

Variable Frequency Microwave and Convection Furnace Curing of Polybenzoxazole Buffer Layer for GaAs HBT Technology

Jiro Yota, Hoa Ly, Ravi Ramanathan, Hsiang-Chih Sun, Dragana Barone, Thinh Nguyen, Kohji Katoh, Masayuki Ohe, Robert L. Hubbard, and Keith Hicks

Abstract—Photosensitive polybenzoxazole (PBO) film has been used in GaAs heterojunction bipolar transistor (HBT) technology for stress buffer and mechanical protection layer applications. However, this film needs to be cured at high temperatures for a long period of time in order to obtain its desired excellent material characteristics. High-temperature curing can result in degradation to the electrical characteristics and performance of the underlying GaAs devices due to limited thermal budget. In this paper, we have characterized the effects of curing the PBO film on GaAs HBT wafers using a conventional convection furnace and using a variable frequency microwave (VFM) furnace. The results show that a VFM cure can achieve similar excellent physical, mechanical, thermal, and chemical material characteristics at a lower curing temperature and in a much shorter time, as compared to convection furnace curing, therefore resulting in minimal GaAs device degradation. Based on these results, an optimum curing condition using the VFM method can be obtained that satisfies both stress buffer layer material and device requirements for GaAs HBT technology.

Index Terms—Buffer layer, convection curing, GaAs, heterojunction bipolar transistor (HBT), polybenzoxazole (PBO), polymer, variable frequency microwave (VFM) curing.

I. INTRODUCTION

POLYMER dielectrics have been widely used in the microelectronics industry for various applications. They are utilized in both front-end and back-end semiconductor processing, including as interlevel dielectric, redistribution layer, final passivation, stress buffer layer, and as encapsulants in chip-scale and wafer-level packaging [1]–[9]. Some of these polymers include parylene, polyimide, benzocyclobutene, and polybenzoxazole (PBO). These polymers have many properties that are desired and required for many of the applications mentioned above, including excellent dielectric, chemical, and mechanical characteristics. In order to achieve these characteristics and good thermal stability at high temperatures, most of these polymers have to be cured for a long amount of time (3 h or longer) at high temperatures (300 °C or higher) [10]–[16]. The lengthy

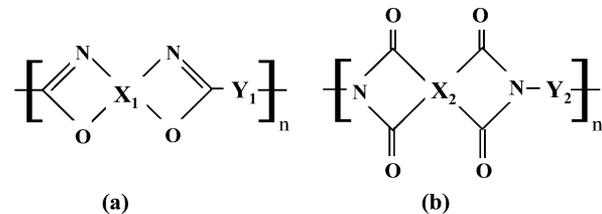


Fig. 1. Example of a monomer of (a) PBO and (b) polyimide with its polar C = O bonds, and with X_1 , Y_1 , X_2 , and Y_2 being aliphatic and/or aromatic parts of the monomers.

high-temperature cure requirements can significantly degrade the performance of many semiconductor devices [11]–[20].

PBO is a group of materials that is preferred and has become the polymer of choice for many thin-film applications recently [11], [21]–[25]. It has the advantage over other polymer films due to its functional group that does not have the polar carbonyl group (C = O), unlike polyimide films [11], [12], [26], [27]. Fig. 1 shows an example of a monomer of a PBO and how it differs from that of a polyimide. The absence of a carbonyl functional group in the PBO polymer prevents the formation of a hydrogen bond between the polymer and water, therefore resulting in less water absorption in the film. Additionally, PBO material is known for its excellent thermal stability and thermo-oxidative resistance, and can be used in and is compatible with various front-end and back-end assembly applications [11], [21]–[25], [27]. The material is also easily processed and with a photosensitizer will act as a photoresist or hardmask during etching, as has been shown with other photosensitive polymer materials [4], [9], [28], [29]. Furthermore, the developer that is usually utilized with this photosensitive PBO is tetramethyl ammonium hydroxide (TMAH) in water, an environmentally benign aqueous solution.

PBO can be cured at various temperatures and times, and this curing condition determines the final electrical, chemical, and mechanical material characteristics. During the curing process, cyclization and crosslinking of the PBO material occurs. PBO cyclization is the reaction in which the ring closure in the PBO precursor occurs to form the cyclic PBO polymer, while crosslinking is the reaction in which adjacent PBO polymer chains react and are bonded together. There are multiple methods to cure a PBO material. These include the conventional convection or diffusion curing, which are usually performed in a furnace under vacuum conditions or with flowing N_2 and/or other gases. However, most of these

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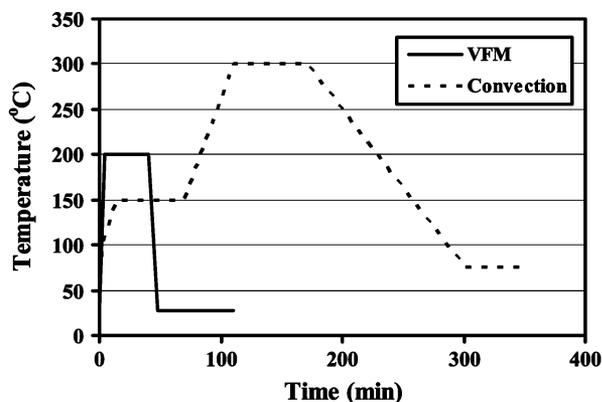


Fig. 2. Typical cure temperature–time profile of polymers using VFM and convection furnace methods. Highest curing temperature and curing time varies depending on the polymer, thermal budget, process, and application requirements.

methods are very lengthy in time, due to the long ramp-up and ramp-down steps required to heat up and cool down the furnace and the wafers inside.

