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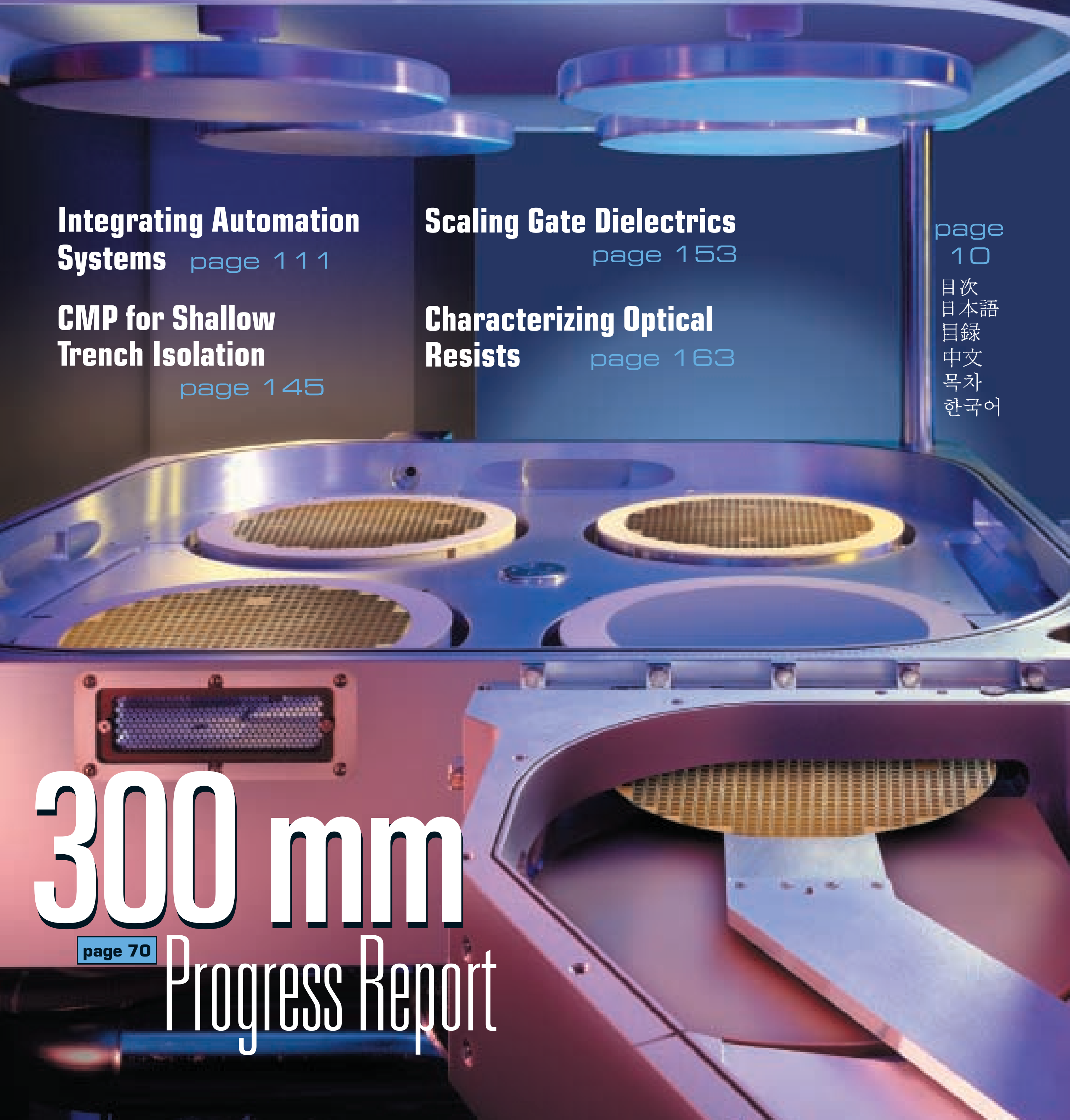

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Carrier Replacement Improves Yield and Tool Availability

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Worldwide, many semiconductor fabs are producing advanced chips using outdated wafer-carrier technology (cassettes). At IBM, we attributed excessive dimensional variation over time and foreign material (FM) directly to our older 200 mm carbon-powder-filled polypropylene (CP/PP) carriers and storage boxes. Carrier dimensional variation produced wafer scratching and breakage, increased tool calibration times, and ultimately reduced yield and tool throughput. Foreign material, visible on tool surfaces, stages, and work-in-progress (WIP) racks, was producing wafer-level defects. Engineers estimated that 20% of all FM defects were related to black powder (from the carbon-powder-filled carriers and boxes). In addition, carrier particles were directly causing wafer defects, also negatively affecting yield.

