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QORVO

RAMPS IN RICHARDSON

BY DAVID LAMMERS

Driven by fast growth in smartphones, RF supplier Qorvo Inc. has been expanding production of BAW filters at a rapid rate. Howard Witham, vice president of Texas operations, sat down with *Nanochip Fab Solutions* at the company's Richardson, Texas, fab to talk about how fab automation tools have helped an experienced workforce deal with rapid capacity expansions.

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When RFMD and TriQuint Semiconductor merged at the beginning of 2015, it brought together two synergistic companies—each with roughly a billion dollars in revenues—and created a merged entity, Qorvo, Inc., which may approach $3 billion in sales this year.

Qorvo's rapid growth is reflected in expansions at all of its manufacturing operations. The company's Richardson, Texas, fab has increased production of bulk acoustic wave (BAW) filters by 10x in the last 5 years, and demand is expected to continue to increase as smartphones using 4G wireless networks proliferate around the world.

Brad Shaffer, senior analyst for mobile electronics at IHS in Tempe, Arizona, said BAW filters, already one of the very high growth areas in smartphone components, will gain further momentum as LTE wireless networks in China come on line.

The LTE networks operate at frequencies above 1.5–2 GHz where BAW filters have performance advantages over surface acoustic wave (SAW) filters. "As LTE gets closer to where Wi-Fi fits into the spectrum, there are possible interference issues," Shaffer noted.

Avago Technologies and Qorvo share about 95% of the market for BAW filters (see figure 1), and are the only BAW suppliers capable of meeting the huge volumes that smartphone vendors Apple and Samsung require. "Avago and Qorvo are both investing a lot of money to meet demand," Shaffer said, noting that Avago has stated it may be late 2016 before it fully catches up to demand for its filters.

"BAW is growing significantly and at a very fast pace, and that is where you are seeing some of these utilization issues," Shaffer said.

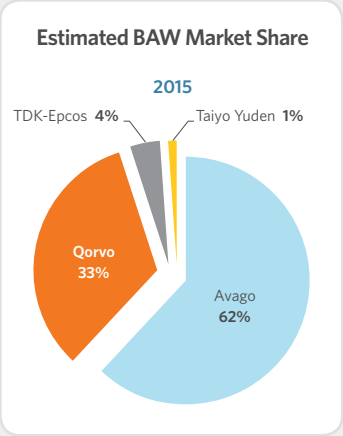

Figure 1. Avago and Qorvo share all but about 5% of the market for BAW filters. (Source: Qorvo, Inc.)

Howard Witham, the Richardson site manager, said Qorvo has invested about $220 million over the last 2 years in the Richardson fab. About 400 employees were added to the manufacturing staff, which raised employment there to 1,200. The Richardson team has brought in about 40 tools for a pilot 200mm line, and expanded the 150mm line by 3x in the last 2 years.

Qorvo's Richardson fab has two quite different product lines: BAW filters and power amplifiers made on gallium arsenide (GaAs) and gallium nitride on silicon carbide (GaN on SiC) for infrastructure and defense customers. As the fab's floor space fills out, the next step is to move to 200mm silicon wafers for the BAW filter line, and from 100mm (4-inch) to 150mm (6-inch) GaAs and GaN-on-SiC substrates. The compound semiconductor line is largely used to make high-power RF amplifiers for infrastructure (base station) and defense customers.

"We are expecting a big pull in 2016. As the fab gets filled out, how do you scale? We can look to a 200mm line for the BAW filters, and are running some 200mm now. Over the last 5 years, it has been mandatory that all of our 150mm equipment be convertible to 200mm," Witham said.

TriQuint bought the Texas Instruments defense electronics business in 1998, and soon after moved its Texas operations into the Richardson fab, which had been making DRAMs for a Hitachi-Texas Instruments (TI) joint venture called TwinStar. Many of Qorvo's current workers had previously worked at the TI gallium arsenide-based defense electronics line.

"The people from the TI defense group were outstanding. They had a healthy chip on their shoulders, and were very eager to show that they had the capability to move into a high-volume manufacturing environment on a commercial product," Witham said.

When he moved from managing fabs for STMicroelectronics to TriQuint in 2010, the company was in the early stages of BAW production. The Richardson fab's GaAs and GaN-on-SiC defense and infrastructure line used only about one-quarter of the 50,000-square-foot fab, processing about 200 wafers per week.

The company quickly began ramping BAW filter production as smartphone sales zoomed up. In those early days of 2009 and 2010, the challenge was to keep up with demand. "We had yield and reliability challenges, moving a young technology into a robust manufacturing state," Witham said.

One answer was to invest in fab automation, including advanced process control (APC) and a new manufacturing execution system (MES).