Recently, a new curing method, variable frequency microwave (VFM) curing, has been developed to cure various polymers on silicon wafers [23], [30]–[36]. This method, which uses microwave at varying frequencies, can fully cure and completely imidize or cyclize various polymers, including PBO films on silicon wafers, at much lower temperatures and in a much shorter time, resulting in excellent material characteristics compared to the conventional furnace cure method. In this method, the polymer absorbs the microwave energy with varying frequencies, which also prevents any charging of metals in the devices as would be the case if single frequency microwave energies were used. The polymer's ability to absorb the microwave energy depends on its dielectric property, the frequency of the microwave, and the temperature of the material. The heating is volumetric throughout the polymer, as compared with the external thermal transfer in conventional convection heating.

Fig. 2 shows a diagram of a typical polymer cure temperature–time profile of the VFM curing method, as compared to that of the conventional convection curing method. As can be seen, in addition to being able to cure the polymer film at lower temperature, the VFM furnace cure requires a significantly shorter overall process time, as there is only minimal time needed for temperature ramp-up and ramp-down steps to heat up and cool down the wafers. This significantly shorter exposure time to the high temperatures of the wafers will then minimize any degradation of device performance.

In the VFM method, the microwave radiation acts at the molecular level by increasing the rotation of any dipoles in the backbone of the monomer, side chain, organic solvents, and additives in the cyclization, polymerization, and cross-linking processes [3], [23], [31], [32], [34]–[37]. The rotation of these dipoles in an uncured polymer then results in the significant and efficient heating of the bulk polymer. These microwave-excited dipoles, in general, are also the reaction sites where frequent collision, re-orientation, and reaction occur. Ring closures, cyclization, crosslinking, and imidization are, therefore, enhanced due to the addition of microwave energy. Additional dipoles

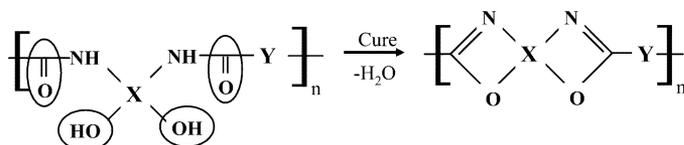


Fig. 3. Cyclization reaction of polyamide to PBO, with the reaction sites in the polyamide being circled and which are also the dipoles that are microwave-excitable. The X and Y are aromatic and/or aliphatic parts of the polymer.

in the polymer not involved in the curing reactions are also rotated which further assists in the overall curing efficiency. Fig. 3 shows the cyclization reaction of the polyamide, which is the PBO precursor, and its dipoles, which are $O-H$ and $C=O$ groups in the polymer. These two dipoles are excited by the microwave radiation, which assists and enhances the polyamide reaction and which results in ring closure to form the PBO polymer.

In this study, we have used a photosensitive PBO film as a stress buffer layer and mechanical protection for GaAs heterojunction bipolar transistor (HBT) technology. In semiconductor processing, the buffer layer should have good physical, mechanical, chemical, electrical, and thermal characteristics, and should be compatible with subsequent processing, including back-side wafer process steps, such as wafer thinning and scribe and break, and assembly process steps, such as die-pick and attach, wirebonding, and mold compound application [1], [4], [13], [26], [28], [38]. In all of these cases, the material used for the buffer layer also has to be stable and be compatible with the materials used in the above processes, including wafer crystal bond material, mold compound, epoxy, and the chemicals used in these processing steps, such as acetone.

The stress buffer layer is typically placed on top of the final passivation layer, which usually is plasma-enhanced chemical vapor deposition (PECVD) silicon nitride (Si_3N_4). The silicon nitride final passivation layer is usually moisture resistant, hard, rigid, and dense, has high stress, and can easily crack [7], [39]–[42]. The silicon nitride film will conformally cover the underlying GaAs device and interconnect topography. The addition of the PBO buffer layer will relatively planarize this silicon nitride surface with topography and will act as stress relief between the die and the package. It will also act as an environmental protection layer against moisture, and as a mechanical protection layer to the underlying devices, and minimize any topography-related damage caused by subsequent processing steps.

The use of this PBO film as a buffer layer, however, will add a process that requires a thermal processing step in the fabrication. In many GaAs HBT processing technologies, the highest processing temperature is $300^\circ C$ [15]–[20]. The thermal budget is limited due to the metallization materials used, the GaAs epitaxial layer characteristics, and the dimension and thickness of the underlying devices. Any high-temperature processing may cause significant degradation to the GaAs device performance due to the reaction of the metals with, and gallium out-diffusion and arsenic evolution from the GaAs [11]–[20]. In this study, we have evaluated the curing of PBO buffer layer on GaAs HBT wafers using both conventional convection method and VFM curing method. Different curing conditions were performed and

the effects on the PBO physical, mechanical, and chemical characteristics were investigated, in addition to the electrical characteristics and device performance.