Although the carrier and box problems were obvious to IBM fab personnel, a cost justification was required for management. IBM put a great deal of effort into determining yield loss, estimated at 1-2% on selected products. The throughput loss was not estimated as part of the initial justification, even though we expected some improvement.

Once justified, IBM was able to obtain the financial support needed to upgrade the carriers and boxes. IBM engineers then evaluated many commercially available carriers and boxes, and

1. The dimensional stability and contamination properties of wafer carriers and boxes affect the yield and tool availability of production fabs. (Source: Entegris)

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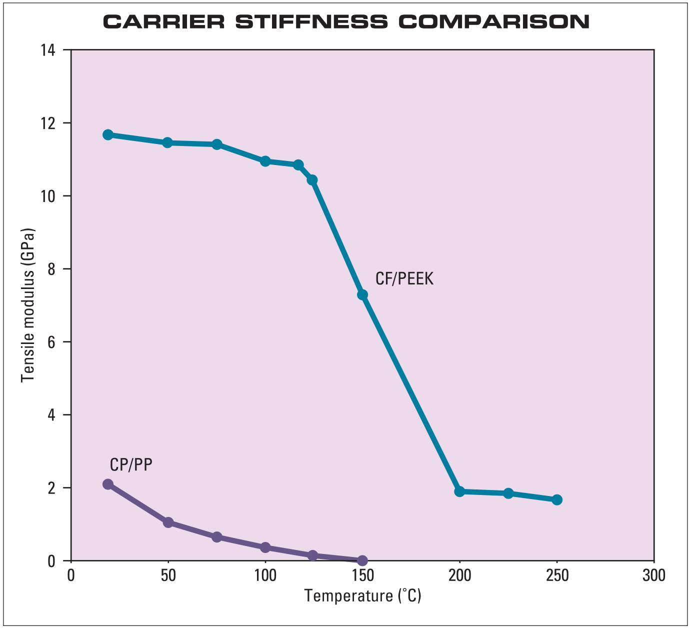
At a Glance

After tracing a 1-2% yield loss to wafer carrier dimensional variation and contamination, IBM evaluated the performance of many commercially available boxes and carriers, and selected a PEEK carrier and polypropylene box combination for significantly better dimensional stability and contamination levels. Through logistics planning, tool preparation and a strong implementation strategy, a joint IBM/Entegris team was able to replace 17,000 carriers within 18 hours. With benefits of yield gain and improved tool availability, the carrier and box conversion easily met IBM's ROI requirements.

finally chose a product combination provided by Entegris (Fig. 1). Due to the critical nature of the change to a new carrier and box in such a large fab, a detailed conversion plan was needed. IBM and Entegris formed a team to plan and execute the conversion. The plan, which covered all logistics and tool readiness, took several months to develop and implement. Thorough preparation allowed us to complete the conversion in less than 18 hours, with minimal disruption to the fab. Upon conversion, the fab realized significant improvements in yield and tool availability.



2. The PEEK material's tensile modulus is >5× that of carbon-powder-filled polypropylene (CP/PP), resulting in better dimensional stability.

Carrier and box selection

IBM engineers judged carrier and box performance based primarily on the material's ability to maintain dimensions over time, and its abrasion resistance to various surfaces. The new carrier and box also had to offer equal or better outgassing properties, low or lower extractable anion/cation contamination levels, and equal or better thermal capabilities. IBM chose a carbon-fiber-filled polyetheretherketone (CF/PEEK) carrier primarily for its quality of dimensional stability, high abrasion resistance and low particle generation.

