Cycle Time and Cost Reduction Benefits of an Automated Bonder and Debonder System for a High Volume 150 mm GaAs HBT Back-end Process Flow

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ABSTRACT

Wafer thinning is commonly employed during fabrication of silicon and compound semiconductor IC's to facilitate through-wafer via formation or otherwise reduce the profile of the finished device. For fragile GaAs substrates, wafers must be attached to a carrier substrate which supports the wafer during the thinning operation. In this paper we review the benefits of employing an automated tool-set for the bonding and subsequent debonding operations during the backend manufacturing process of 150mm GaAs HBT wafers. We compare the cycle time and cost benefits of the automated tools to a legacy time intensive and manual process. We also discuss the lessons learned in transferring the automated tools into volume production.

INTRODUCTION

The bonding of device wafers to temporary support carrier wafers is the standard method for supporting soon to be thin GaAs, GaN, SiC, InP, and Silicon substrates. Most, if not all, compound semiconductor devices require wafer thinning for form factor and heat dissipation, and thus need support for downstream processes steps which may include: photolithography, via etching, metal deposition, electroplating, or polymer passivation. GaAs wafer bonding solutions must satisfy several important requirements. The bonder and adhesive system must create a planar bonded couple that will ensure uniform wafer thinning. The adhesive system must also be thermally stable to survive temperature excursions encountered during grind, plasma etching, and metal deposition. Finally, the bonded couple should be easily separated without leaving behind any residues that would hinder subsequent packaging operations such as die attachment or wire bonding.

There are an abundance of adhesives available in the market [1-4] which use a standard chemical release process. Chemical release processes are mostly manual and need to use expensive perforated carriers, special fixtures, and a manual handling step to get the thin wafer (25-100um) to transfer to dicing tape. For a low through-put fab, a release time between 1 and 8 hours may not be an issue, but in high volume GaAs manufacturing an automated process is preferred [4].

In this paper we describe the production benefits of an automated 850 series wafer bonding and debonding system from EV Group (EVG) that utilizes a high temperature–stable (i.e., greater than 180ºC) adhesive, designed by Brewer Science [5,6]. The automated bonder performs coat, bake, and bond operations on a single tool, while the automated debonder automatically separates the thinned wafers, cleans off the wafer and carrier disk, and outputs the thinned wafer directly to a frame mount for subsequent dicing.

In contrast, the manual legacy bonding operations require two adhesive coat operations and a manual mounting step onto costly perforated sapphire carriers, while the manual demount requires time intensive solvent soaks and plasma cleans, followed by manual thin wafer handling by operators for frame mounting.

COMPARISON BETWEEN MANUAL AND AUTOMATED PROCESS

Bonding process comparison:

Anadigics' legacy bonding process utilizes a chemical release of the adhesive, necessitating the use of perforated sapphire carriers to allow for diffusion of the solvent during the debond process. Perforated sapphire carriers are expensive, have long lead times to procure, and suffer from higher breakage during processing and handling due to the presence of the perforations. In contrast, automated bonding and debonding tools utilize vacuum pick-up requiring the use of non-perforated sapphire or alternately glass carrier disks. These have the benefit of a 50% or greater cost savings, shorter fabrication times and reduced breakage rate.

Prior to mounting and grind operations HBT wafers complete front-end fabrication, receive nitride and overcoat protection layers, and complete electrical testing. In the legacy mounting process, operators coat wafers with a polymer planarization layer which must be oven cured. A second adhesive layer is then applied and is also oven baked. Operators then place the carriers and adhesive coated wafers onto a hot plate mounting station, which is sealed, and a vacuum applies pressure to bond the stack. The entire sequence of steps typically takes 3-4 hours for a cassette of 12 wafers.

In contrast, the EVG 850 TB bonder (Fig 1a. & 1b.) coats, soft bakes, and bonds a cassette of 12 wafers in approximately 70 minutes, shaving more than 50% off the cycle time and reducing the operator handling steps from 5 distinct operations to a single step of starting a recipe. The manual operations require the use of 3 distinct tool sets, which are consolidated into a single tool on the EVG system. Wafers bonded on the automated system have the added benefit of reduced voids in the adhesive layer and no seepage of adhesive out of the carrier perforations during subsequent thermal and vacuum processing. At the same time, these wafers meet all specs for low as-bonded bow and TTV, allowing for comparable performance during wafer thinning and back side via formation.

Figure 1a. EVG 850 TB Automated Bonder System

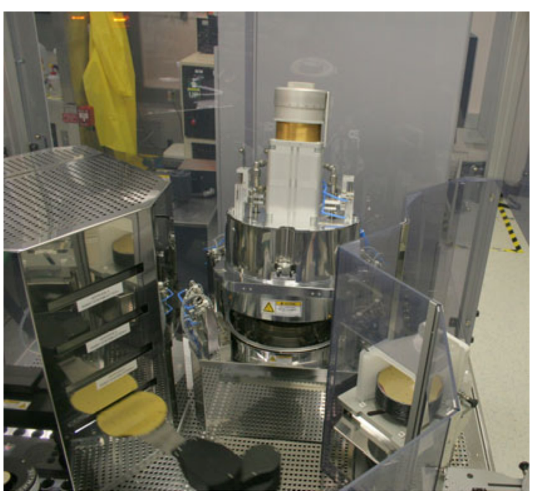

Figure 1b. EVG Bonder shown with a coated wafer exiting the hot plate on its way to be loaded into the bonder unit.