II. EXPERIMENT

The stress buffer dielectric film investigated in this study is a PBO material manufactured by HD Microsystems. This PBO film is a positive tone, photosensitive material and comprises the precursor, which is a polyamide, photoactive compounds and crosslinkers, in addition to solvents of propylene glycol monomethyl ether acetate and 4-butyrolactone. The photopackage in this system is sensitive to the typical broadband UV exposure between 350 and 465 nm.

The PBO film was coated on 100 mm diameter GaAs (100) wafers. The wafers are either bare GaAs wafers, or GaAs HBT device-patterned wafers that have been deposited with PECVD Si_3N_4 film as a final passivation layer. The GaAs HBT device wafers used are wafers onto which multiple GaAs epitaxial layers with different thicknesses, and dopant types and concentrations were grown. The GaAs devices, including the HBT and other active and passive devices, and interconnections were fabricated using a GaAs HBT technology utilizing various metals and dielectrics deposition and patterning process steps. The metallization materials used to form the contact layer stacks for the emitter, base, and collector of the HBT transistors, include Au, Ge, Ti, Pt, and Ni. These contact metal stacks form Ohmic contact with the underlying GaAs epitaxial layers after alloying.

The bonding pad and street opening was performed using a single-mask approach. In this method, the photosensitive PBO is exposed and developed, and is used as a hard mask or photoresist during a subsequent Si_3N_4 final passivation etch to open the underlying bonding pads and street. After the etch, this PBO film is left on the wafer surface, and this remaining film will function as mechanical protection and stress buffer layer. The develop process step of the PBO material was performed in an aqueous solution of TMAH.

The PBO curing was performed after the expose and develop process steps. Both the conventional convection and the VFM methods were evaluated. The convection furnace cure was performed at temperatures ranging from 200 °C to 300 °C and with curing time from 30 to 60 min under a nitrogen atmosphere. The VFM cure was performed using a Lambda Technologies Microcure MC2100-700 system. Irradiation in air was performed with power ranging between 0 and 500 W, with temperatures ranging from 200 °C to 300 °C and with curing time of 15 to 90 min. The frequency ranges from 5.85 to 7.0 GHz with a step scan time of 100 ms each sweep of the 4096 scanned frequencies, providing a time-averaged uniformity in energy distribution throughout the cavity, and therefore eliminating the non-uniformities in temperature that occur in the traditional single frequency systems [31], [32], [35], [36]. The curing time and temperature is defined as the length of time the wafers were exposed to that particular highest set temperature. It does not include the ramp-up and ramp-down steps to heat up and cool down the furnace and the wafers, which are typically 3–4 min for the VFM cure method and up to 4 h for the convection cure method.

After cure, the exposed Si_3N_4 on the device wafers was then etched in a SF_6 —and oxygen-based gas chemistry to open

the bonding pads and streets, before electrical testing of the devices was performed. The front side of the device GaAs wafers was then bonded to sapphire plates using wafer crystal bond material dissolved in acetone, after which the back side of the wafer was thinned by grinding. During this back-side wafer processing, the back side via patterning was also performed. The wafers were then de-bonded by dissolving the crystal bond in acetone to separate the wafers from the sapphire plates. After de-bonding, the wafers were then singulated into dies by scribing and breaking. During these steps, the wafers and dies were inspected optically for any issues that may occur during the back-side processing steps, including whether the PBO on the wafers is compatible with back-side processes and is chemically resistant against acetone.

Multiple material analyses were performed in order to characterize the PBO film on the GaAs wafers. Fourier transfer infrared (FTIR) analysis was performed using a Shimadzu FTIR-8300 system to determine the degree of cyclization of the PBO films before and after curing. The glass transition temperature (T_g) was obtained by thermomechanical analysis of the films using a Seiko TM/SS6000 system. The T_g is defined as the inflection point in a temperature-displacement curve, and is used to characterize the physical, thermal, and mechanical quality of the different cured PBO films. The temperature is measured from 30 °C to 420 °C, and the rate of temperature increase is 5°C/min, with a load of 10 g. The accuracy of the results is approximately ± 2 °C.

The curing can affect the electrical performance of GaAs devices, as the metallization materials and the epitaxial layers used can react and degrade with increasing temperature. For electrical characterization, the contact resistance R_c of the emitter, base, and collector of the HBT is measured. Any increase in the electrical resistance of the contacts will result in the degradation of the device performance. The contact resistance is obtained using a typical transmission line model (TLM) and using contact chain test structures [15], [43]. The TLM technique test structures use a single contact, while the contact chain test structures comprise a string of contacts in series. The R_c obtained from a device test structure on a wafer with PBO is then compared to the R_c obtained from the same device test structure on a reference wafer with only the Si_3N_4 final passivation layer, without the PBO buffer layer.

