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INTEL GOES QUAD

Quad-Core Processors and 65nm Volume Shipments Beat AMD

By Tom R. Halfhill {10/16/06-01}

Intel isn't out of the dark yet, but there's light at the end of the tunnel. And no, that glow isn't the laser beam of Intel's recent experiments with silicon photonics, which is a long-term beacon. Intel needs immediate results. Wisely, the company is returning to its traditional strengths: x86 processors manufactured with the world's best high-volume fabrication technology. It's a combination that competitors have found unbeatable.

On September 26, Intel announced that quad-core server and desktop processors will begin shipping in November. Both product lines are months ahead of previously disclosed schedules. At the Intel Developers Forum, the company proudly referred to its new Quad-Core Xeon 5300 (Clovertown) and Core 2 Extreme QX6700 (Kentsfield) as "the industry's first production quad-core processors." That's not exactly true—other companies have been shipping processors with four or more cores for years—but Intel's new chips are indeed the first PC processors worthy of that claim.

These initial quad-core processors are actually pairs of dual-core chips packaged together in a multichip module (MCM), instead of single-die monolithic chips. Intel prefers the term multichip package (MCP) for this technology. As Figure 1 shows, each half of the quad-core device is a separate die, as found in the dual-core Xeon 5100 and the Core 2 Duo. (The Xeon 5100 has one Woodcrest die, and the Core 2 Duo has one Conroe or Merom die.) To make the coupled design work, Intel is dialing down the maximum clock frequency to 2.66GHz, compared with 3.0GHz in the dual-core parts. Nevertheless, four cores in a single package will raise the bar of performance. Intel says the quad-core server processor is up to 50% faster than its dual-core predecessor (Xeon 5100), and the quad-core desktop chip is up to 70% faster than its dual-core predecessor (Core 2 Duo desktop). These performance comparisons are based on the SPECint_rate2000 benchmark.

What's more important than having four cores is that Intel is manufacturing all these chips in its latest 65nm fabrication process and is ready to ship them in volume. Indeed, Intel has now been shipping 65nm chips for a whole year. In contrast, AMD is just beginning to ship 65nm parts. *Microprocessor Report* believes that Intel's lead in high-volume fabrication technology—along with its rejuvenated processor cores—will position the wounded company for a comeback in 2007.

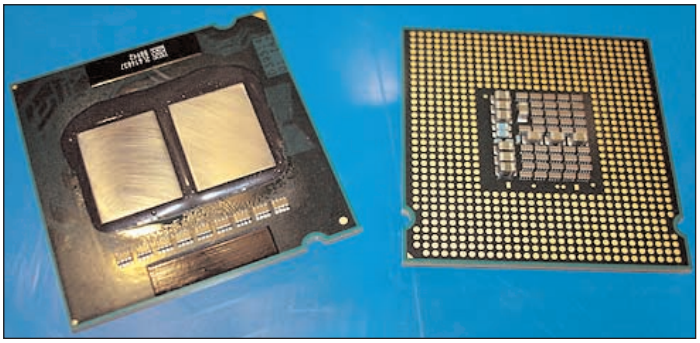

Figure 1. Intel's first quad-core x86 processors package two dual-core dies in a multichip module (MCM), which Intel calls a multichip package (MCP). At right is the pad layer. (Photo: *MPR*)

Fastest Process-Node Transition Ever

To be sure, Intel still faces tough times. Past mistakes and stiffer competition from AMD have taken their toll, so Intel must lay off 10,500 employees in the next year. That can't be good for morale, but the company is laying a foundation for recovery. (See *MPR 9/25/06-03*, "Intel's Comeuppance.")

Intel says its transition from 90nm to 65nm is happening faster than any previous process-node transition in the company's 37-year history. That's impressive, because Intel has always been one of the fastest-moving semiconductor manufacturers in that regard. Intel introduces a process shrink every two years, almost like clockwork. Shipments of 65nm parts began in October 2005, and Intel says the next-generation 45nm process is on schedule to debut in 2H07. Production in 65nm is ramping up so quickly that it has already overtaken 90nm shipments. In addition, Intel says its 65nm process has lower defect densities than any previous Intel process—another impressive accomplishment.