PAINFUL EXCURSIONS

At last year's Advanced Process Control (APC 2014) meeting in Ann Arbor, Michigan, Witham detailed how

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he brought modern process control techniques to Richardson.

"My feeling at that time [2010] was that we were about 15 years behind, and that we had about 2 years to show some progress," Witham said. He recalled coming into "an environment where every day our MES was crashing."

One challenge was to convince management to release the capital expenditures needed to modernize the fab with new factory automation hardware and software. "We were begging for APC and process control, for improvements in our MES. Our management said 'OK, if you want a new MES, you have got to commit to a return on that investment. You have to put a dollar value on it,'" Witham said.

The TriQuint senior managers were receptive because they had gone through several "extremely painful" excursions that resulted in million-dollar financial losses. Problems—ranging from a helium leak in a cryogenic pump to fluctuations in CMP carrier speeds to an irregular argon supply—were slowing down the yield ramps at Richardson.

"The engineering team started documenting things that they were guessing at before. The team scrubbed its quality database and found that about 8% of the scrapped wafers were preventable.

"We figured out how to do automated optical inline inspection in a fab that was not looking at anything inline. Nothing we did was novel, but I can tell you that we got huge benefits very quickly," Witham said, adding that "matching equipment becomes possible when you have these tools."

RIGHT TOOLS FOR THE JOB

Initially concerned that the Richardson engineers' experience with defense ICs would prove a handicap, Witham found the opposite to be the case. "I thought I would have a fight on my hands, but they were so ready. They tell me now that if I ever wanted to reverse directions on these automation tools, that I had better watch it," he said.

Process control is a big reason to move to 150mm wafers for the compound semiconductor line, beyond the sheer boost in capacity with the larger wafers. Witham said as Qorvo moves from "vintage" 100mm equipment to 150mm tools, it can support improved recipe downloading, easier operation for the direct labor force, and data capture.

With the newer 150mm refurbished tools, "the engineers can see what is happening with the equipment. Operators don't have to make decisions with poor data; we can set up algorithms to make the decisions for them," Witham said.

The 150mm compound semiconductor line paves the way for what could be a boom in GaN-based power amplifiers, as customers beyond the defense sector turn to GaN for improved power efficiency. GaN is increasingly used in LEDs, led by Cree, Sumitomo Electric, and others. And power transistors are taking advantage of the increased power densities and heat dissipation with GaN. A U.S. power electronics research consortium, based near Albany, New York, and led by General Electric, is now getting underway.

"We see more GaN in the future," Witham said, noting that there is a "lot of pull from our customer base. We have a very competitive GaN amplifier product line now and over the next two or three years we see that potentially really taking off in the commercial space."

BAW FILTER BOOM

While Qorvo's compound semiconductor production line continues to thrive, much of its growth has come

Howard Witham, vice president, Texas operations, at Qorvo.

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from making BAW filters. They are made on a silicon wafer that acts as a simple carrier, with nothing active in the wafer. Above the silicon, Qorvo deposits aluminum nitride and other films, which form a piezoelectric layer that acts as an acoustic resonator, filtering out unwanted frequencies. The goal is to pass on 100% of the in-band frequency.

"This is not like GaAs or silicon where the active component is in the wafer. What we do is all up above the silicon. With these acoustic resonators, the piezoelectric layers are not easy to do," Witham said. At the high frequencies in which BAW filters are effective, the piezo layer must be only hundreds of nanometers thick, and the acoustic Bragg reflector is created by stacking thin layers of alternating stiffness and density.

Physical vapor deposition (PVD) is a key process step, and finding used tools has been a challenge, forcing Witham to buy some new PVD equipment at higher prices. (See "Demand for 200mm Tools Outstrips Supply," *Nanochip Fab Solutions*, Vol. 10, Issue 1, 2015.)

Witham said that during the recent 3x production expansion at the Richardson fab, the company's suppliers did not have a shortage of cores, although some of the tools were in "tough shape" before refurbishment. Buying largely brand-new equipment is not an option given the company's wafer cost targets.

FROM LEMONS TO LITHOGRAPHY

"We did not feel the shortage [for used cores], and maybe that's because this RF market is now big enough that we get more attention from the suppliers. I felt the biggest pinch on the steppers. We found some lithography tools on the used market, but we got some real lemons. Fortunately, we have at least two former litho vendor field service reps working here at Qorvo, and if you can give them a frame, they can build you a stepper. That's the dice you are rolling. That's what can be the difference [between success and failure]."

The connected life is enabled by advanced RF technologies from Qorvo.