III. RESULTS AND DISCUSSION

A. FTIR Analysis

The degree of cyclization of the PBO can be obtained from the FTIR spectra of the film. It is calculated from the peak height of the C–N stretch at 1539 cm^{-1} and of the C = O stretch at 1651 cm^{-1} of the spectra of a film obtained after cure at a particular condition, and compared to the peak height before cure, and that of a completely cured film. The complete equation is shown

$$\text{Degree of Cyclization}(\%) = [1 - \{(I_t/I_{100})/(I_0/I_{100})\}] * 100 \quad (1)$$

where I_t is the peak height of the PBO material after curing at a certain condition at either 1539 or 1651 cm^{-1} , I_{100} is the

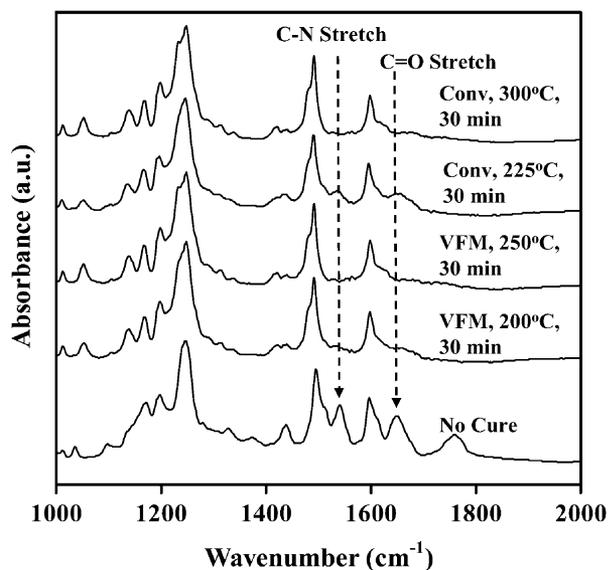


Fig. 4. Infrared spectra of the PBO films coated on GaAs wafers before cure, and after cure using VFM and convection methods at various conditions.

peak height of the film with 100% cyclization, and I_0 is the peak height at 0% cyclization. A 100% cyclization is obtained from the PBO material fully cured at 300 °C for 60 min, and 0% cyclization is obtained from PBO material as-coated, before the cure. In order to minimize the error due to interference and to obtain more accurate results, the degree of cyclization of both peaks at 1539 and 1651 cm^{-1} is calculated, and the average of these two numbers is taken as the actual degree of cyclization of the PBO material.

Fig. 4 shows some selected infrared spectra of PBO film on GaAs wafers before cure and after cure at various conditions using both VFM and conventional convection furnace methods. The spectra show the changes occurring for both the peaks of C–N and C = O stretches at 1539 and 1651 cm^{-1} , respectively. As the cyclization progresses, the smaller the C–N and C = O peak heights become. When the cyclization of the PBO is complete (or 100% degree of cyclization), there is no significant difference between the spectra of the films cured by both the VFM and the convection furnace methods. Using the VFM method, no peaks associated with the C–N and C = O stretching frequencies are observed after curing at 250 °C for 30 min. For the convection furnace method, the peaks completely disappeared after curing at 300 °C for 30 min.

Figs. 5 and 6 show the degree of PBO cyclization on GaAs wafers as a function of cure temperature and cure time, respectively, for both the VFM and convection cure methods. For both curing methods, the degree of cyclization is dependent on the PBO curing temperature. The data show that the degree of cyclization decreases as the PBO curing temperature is reduced. As discussed earlier, the VFM cure method will achieve the same degree of cyclization at a lower temperature and in a shorter time than the convection furnace method. A VFM curing condition of a temperature of only 250 °C for 30 min results in complete cyclization of the PBO film. However, using a convection cure method, this same complete cyclization can only be achieved when curing at a temperature of at least

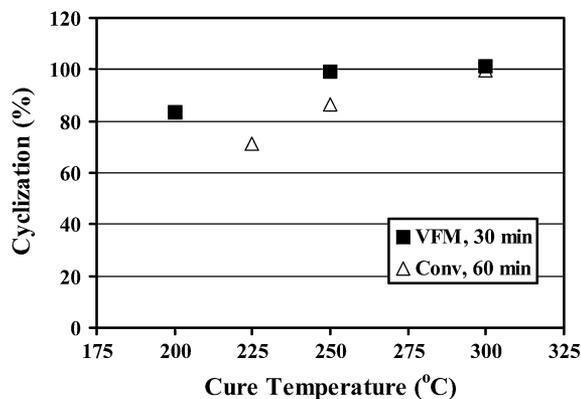


Fig. 5. Degree of cyclization of the PBO on GaAs wafers cured using VFM and convection methods for two different cure times, as a function of curing temperature.

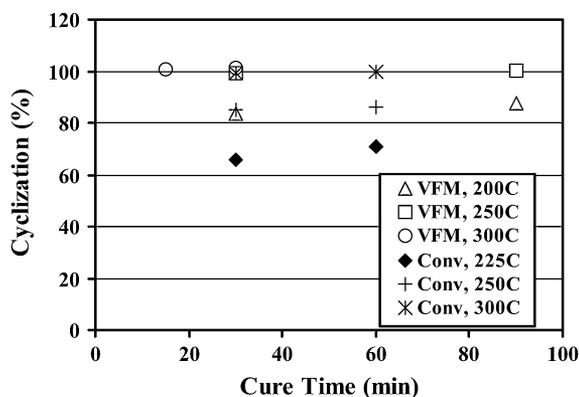


Fig. 6. Degree of cyclization of the PBO on GaAs wafers cured using VFM and convection methods at various curing temperatures, as a function of curing time.

300 °C for 30 min. Furthermore, for films that are not fully cyclized and cured using both methods, the shorter the curing time, the lower the cyclization degree.