By the end of this year, Intel will have four 65nm fabs up and running: D1C and D1D in Oregon, F12 in Arizona, and F24 in Ireland. All four are producing state-of-the-art 300mm wafers, too. In contrast, AMD has been shipping everything in 90nm this year and plans to introduce its first 65nm parts (new processors with faster DDR2 memory controllers) this quarter. AMD hopes to ramp up production quickly, aiming for a 65nm–90nm crossover as early as 1Q07. The 65nm process is at AMD's new Fab 36, which produces 300mm wafers. AMD's manufacturing partner, Chartered Semiconductor, isn't expected to debut 65nm until mid-2007. AMD's 45nm process is scheduled for introduction in mid-2008, using an older fab converted to 300mm. (See *MPR 6/26/06-01*, "AMD Round II.")

In the PC-processor business, having the lead in process technology confers an automatic advantage—as long as the advantage isn't squandered on misguided CPU designs. Intel's new Core microarchitecture and multicore chips are beginning to make the Pentium 4 and its NetBurst microarchitecture a dim memory. (See *MPR 3/27/06-01*, "Intel Looks to Core for Success.") The Core microarchitecture is a more power-efficient design that lends itself to a variety of multicore implementations, including the new quad-core processors. (See *MPR 4/3/06-01*, "Intel's Road to Quad-Core.")

Thanks to their lower clock frequencies (2.66GHz instead of 3.0GHz), Intel's first quad-core chips have tolerable power consumption. Intel says the Quad-Core Xeon 5300 will consume 80W thermal design power (TDP). A near-future lower-voltage version for dense server racks will consume only 50W. However, a higher-performance server processor on the roadmap could reach 120W.

On the desktop, the Core 2 Extreme QX6700 will consume 130W—63% more than today's dual-core Core 2 Extreme X6800 (75W). No wonder so many power users are installing liquid-cooling kits in their PCs. For those who are somewhat less obsessed with performance, a slightly slower version of the quad-core Core 2 Extreme will hold power consumption to about 100W. That's hotter than an Easy-Bake Oven but still within the safety limits of a thermally efficient PC.

These first-generation quad-core designs are probably too hot for mainstream desktop PCs and especially for notebooks. Not that it matters, because right now it's difficult to justify a quad-core processor in a mainstream PC or notebook, anyway. Servers will be the main beneficiary of these powerful processors. Intel won't be able to deliver a significantly lower-power quad-core processor without introducing a monolithic quad-core die. Unfortunately for Intel, AMD will get there first, despite its handicap in fabrication technology. Although Intel's MCMs are the first quad-core PC processors, they are largely stopgap measures.

Multichip Packaging Is a Compromise Solution

Intel's initial quad-core processors are reminiscent of the Pentium Extreme Edition 955 (Presler), a dual-core processor introduced last December. AMD's surprisingly fast leap to dual cores put great pressure on Intel, so Intel responded with two stopgap products. First came the Pentium Extreme Edition 840 (Smithfield), which unites two Pentium D cores on a single die, albeit with minimal integration. Next came the Pentium Extreme Edition 955, which packages two of the older Pentium 4 Netburst cores in an MCM. Not until last June and July did Intel introduce its first monolithic dual-core processors (Woodcrest, Conroe, and Merom), which fully integrate two power-efficient Core-based processors on a single die. (See *MPR 12/19/05-01*, "Ringside for 2006 Dual-Core Fights.")

Last year, when Intel announced the dual-core Presler, the company said that packaging two separate dies in an MCM could reduce costs by increasing yields. A manufacturing defect on one die wouldn't force the fab to discard the other die, whereas if one core on a dual-core die is defective, the fab discards the whole processor. In addition, using two separate dies allows Intel to bin-sort all the good dies on a wafer to find the best-matched pairs, as judged by their tested clock frequencies, operating voltages, current leakage, and other characteristics.

Now Intel is making the same argument in favor of its first quad-core processors, which package two monolithic dual-core dies in an MCM. In this case, if one dual-core die is defective, the fab needn't discard the other dual-core die in the pair. And Intel can bin-sort all the good dual-core dies to find the best-matched pairs. These tactics will help Intel produce the optimum mix of quad-core server and desktop processors at various clock speeds.