The equipment refurbishment team has worked with equipment OEMs, including Applied Materials. Qorvo also relies on local refurbishers who work hand-in-hand with the in-house equipment technicians.

By mixing large OEM and local refurbishment suppliers, and converting 150mm tools to 200mm, Witham believes he will be able to add enough capacity while staying within his equipment cost targets.

FAST AND SLOW YIELD RAMPS

One challenge Qorvo faces is how to meet the demands of the fast-changing smartphone market, where the RF modules are upgraded regularly. A BAW filter might be in production for only 12–14 months before production switches to a new design, and profitability depends on winning key sockets and then meeting demand with a fast yield ramp (see figure 2).

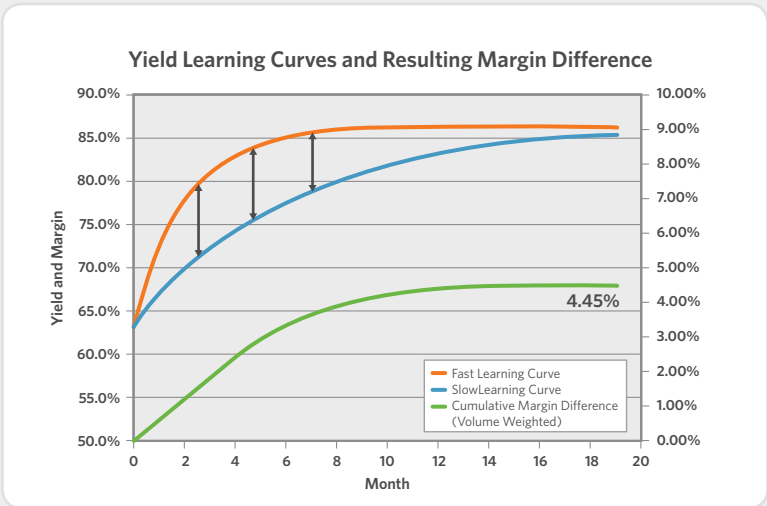

Figure 2. A fast yield ramp is key to profitability in the smartphone components business, where products can change in about a year. A fast yield ramp resulted in a significant boost in margins. (Source: APC 2014 proceedings.)

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Witham said smartphone makers factor in manufacturing capacity as one criterion in their component selection process. "If I have manufacturing clout compared to competitors, that's a big plus for the smartphone manufacturers. They have to believe you have put in the necessary capacity. At Qorvo, we have to bet early. We can still be under capacity, but then we are scrambling to put in new capacity and scrambling to get every bit out of our existing tools as we work with our supply chain to put in new capacity."

The key to success is not being overloaded, which can put the fab into overdrive mode. That can result in quality issues, while keeping volumes high and wafer costs low.

"Volumes are everything when it comes to the best financial performance. Semiconductors are a very heavily capitalized industry, and we want to keep this fab full so we can contribute to a good P&L," Witham said.

At CS MANTECH, a recent compound semiconductor manufacturing technology conference, Witham detailed the profit difference between slow and fast yield ramps, with a 4.45% difference in margin impact over the product's relatively short run.

In his keynote speech at the conference, Witham said that "the fab must have excellent speed for NPD [new product development] prototypes during development and also for fast engineering learning cycles when working to improve yields."

Witham explained the difficulty. "You have to win [the BAW filter sockets] every year. The competition is fierce to win sockets, with new specs, and more stringent limits on battery power. Every year you have to win at all the big smartphone makers."

A SIGNAL IS NEEDED

Witham added that "if you think the company will win something big, you want to learn about your win within your capacity lead time. You have to get some signal in order to make a $200 million investment, and our customers understand that. The equipment manufacturers are not going to sit there with their own supply, waiting for us, and it is the same for all of us in the [production] chain."

Suppliers must have a certain size, and a willingness to play in a smartphone game where decisions are necessarily made late, with precious little spare time to add capacity.

"You tend to go late, and when you do, you have got to be firing on all cylinders. You cannot afford any significant hiccups. You can't hire people too soon, and you can't buy equipment too soon," Witham said.

One plus has been the availability of a skilled workforce in the Dallas area. Several IDMs have either closed their fabs there or reduced their Dallas area manufacturing footprints considerably.

"We've heard of other locations that are having trouble finding experienced people, but we are fortunate in Dallas, because we can hire people who used to work at all the various semiconductor fabs here," Witham said.

Qorvo's management and workforce have met some incredible challenges: quickly expanding production of high-volume RF components—BAW filters—at a time of amazing growth in smartphone and wireless infrastructure shipments. Along the way, they have learned to use new productivity tools to get the most out of a fleet of mostly refurbished tools, coping with steep ramps of a truly unique product.

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