This particular model of carrier also had the desired compatibility with the existing toolset and the capability of handling the necessary temperatures, leading to shorter wafer-cooling times and increased throughput. A CF/PP box was selected for its low particle levels and compatibility with the existing automated material-handling system. This box, in combination with the CF/PEEK carrier, also generated low particle levels.

Dimensional characteristics

Maintaining physical dimensions over time is critical to minimizing particle generation from wafers rubbing against the carriers during pick-and-place operations. In severe cases, wafer scratching and breakage occurs during wafer moves. Dimensional changes also cause tool interruptions, requiring the assistance of an operator to restart the tool.

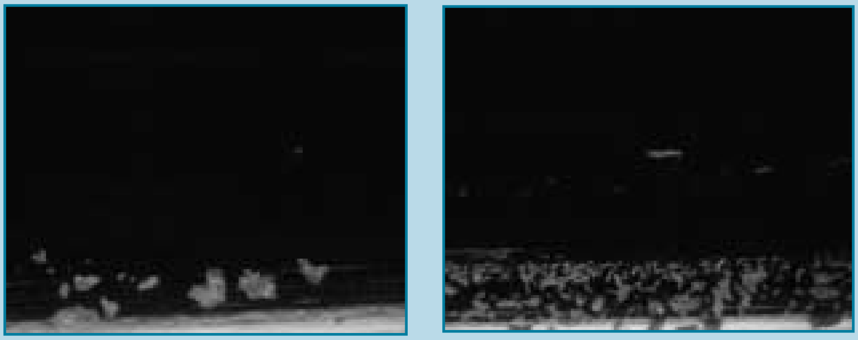
To account for the dimensional variation in the large population of carriers, long tool teaching and calibration times were required at IBM. The magnitude of the problem caused by dimensional variation in the old carriers was so great that some tools had special fixtures for the input/output stages that actually clamped the carriers to create a predictable wafer location.

Various tests were performed to predict the dimensional performance of carriers over time. In one test, a constant load was applied to carriers and dimensional changes over time then were monitored.[1]

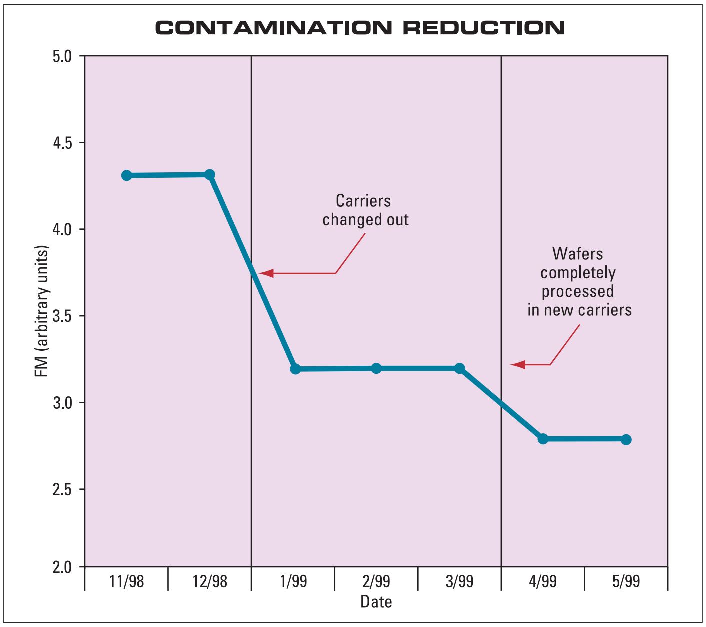
The CF/PEEK material performed well compared with the other carriers tested. A different comparison of the CP/PP and CF/PEEK carriers (Fig. 2) revealed that PEEK's tensile modulus (stiffness) is more than 5× that of CP/PP over a range of temperatures. The high modulus, combined with its high glass transition temperature, results in a very stable carrier over both time and a wide temperature range.

Particle performance

Carrier resistance to abrasion was critical for selecting the new carrier and box. Of particular importance was the carrier's resistance to abrasion by the wafers, which can directly cause defects and yield loss. The particles generated can also adhere to the wafer backside, near the edge, causing focus problems during the lithography steps.