B. Glass Transition Temperature (T_g) Analysis

The glass transition temperature (T_g) is one of the most important property of all polymers. The T_g of a material is the temperature below which molecules have little relative mobility. For polymers, it is the temperature below which they become rigid and brittle. Above the T_g , the polymer becomes rubbery and is capable of elastic or plastic deformation. Factors, such as heat treatment, molecular rearrangement, vacancies, induced strain and other factors affecting the condition of a material, could have an effect on this T_g . At the T_g , the hardness, volume, modulus and elongation of the polymer undergo a significant and drastic change. For these reasons, the glass transition temperature is collected in order to characterize the physical, thermal, and mechanical quality of the cured PBO films. A PBO film with higher T_g signifies a better quality film. The higher T_g film is in general thermally more stable, deforms at higher temperature, and is harder, all of which makes it suitable for a stress buffer and mechanical protection layer applications.

Fig. 7 shows the T_g of the cured PBO as a function of cure temperature for both VFM and convection cure methods on

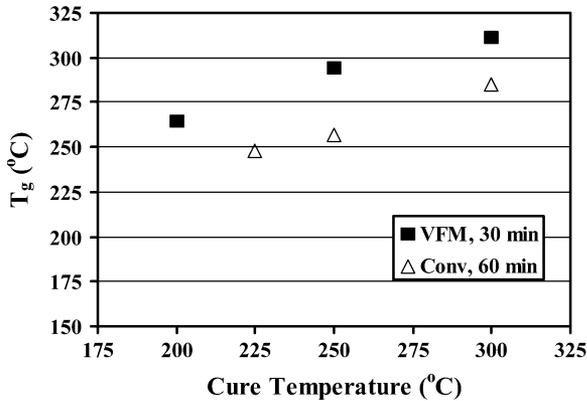


Fig. 7. T_g of the PBO on GaAs wafers cured using VFM and convection methods for two different cure times, as a function of curing temperature.

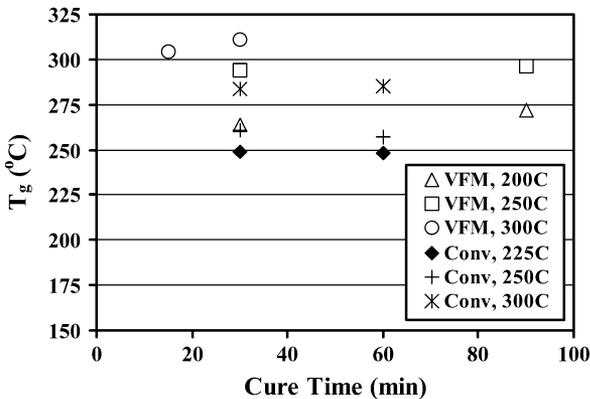


Fig. 8. T_g of the PBO on GaAs wafers cured using VFM and convection methods at various curing temperatures, as a function of curing time.

these GaAs wafers. As observed, the T_g of films cured using the VFM method is much higher than that cured using the convection method at the same temperature. This is true even with the conventional convection furnace cure time being twice as long as the VFM furnace cure time (convection furnace cure for 60 min at 250 °C versus VFM furnace cure for 30 min at 250 °C). Using the VFM method, the applied microwave energy causes the dipoles in the PBO material to rotate, which results in the rotation of the whole molecule itself and which in turn generates significant heat. This efficient molecular heating process increases the efficiency in cyclization and crosslinking of the PBO material, which results in higher T_g .

Fig. 8 shows the T_g of the cured PBO as a function of cure temperature and time for both VFM and convection cure methods on these GaAs wafers. The data show that, in general, for the VFM cured films, the T_g increases with increasing cure time, for the temperature range investigated. No such effect is seen on the PBO film cured using the conventional convection method, where the T_g did not change with time. Higher curing temperature increases this T_g , as expected for both the VFM and convection furnace cured films. However, the T_g of the VFM-cured PBO films is much higher than that obtained at the same curing conditions using the convection furnace.

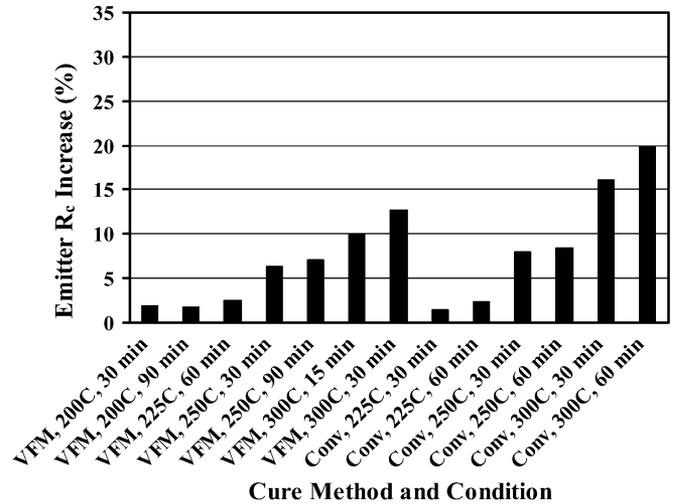


Fig. 9. Increase in the emitter R_c due to curing using both VFM and convection methods at various conditions.

