tool. An analysis of test data confirmed that polyimide films from both the new and the POR cure ovens were cured sufficiently.

During Phase 5 of the qualification process, production lots were split to run with the new equipment and the POR equipment. Along with each production lot, mechanical wafers were run to measure a pre-cure and a post cure thickness. Within each lot, half of the wafers were run with the POR coat track (for coating step) and the POR cure oven (for the cure step). The other half of the wafers were run with the new coat track and the new cure oven.

The production wafers were electrically tested (at the end of the fabrication process) to evaluate a MMIC device performance. A MMIC RF performance was compared on the production split wafers using standard device testing techniques and equipment. For electrical on-wafer testing, DC breakdown, small signal parameter, and large signal parameter data was collected. Figure 6 shows a performance comparison of one such electrical test parameter. A variation in the S21 magnitude (dB) is plotted against an increase in frequency (GHz). Figure 6 has S21 data overlaid for the production wafers run with the new equipment and the POR equipment.

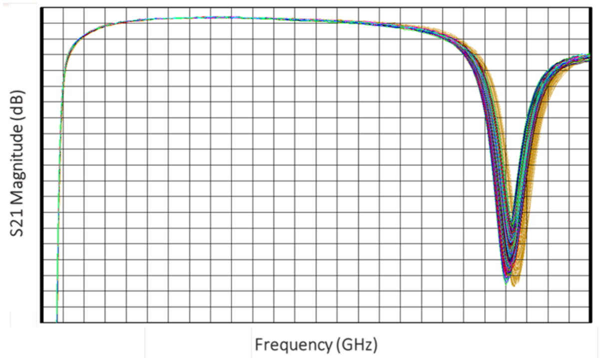

Fig. 6. A S21 magnitude (dB) plotted against Frequency (GHz) for the production wafers run with the POR equipment and the new equipment.

RESULTS AND DISCUSSION

An analysis of the data was performed using JMP, Microsoft Excel, and Minitab software packages. Data from pre-cure, post cure, and post NMP soak thickness were compared for the wafers used in Phase 2 to Phase 5. A null hypothesis was defined. It stated that polyimide film thickness for different conditions (pre-cure, post cure, and post NMP soak) were similar when the POR tools and the new tools were used. This null hypothesis was tested using thickness data collected in different qualification phases. An analysis of the data yielded a p-value which was compared with an α value of 0.05. Table II shows p-values received from an analysis of polyimide film thickness data in different qualification phases. Based on the p-values in Table II, it can be concluded that there isn't enough evidence to reject the null hypothesis. Thus, polyimide film thickness pre-cure, post cure, and post NMP soak was statistically similar.

TABLE II

THE P-VALUES OF THE PRE AND POST CURE THICKNESS DATA COMPARISON FOR THE PHASES OF QUALIFICATION

Phase No.	Description	Pre-cure Thickness	Post-cure Thickness	NMP soak thickness
2	Coating tools split runs	0.3927	0.1943	n/a
3	Cure ovens split runs	n/a	0.1494	n/a
4	NMP soak	n/a	n/a	0.4782
5	Production lot split run	n/a	0.2212	n/a

The measured temperature data was plotted for the duration of the cure run in both the cure ovens as shown in Figure 5. The temperature profile faithfully follows the POR cure recipe which was programmed in the new cure oven during Phase 1. An analysis of the temperature data using the JMP software showed no statistical difference in cure temperature variation during the run. Thus, the polyimide film cure process for the new programmable cure oven is the same as the POR cure oven.

On wafer electrical testing data was compared for the new equipment polyimide process with the POR equipment polyimide process. The collected data for various testing parameters such as DC breakdown, small signal parameters, and large signal parameters were analyzed. An analysis of the test data showed no statistically significant difference for both the POR and the new equipment polyimide process. An electrical test yield was satisfactory and comparable in both cases.

Reliability testing on the MMIC devices fabricated using the new equipment polyimide film process is underway. Initial reliability test data shows stable and comparable performance.

CONCLUSIONS AND NEXT STEPS

To increase throughput and create redundancy, new polyimide film processing equipment – a coat track (C&D) and a programmable cure oven (CascadeTek) were installed at the MEC. Qualification of this new equipment was divided in five qualification phases. The results from each phase showed a comparable performance between the POR polyimide film process and the new equipment process. There is no statistically significant difference between the new equipment polyimide film process data and the POR equipment polyimide film process data. The electrical testing data on the production wafers also didn't show a statistical difference in performance of the devices. Based on data, the new equipment– coat track (C&D) and the programmable cure oven (CascadeTek) are fully qualified to use for production lots.

The next step in the project is to evaluate the feasibility of a photodefinable polyimide process to reduce the cycle time by eliminating the etch step after NPPI film processing. Additionally, work is ongoing to evaluate the interchangeability of the tools.

ACKNOWLEDGEMENTS

The authors would like to thank the MEC-AMP Center Operations, the Equipment, and the Integration team for all their support. The authors will also like to extend a special thank you to Kanin Chu and Michael Ashman for their help and support.

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ACRONYMS

IC: Integrated Circuit
POR: Process of record
MEC: Richard Reed Microelectronic Center AMP Center
MMIC: Monolithic microwave integrated circuit
EBR: Edge Bead Removal
NMP: n-methyl-2-pyrrolidone
NPPI: Non-photodefinable polyimide