3. SEM of wafer backsides shows higher particle levels and roughness after CF/PEEK carriers (left) and CP/PP carriers (right) were intentionally abraded.



4. The new PEEK carriers allowed a significant reduction in levels of foreign material on the wafers.

The abrasion resistance of CP/PP vs. CF/PEEK materials was tested by intentionally abrading wafers with polished edges against the carriers for 1000 insertions and extractions. To ensure that abrasion occurred, after initial contact between the wafer and carrier, the wafer-handling robot was lowered an additional 0.020 in.

Then the wafer was slid to within 0.25 in. of being fully extracted from the carrier and re-inserted into the carrier with no vertical movement. Compared with the CF/PEEK material, the CP/PP material formed more particles on the wafer backside at the point of contact between the wafer and the carrier tooth (Fig. 3).

Similar performance was seen where caustic etch wafers with ground edges were abraded against carriers.[2] This reference also compares performance of various carriers to abrasion against other surfaces such as stainless steel and sharp objects.

Conversion planning

Because of the size of the conversion and the risk to the fab, IBM sought a process that would minimize throughput loss while maximizing the benefits of the upgrade. A team of IBM and Entegris personnel planned the conversion, which took about three months.

The team first addressed the method used to introduce new boxes and carriers into the line. After considering many options, including gradual bay-by-bay conversion and attrition, we ultimately decided on mass change-out of carriers. The team changed the boxes before the carriers, thereby limiting the amount of work to be done on the actual day of carrier conversion. The conversion process consisted of two major aspects: logistics and tool readiness.

Logistics

Given the goal of changing out 17,000 carriers in less than 24 hours, a significant amount of logistics planning was required. We formed teams with representatives from manufacturing, engineering, safety, and other affected departments to determine how to best execute the mass change-out of carriers. The main considerations were as follows:

- **Resource planning** — Determining the number of people required for the conversion.
- **Number of carriers needed** — There were many dormant and engineering lots in the fab that needed purging prior to conversion.
- **Training** — It was important to alert everyone in the fab prior to conversion that the change-out would occur. IBM and Entegris produced a training video to familiarize everyone with the new carriers and boxes. The new carrier was also put on display in a number of locations to heighten awareness.
- **Transfer equipment** — We needed a quick, non-contaminating wafer-transfer method that could be performed throughout the fab. Entegris provided temporary transfer tools for the day of conversion. We performed transfers on specially build carts, which acted as movable work surfaces.
- **Manufacturing, storage and staging of carriers** — It was critical that all 17,000 carriers and boxes be provided on time and that they arrived clean and fab-ready. Further, the carriers and boxes had to be unpacked and stored in strategic locations throughout the fab to ensure quick access during conversion.

Tool readiness

Making sure the process tools were ready to accommodate the new carriers was perhaps the toughest part of the conversion process. With more than 1800 process tools, it was critical to thoroughly track the compatibility of the tools in the fab. While the new CF/PEEK carrier was a very close

Table 1. Tool Failure Improvements

Tool type	Prior failures	Post failures	Change
HDP	66	20	70.0%
Sputter wiring	47	21	55.0%
Sputter liner	29	23	21.0%
Etch	41	8	80.0%
Photo	39	12	69.0%
Average	222	84	62.0%