C. Electrical Characterization

The curing process in semiconductor manufacturing can significantly affect the electrical performance of devices. This is especially true for GaAs HBT devices, in which many of the metals used to form the Ohmic contacts to the underlying GaAs are not thermally stable and are significantly affected by the GaAs/metal interface quality, GaAs epitaxial layer thicknesses, dopant types, and concentrations. High-temperature processing can result in Ga out-diffusion and metal diffusion from the contact metal stack into the GaAs, affecting the interface layer. This then degrades the contact quality, resulting in higher contact resistance, and therefore degrading the device performance.

Electrical characterization was performed by measuring the R_c of the emitter, base, and collector that forms the HBT. Fig. 9 shows the emitter contact resistance percent change (or percent increase or percent degradation) as a function of the various curing methods and conditions. The electrical resistance change of the contacts is obtained by taking the ratio of the R_c of a device with PBO cured using a certain method and condition, to that of a device processed without any PBO buffer layer. As can be seen, the R_c degrades with increasing curing temperature and time. However, the emitter R_c increase that is obtained using the VFM cure method is significantly less than that obtained using conventional convection furnace curing for the same curing temperature and time condition. This is caused by the shorter amount of time the GaAs devices were exposed to the high temperature, due to the minimal ramp-up and ramp-down times required by the VFM cure method.

Figs. 10 and 11 show the R_c percent increase or degradation of the base and collector, respectively, as a function of the curing method and curing conditions. As observed, there is a slight increase of base R_c with curing. However, there is no dependence on the different curing methods and conditions. This is expected since the base metal stack used and the underlying base epitaxial layer in this GaAs HBT technology is relatively stable thermally and is not significantly affected by curing. The collector, however, is significantly affected and its R_c change

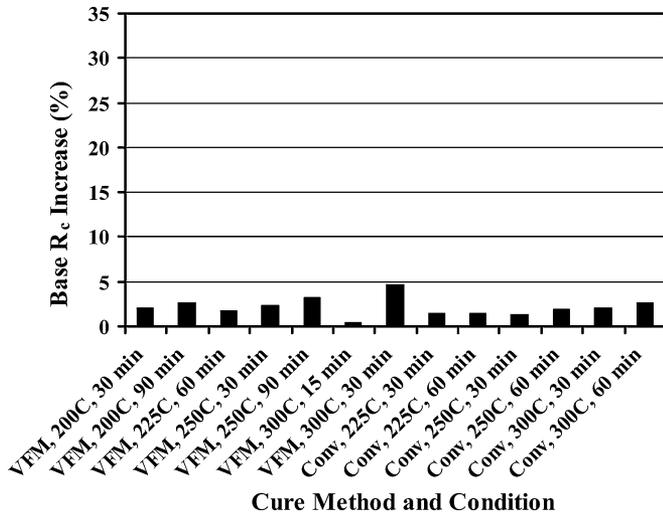


Fig. 10. Increase in the base R_c due to curing using both VFM and convection methods at various conditions.

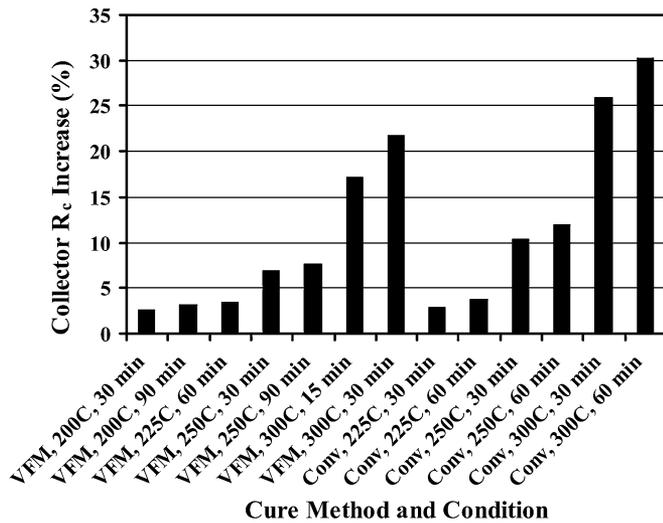


Fig. 11. Increase in the collector R_c due to curing using both VFM and convection methods at various conditions.

increases with increasing curing temperature and time. As with the emitter R_c , lower collector R_c increase is obtained with the VFM cure method, compared to the conventional convection furnace cure method for the same conditions. These results indicate that the minimal ramp-up and ramp-down time during VFM cure does not increase the R_c as much as that of the conventional convection cure and only minimally degrade the electrical performance of the devices.

D. Other Results and General Discussion

After the front-side GaAs wafer processing had been completed, including the PBO stress buffer layer process steps, back-side wafer processing was then performed, including wafer bonding onto sapphire plates, back-side wafer grinding and via patterning, and wafer de-bonding. During some of these steps, the wafer is exposed to acetone. It is known that some polymers, when cured insufficiently, can be attacked by acetone and can result in cracking. To evaluate the chemical

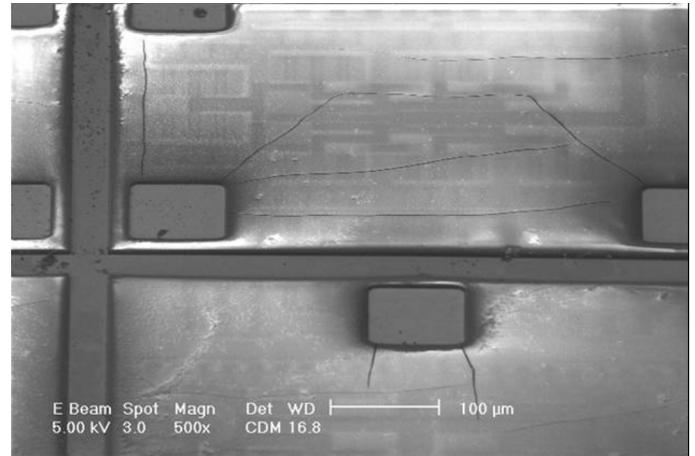


Fig. 12. Image of the cracks observed on GaAs device wafer coated with insufficiently cured PBO buffer layer when exposed to acetone during wafer back-side processing.