Debonding process comparison:

In the legacy demount operation, operators manually place thinned bonded stacks onto metal catch fixtures, which are then loaded into a cassette and immersed in a series of 4 heated and agitated solvent baths. Operators manually transfer the cassette of fixtures between baths, then to an oven for drying, and finally to an oxygen plasma clean for final residue removal. After cleaning, operators disassemble the fixtures and manually slide off the thinned wafers onto a frame mounting station. The individual clean steps can take 4 hours and require the use of 2 wet benches, an oven, a plasma cleaner, and frame mount station.

Rather than chemical dissolution, the EVG 850 DB debonder (Fig 2a & 2b.) utilizes a thermal slide off process to debond the thinned stack. A pair of heated vacuum chucks grips the carrier and wafer side of the bonded stack, and then slides the wafer off of the carrier. The thin debonded wafer is then transferred to a cleaning station that spins and dispenses a solvent stripping off the residual polymer adhesive. The cleaned wafer is subsequently transferred to an automatic frame mounting station and returned to a frame cassette ready for dicing.

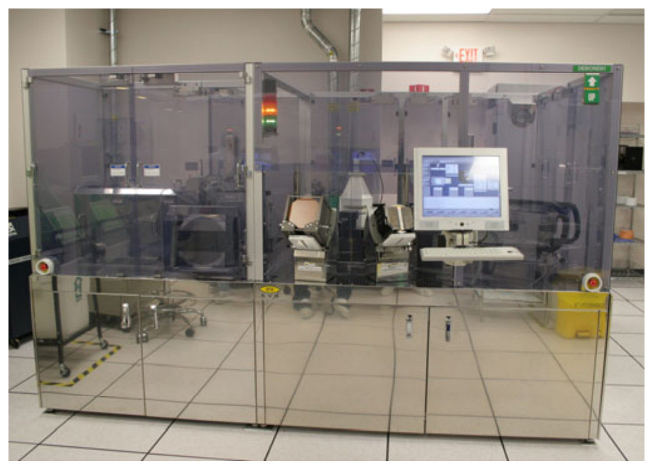

Figure 2a. EVG 850 DB Automated Debonder System

Figure 2b. Debonder with a wafer on the cleaning station at the left, and a bonded stack ready to be loaded into the debond chamber center.

While the wafer is frame mounted, the carrier is cleaned and returned to the send cassette. The automated system can debond, clean, and frame mount a cassette of 12 wafers in 80 minutes, which cuts the debond cycle time to a third, reduces the 5 tools required to one, and reduces handling steps from 7 to one. The automated process has the added benefit of reduced scrap due to wafer breakage. A comparison of both the legacy and EVG process can be found in Table 1.

Table 1. Process Comparison

	Manual Bonding	Automated Bonding	Benefit
Carrier Type	perforated sapphire	non perforated sapphire or glass	>50% cost reduction and 10X longer lifetime
Adhesive system	two layer adhesive	single coat adhesive	Source and control a single coating chemical as opposed to two
Bonding Operation	Coat planarization layer 1	Automated Coat-Bake-Mount	Reduces 5 steps to 1.
	Oven Bake		Reduces equipment set from three to a single tool (coat, oven, bonder).
	Coat adhesive layer 2		Reduced cycle time >50%, from 3-4 hours to 70 min.
	Oven Bake		
	Vacuum Bond		
Demount Operation	solvent soak 1	Automated demount-solvent strip-Rinse-Frame Mount	Reduces 7 operations down to1.
	solvent soak 2		Reduce 5 tools down to 1. (2 wet benches, oven,
	IPA soak 1 Water rinse		plasma clean, frame mount).
	Oven Bake		Reduce cycle time > 50%, from 4 hours to 80 minutes
	Plasma clean		
	Inspect		
	Frame mount		

TRANSFERRING THE AUTOMATED TOOLS INTO PRODUCTION

In principle, the concept of replacing a series of manual operations with an automated tool set that greatly reduces cycle time, opportunities for misprocess, and chemical usage is a winning one. However, in a production environment nothing is ever simple. The complexity of the finishing process is often overlooked, and process variations introduced from mount, grind, polish, or back side via formation can destroy a product just as it is nearing the end of its fabrication cycle. Thus, the importance of a methodical approach in validating the integrity of all of the finishing operations between the bond and debond operations has been at the core of the Anadigics philosophy to bringing these tools from factory acceptance all the way into production.