Nevertheless, everyone knows that a monolithic quad-core die is where Intel really wants to go. In the past, the extra packaging cost of an MCM usually outweighed its aforementioned advantages. That extra cost has surely declined; otherwise, Intel couldn't afford to produce such large volumes of dual- and quad-core processors in MCMs. But it's still an extra cost, as well as an additional manufacturing step that, by itself, could reduce yields if the packaging is defective.

Moreover, a monolithic quad-core die is a better-integrated multicore processor, if done right. For instance, Intel's MCMs require core-to-core communications and cache snoops to traverse the front-side bus. That's a time-consuming detour, even with Intel's improved bus frequency (1.3GHz). AMD's monolithic quad-core processors (AMD prefers to call them "native" quad-core processors) will allow all the cores to communicate without venturing off the die. The cores will share the same L3 cache, in addition to having independent L2 caches. Also, AMD's quad-core processors will integrate two DDR2 memory controllers, further reducing traffic on the front-side bus. AMD says these processors will consume about the same power as its dual-core parts and will be compatible with the same socket.

The freshly minted code-name for AMD's first native quad-core device is Barcelona. AMD plans to introduce Barcelona in the 65nm generation, probably in mid-2007, skipping MCMs altogether. Intel doesn't expect to ship a similar quad-core device until the 45nm generation. Intel's 45nm process comes online in 2H07, so the monolithic quad-core processor should appear sometime later. Reportedly, the code-name for Intel's monolithic design is Yorkfield.

Will Intel Double-Down Again?

Another reason for producing a monolithic quad-core die is that it's a logical bridge to an eight-core processor. If Intel follows its recently established pattern, its first eight-core device will package two Yorkfield-type dies in an MCM, or perhaps graft them side by side on a single die, in the manner of the Pentium Extreme Edition 840 (Smithfield). By the time Intel is ready for this step—perhaps mid-2008—the next-generation 45nm process will be in volume production, shrinking the die size and (we hope) the power consumption. Whichever path Intel chooses toward the first eight-core x86 processor, it would be another temporary solution on the way to a monolithic eight-core die.

Intel's roadmap calls for processors with four or more cores (but not necessarily eight cores) to arrive sometime in the 45nm generation. Code-names for those desktop processor families include Penryn and Nehalem. A code-name for a server processor family is Dunnington. *MPR* thinks Intel will move aggressively to introduce eight-core, and perhaps even 16-core, x86 processors in the next few years.

Price & Availability

Intel plans to ship the new Quad-Core Xeon 5300 (Clovertown) and the Core 2 Extreme QX6700 (Kentsfield) in November. Intel hasn't announced pricing. For more information about the product announcement, see: *www.intel.com/pressroom/kits/events/idffall_2006/pdf/Intel%20Quad%20Core%20Processor%20Update%20%E2%80%93%20Sept.%202006.pdf*

For Intel's white paper, "Intel Multi-Core Processors: Making the Move to Quad-Core and Beyond," see: *www.intel.com/technology/architecture/downloads/quad-core-06.pdf*

Beyond that, however, we anticipate a pause in x86 multicore integration. The ability to build more-populous multicore processors will probably outstrip the ability of programmers to use them effectively—and the market's desire to pay for them. Instead, we expect Intel and AMD to explore other ways of spending their growing transistor budgets. The most likely next step in multicore evolution will be heterogeneous designs that surround x86 cores with specialized coprocessor cores.

AMD's recent $5.4 billion acquisition of ATI is a sign of what's to come. (See *MPR 8/28/06-03*, "AMD Writes a New Chapter for PCs.") *MPR* expects AMD to introduce a single-core, and perhaps even a dual-core, x86 processor with integrated ATI graphics in 2008. Perhaps in response, Intel's venture-capital arm recently invested about $10 million in Imagination Technologies and announced a collaboration agreement. Imagination Technologies is a British company known mainly for licensing graphics coprocessor cores for use in cellphones and other mobile consumer-electronics products.

As this story went to press, there were rumors in the financial community that Intel would acquire Nvidia, the last major independent graphics-processor vendor. Whether or not those rumors prove true, it's clear that future PC processors will integrate not only more x86 cores but also a wider variety of cores.