TABLE I
RELATIVE AMOUNT OF CRACKS OBSERVED ON THE PBO STRESS BUFFER LAYER WITH EXPOSURE TO ACETONE ON GaAs HBT DEVICE WAFERS AS A FUNCTION OF PBO CURING METHOD AND CONDITION

Cure Method	Cure Temperature (°C)	Cure Time (min)	Amount of Cracks
VFM	200	30	Large
VFM	200	90	Large
VFM	225	60	Small
VFM	250	30	None
VFM	250	90	None
VFM	300	15	None
VFM	300	30	None
Convection	225	30	Large
Convection	225	60	Large
Convection	250	30	Large
Convection	250	60	Large
Convection	300	30	None
Convection	300	60	None

resistance of the PBO material to acetone, we inspected the GaAs device wafers after back-side thinning and via formation for any chemical attack and cracks.

Fig. 12 shows an image of the typical cracks of the PBO buffer layer material on the GaAs die that is observed when the PBO that is insufficiently cured is exposed to acetone during back-side wafer thinning and via processing. Table I lists the results of the optical inspection and the relative amount of cracks observed on the PBO film on the wafers cured using VFM and convection furnace methods at various conditions. As can be seen, lower curing temperature and shorter curing time results in cracks observed on this PBO buffer layer. Using the convection furnace cure, cracks were observed on the PBO film when

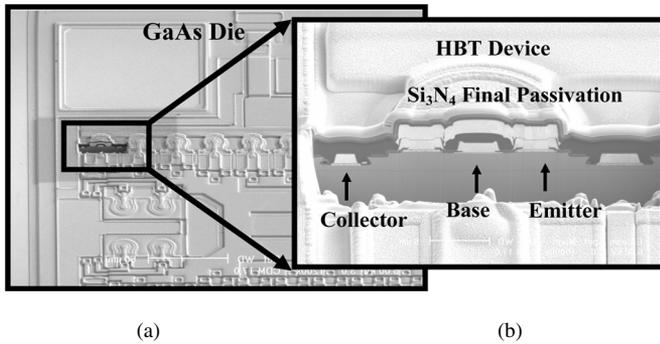


Fig. 13. Images obtained using SEM of (a) topdown of a GaAs die with only Si_3N_4 final passivation, without the PBO buffer layer and (b) cross section of the HBT showing the emitter, base, and collector regions.

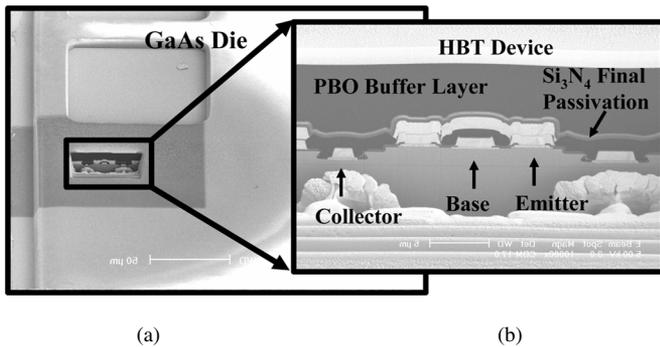


Fig. 14. Images obtained using SEM of (a) topdown of a GaAs die coated with the PBO buffer layer and (b) cross section of the HBT showing the emitter, base, and collector regions.

cured at $250\text{ }^\circ\text{C}$ for 60 min. However, as shown, no cracks were seen for VFM-cured wafers, even when cured at that same temperature of $250\text{ }^\circ\text{C}$ for a shorter time of 30 min. This is consistent with the FTIR and mechanical characteristics analysis which show that a higher cyclization degree and a higher T_g can be obtained at lower temperatures and in a shorter time when using the VFM method. These results further show that a PBO material, with good mechanical and chemical characteristics, can be used for GaAs HBT processing, with minimal degradation to the device performance, by curing the wafers using VFM furnace method.

Figs. 13 and 14 show the images obtained using scanning electron microscope (SEM) from the top down and cross sections of GaAs dies, showing the HBT without and with the PBO buffer layer on top of the Si_3N_4 final passivation layer. As can be seen, the buffer layer significantly planarizes the surface of the die. Fig. 15(a) and (b) shows the top down and cross-sectional SEM images of a GaAs die, respectively, without the PBO buffer layer and a typical defect that damages the Si_3N_4 final passivation layer and the underlying die, while Fig. 16(a) and (b) shows the top down and cross-sectional SEM images of how the PBO buffer layer helps mechanically protect the underlying GaAs die against defects, scratches, and particles.