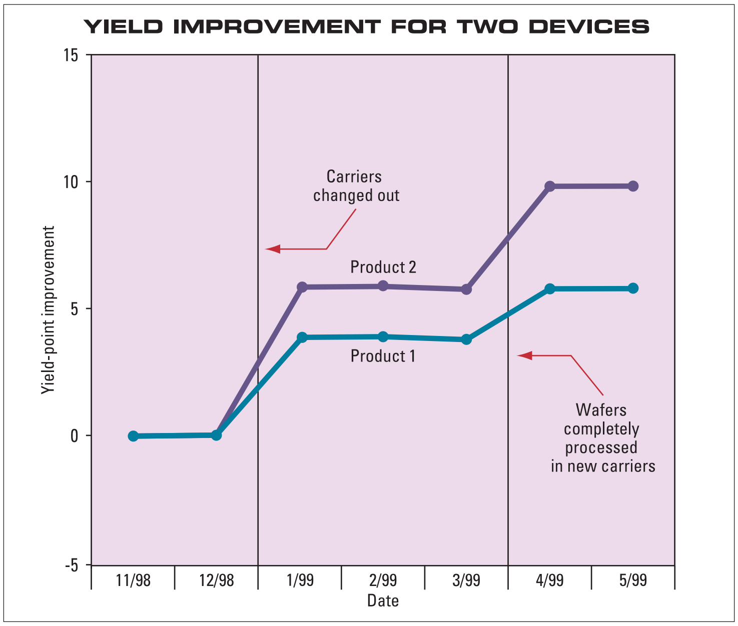
Table 2. Increase in Tool Availability

Tool type	# of tools	Change
HDP	6	3.4%
Sputter wiring	12	3.2%
Sputter liner	12	0.2%
HDP speed	9	4.6%
HDP 6	6	0.8%
HDP 8	9	4.6%
Etch	63	2.5%
Hot-process tools	13	0.4%
Photo	85	0.4%
Average	21.5	1.1%

model to the carrier we used previously, slight differences in tolerances and non-standard interface features had the potential to cause interface issues.

After a preliminary audit performed by IBM and Entegris, carrier samples were distributed to the tool owners to check compatibility. We then implemented a tracking system to monitor the progress of the tool-readiness effort and to provide visibility to management on tool status.

While most tools could interchangeably run both the new and the old carriers, several toolsets required modifications to accommodate the new carrier. Also, tools with highly sensitive wafer-handling systems required re-calibration for the new carriers. Entegris and IBM worked very closely with the OEMs and on-site maintenance teams to resolve all tool-interface issues prior to conversion.



5. Yield improvement for two devices over time. Analysis of all products showed improvements as high as 8%.

Implementation

To make carrier conversion run more smoothly and to reduce workload, we converted the boxes in a span of three months prior to carrier conversion. New boxes were introduced at the run-start and box-clean areas.

The carrier conversion was scheduled to take place over a 24-hour period during full production mode (i.e., products continued to run on tools throughout the day). The actual conversion went very smoothly with minimal loss of production or wafer breakage.

All participants were provided with clear responsibilities prior to the conversion. Approximately 20 teams of three people were formed to carry out the actual wafer-transfer process. Additional personnel (60-70 people) supported the conversion activities by supplying/disposing of carriers, troubleshooting interface issues and coordinating resources.

The product was converted bay-by-bay using temporary slide transfer tools and work surfaces. WIP racks were converted using dedicated operators from other shifts, while the WIP stockers/tracks were converted by people qualified to work on those systems. After a carrier was changed out, personnel placed a bright pink label on the storage box, identifying it as a converted product. The entire IBM fab was converted in less than 18 hours. Among more than 300,000 wafers handled, only five were broken!

Utilization/yield improvement

Figure 4 shows the reduction in FM achieved through the conversion, with vertical lines indicating the start and completion of the convesion. When improvements from general fab learning are excluded (as shown in the figure), the reduction in FM is >35%.

IBM also achieved significant improvements in equipment utilization. Table 1 shows the pre- and post-conversion numbers for tool failures. The average reduction in failures for selected critical tools was 62%, equating to a 1.1% improvement in tool availability, calculated using standard SEMATECH models (Table 2).

Figure 5 shows the change in yield attributed to the conversion for two products. Yield-analysis techniques provided the means to separate box/ carrier yield improvements from normal line-yield improvements. This analysis indicated an average yield improvement of eight points on selected products — more than quadrupling the forecasted improvement.

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Conclusion

Through teamwork and planning, IBM and Entegris successfully converted two fabs to a new wafer-carrier and storage-box technology. Approximately three months of planning by the team enabled a conversion of all carriers in an 18-hour period during normal production, with minimal loss in output.

Most important, foreign-material problems and carrier dimensional variation were reduced, leading to yield gains and increased tool availability. With the higher-than-expected yield and tool-availability improvements in place, IBM realized a return on investment well within its acceptable timeframe. •

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