Bonder process differences:

The automated mounting introduces some important process differences from the legacy process it replaces. For example, the adhesive thickness of the bonded stack on the EVG tools is 10 µm thicker as compared to our legacy process. Though the original coat thickness of both processes is similar, on the legacy bond process the bulk of the adhesive is squeezed into the perforations of the carrier disk. In contrast, in the automated tool the non perforated disk encapsulates the full thickness of the adhesive that is spun onto the wafer. Reducing as-spun thickness is not viable since the adhesive layer needs not only to planarize the full topography, which can be close to 10 µm in height, but also to include an additional buffer layer of adhesive to allow for the slide off demount to occur without wafer damage. The thicker adhesive layer from the EVG process demands the recalibration of the grind and polish targets so that the final thickness of the wafer remains unchanged.

A second consequence of bonding with non-perforated carriers is that the bonded stack can have thicker adhesive in the wafer center, mirroring the coat thickness variation from center to edge. Optimization of the total thickness variation (TTV) of the bonded stack is important to ensure that the as-bonded wafer non uniformity is not transferred by the thinning operations into unacceptable variation of the final wafer thickness. For the EVG bonder this optimization can be achieved by adjustments of the force distribution in the bond head. During production the as-bonded TTV continues to be an important parameter to monitor to ensure that the bonding process does not drift.

Debonder process differences:

Just as in the bonder, the automated debond process is sufficiently different from the manual process to introduce concerns into the demount operation. In the automated tool the debond mechanism is a high temperature 175-200°C mechanical slide off, followed by a solvent rinse with a direct transfer of the cleaned wafer to a tape frame. The new process demands ensuring that no damage is imparted to the wafer from either the high temperature or mechanical stress of the slide-off, and that no adhesive residue remains that can affect packaging reliability. In the legacy process, although there is a frequent manual handling of the wafer, the solvent release is mechanically gentle and at a lower temperature, and the additional plasma cleans add margin to ensure that no adhesive residue remains.

An additional difference introduced by the automated bonder is an integrated frame mount station that utilizes a new dicing tape. Introducing a new frame mounting tape further adds to the complexity of the process release, requiring the full qualification of tape adhesion, expandability, ease of die picking, and tape storage longevity. Apart from process differences in bonding, demounting, and retargeting of the wafer thinning operations, the remaining finishing operations such as back side photo, via formation, or metallization remain unchanged.

Tool Qualification Data Collection:

Although many of the intermediate finishing operations remain the same, the automated finishing flow requires the approval of a rigorous change review committee. During the process transfer phase of the program, split lots were run using the legacy and new EVG finishing flows. Data was collected on hundreds of wafers measuring parameters such as: adhesive coat thickness target and uniformity, as-bonded TTV, deviation from grind target, grind TTV, post polish final wafer thickness, final wafer TTV, back side photo CD before and after etch, back side via electrical tests, debond process yield, and wafer cleanliness inspection. Following demount and frame mounting, wafers were diced by either laser or scribe and break tools and sent offshore for assembly and packaging.

At the assembly house the new tape was checked for the ease of die picking, and the integrity of back side metal adhesion. Further Tests, including die shear, ball lift, ball shear, and wire pull, were performed by the assembly house and at Anadigics to verify the mechanical strength of die attach, bond pad cleanliness and the strength of wire bonds. After offshore assembly, packaged parts received full electrical testing, and were evaluated for reliability through thermal cycling, high temperature operating life (HTOL), and highly accelerated stress testing (HAST).

Tool production transfer logistics:

Once parity between the legacy and the automated process is demonstrated, the logistics of running the new finishing flow have to be in place to allow for a smooth ramp to production. Communication between technology development, production, maintenance, and support groups such as IT, is critical to ensure a smooth transition. On the IT side, electronic travelers have to be updated with switches to allow certain products to utilize the new finishing flows. The flows have to accept SPC data entry, as well as monitor the quantity of wafers run to automatically schedule preventative maintenance shutdowns. Production has to ensure that all documentation and protocols are in place, and provide operator training. Additionally, the maintenance group needs to have sufficient training to respond to common tool errors to ensure high tool up time.

CONCLUSIONS

The authors have described how the backside cycle time, operator handling, and overall cost were reduced at Anadigics by using a fully automated bonding, debonding, and tape frame process. The cycle time for a typical lot of wafers through the entire backside process was reduced 66% from 7 hours to 2.5 hours at bonding and debonding, and operator handling was reduced from 12 total individual steps in the manual process to 2 steps in the automated process. Additionally, the use of non-perforated sapphire reduced the consumable cost by 50%. The enabling adhesive and remover by Brewer Science and automated equipment by EVG provide a robust and cost-effective solution for thin wafer handling.

We also describe the lessons learned from transferring the tools to production. Differences in adhesive thickness differences and as-bonded TTV required optimization of the bonding process and re-adjusting thinning thickness targets. For the debonder the impact of debond stress, temperature, wafer cleaning, and new dicing tape needed offshore packaging, electrical, and reliability testing to verify that the automated process had not impacted the device quality. Furthermore, the logistics of tool transfer to production is discussed.

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ACRONYMS

HBT: Heterojunction Bipolar Transistor
TTV: Total Thickness Variation
HAST: Highly Accelerated Stress Test
HTOL: High Temperature Operating Life