Based on these results, a PBO film that has excellent mechanical, chemical, and electrical characteristics can be obtained using the VFM cure method. An optimum VFM cure condition of $250\text{ }^\circ\text{C}$ for 30 min will result in a cure process that has a

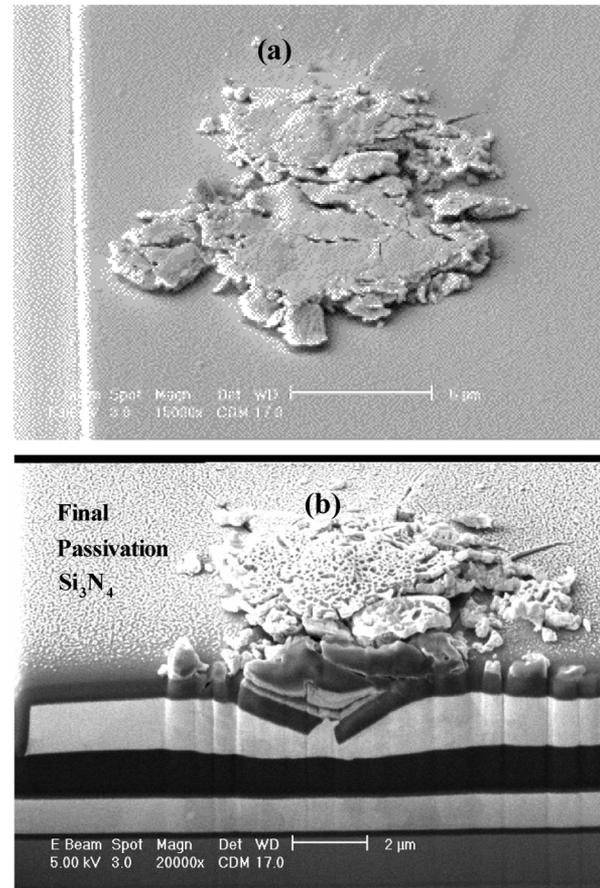


Fig. 15. Images obtained using SEM of (a) topdown and (b) cross section of a typical defect that damages the Si_3N_4 final passivation layer and the underlying GaAs devices, when there is no PBO buffer layer on top.

short overall processing time, and in a PBO film that can be utilized in and is compatible with GaAs HBT processing, with excellent material characteristics, and which results in minimal degradation to the GaAs devices. If the cure was performed using the conventional convection furnace curing, a processing condition of at least $300\text{ }^\circ\text{C}$ for 30 min is needed in order to have good mechanical and chemical characteristics. However, at this condition, the GaAs devices will be degraded significantly.

IV. CONCLUSION

We have evaluated the use of VFM and conventional furnace curing of photosensitive PBO film that is used as a buffer layer and mechanical protection on GaAs HBT devices. The results show that the VFM method cures the PBO material in significantly less time and at lower temperature than the conventional convection furnace cure, while achieving the same excellent mechanical and chemical characteristics, such as high degree of cyclization, high T_g , and high resistance to acetone. As a result, minimal GaAs device degradation was observed when cured using the VFM method, as compared to significant degradation seen when cured using the conventional convection furnace method. Based on these results, a PBO buffer layer film that has excellent material characteristics is obtained and is suitable for and compatible with GaAs HBT processing.

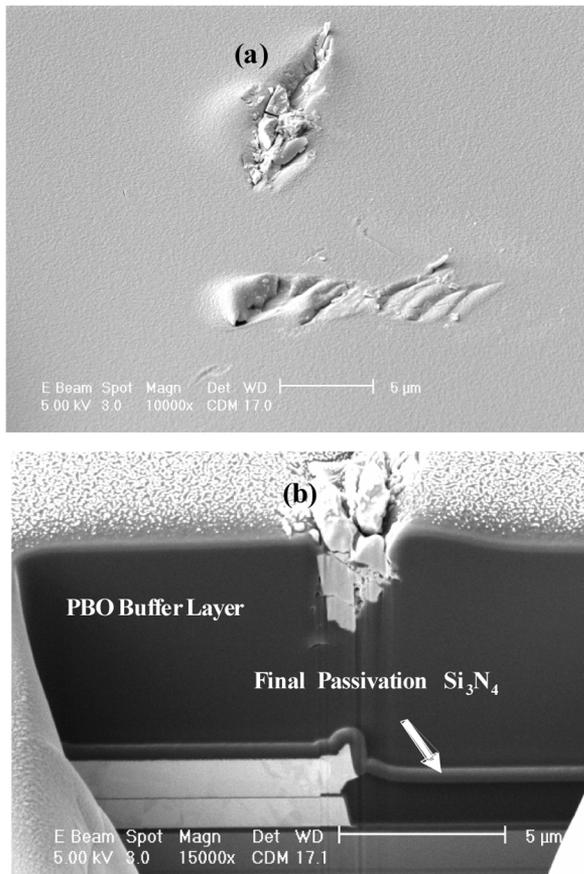


Fig. 16. Images obtained using SEM of (a) topdown and (b) cross section that show how the PBO buffer layer protects the underlying Si₃N₄ final passivation layer and GaAs devices from a defect protruding into the die.

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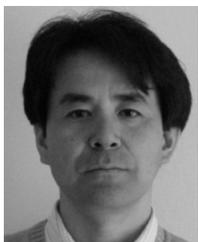
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