Pentium Is First CPU to Reach 0.35 Micron

New Manufacturing Process Pushes Intel Processor to 120 MHz

by Linley Gwennap

Becoming the first microprocessor vendor to make the move to a true 0.35-micron process, Intel has announced a 120-MHz version of its flagship Pentium processor. In addition to enabling higher clock speeds, the new process will reduce Pentium's manufacturing cost and greatly increase Intel's capacity to deliver Pentium processors. By forging ahead to the next-generation process, Intel makes it more difficult for other x86 vendors, as well as the PowerPC backers, to keep pace.

The 120-MHz Pentium is rated at 140 SPECint92, a 15% increase over the previous high end, the 100-MHz part. Its external bus runs at 60 MHz, one-half of the CPU speed. The new device is otherwise functionally identical to the 0.5-micron P54C processor. At 120 MHz, its maximum power dissipation is 10 W, about the same as that of a 100-MHz P54C; the more advanced process helps keep the power consumption down despite the higher clock frequency.

Intel is already sampling the faster part, code-named P54CQS, and plans immediate volume shipments, quoting a 1,000-piece list price of $935. The large gap between this price and the $673 tag on the 100-MHz part should close in the coming months.

Initial P54CQS Is Pad-Limited

To bring the 120-MHz part to market as quickly as possible, Intel is using an unusual-looking die that, as Figure 1 shows, combines the P54C pad ring with the core circuitry optically reduced to 0.35-micron rules.

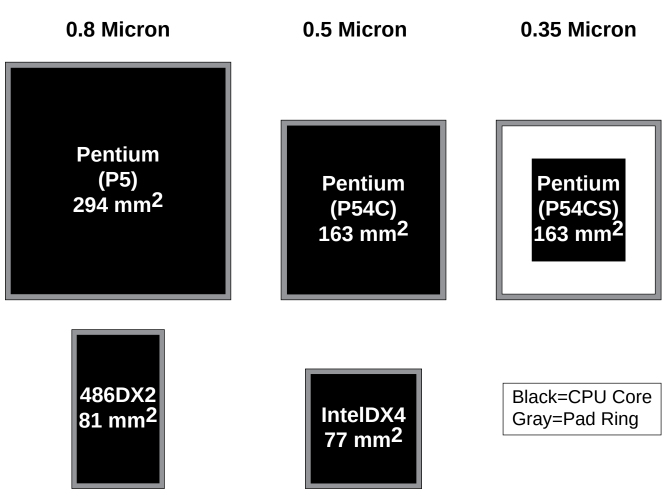

Figure 1. The 120-MHz Pentium die has the same die area as its predecessor but a much smaller CPU core size.

Thus, the die size of this version is 163 mm^2, the same as that of the P54C.

By retaining the old pad ring, Intel can continue to use the same packaging and wire-bonding machines it uses for the current parts. The smaller transistors run faster, however, allowing the higher clock speed. Furthermore, the effective area *(see* ***071004.PDF****)* of the die is much less than that of the P54C, improving yield. Thus, despite the increased wafer cost of the 0.35-micron process, the 'CQS parts will carry about the same manufacturing cost as the P54C, according to the MDR Cost Model.

The 'CQS is based on the C2 stepping of the P54C, so there are relatively few known bugs. One problem with the 120-MHz part, however, prevents operation in dual-processor mode with a shared cache. The optical shrink caused timing changes that do not allow signals to propagate properly between the processors. Multiprocessor systems that do not use a shared cache will work correctly. Intel plans to fix this problem in a future version.

Over time, Intel plans to deploy a redesigned 'CQS die that takes full advantage of the 0.35-micron design rules and eliminates the empty area inside the pad ring. This new design, code-named P54CS, will use a smaller pad pitch to reduce the size of the pad ring; this new pitch requires some modifications to the existing wire-bonding machines.

The die size of the P54CS will be about 90 mm^2, nearly as small as a 486DX2 or DX4. At this size, the number of good die per wafer (according to the MDR Cost Model) will increase from about 65 for the P54C to roughly 130 for the P54CS, potentially doubling Intel's capacity for Pentium chips. Of course, the full effect of this change will not be seen until Intel implements sufficient capacity in the new process, which will take a year or more; currently, the 0.35-micron process is available only in Intel's Aloha (Oregon) facility.

We estimate the manufacturing cost of the P54CS at $85, about 20% less than that of the P54C. As the new process matures, the defect density will drop, raising the number of good die per wafer above 180. Combined with new fabs, this change will triple Intel's current Pentium capacity by 1997. At that point, the manufacturing cost of a P54CS in a TAB package will be about $45, allowing Intel to bring its low-end Pentium pricing below $150.

Enhanced "P55C" Yet to Come

The P54CS is likely to be the end of the Pentium line as far as lowering cost is concerned; by the time the next process (0.25 micron) is available, Intel will be focused on its P6 and P7 products. It is interesting to note that, even with the 0.35-micron process, the P54CS will be about twice as expensive to manufacture as a 486DX2 when both use plastic packages. The P54CS is slightly larger, and the wafer cost of its more advanced process is much higher. It is difficult to see how Intel will get Pentium prices below $100, a spot that the 486SX occupies today. The price of a low-end PC processor may creep up over time, compensating for this problem.

From a performance standpoint, there is still more to come from the Pentium line. Intel expects to get yield at 120 MHz from the P54C in the future, with the P54CS reaching 133 MHz and possibly 150 MHz. Intel is also developing a new device, code-named P55C, that is slated to operate at 150 MHz. We expect the P55C to double the on-chip cache size, including a total of 32K of cache, to improve performance when running the CPU clock at 2× or 2.5× the system-bus speed.

The P55C may include other functional enhancements. One persistent rumor is that this chip will include instruction extensions similar to those in HP's processors *(see **080103.PDF**)* to speed the handling of multimedia data types. This relatively simple change could greatly improve the P55C's performance on Indeo video, ProShare video-conferencing, and other NSP (native signal processing) applications.

We expect the P55C to debut by the end of this year. In 1996, this part will offer high performance at a mainstream price while the P6, at a variety of clock speeds, holds down the high end. At the same time, Intel will take advantage of the lower manufacturing cost of the P54C and P54CS parts to offer aggressive prices in a competitive Pentium-class market.

Manufacturing Investment Pays Off

Intel has invested heavily in IC process development during the past two years. Compared with RISC vendors, Intel was a bit late in moving to a 0.8-micron process, but its 0.5-micron process (which Intel calls a 0.6-micron process) is comparable to other half-micron processes in capabilities and initial shipment date.

In moving to the next generation, Intel has pulled ahead of the pack. Several semiconductor vendors, including IBM, are building 64-Mbit DRAM chips in 0.35-micron CMOS today, but these memory processes use fewer metal layers and thicker gate oxides than logic chips typically use. Toshiba recently announced that it has modified its 64-Mbit DRAM process for ASICs but has not begun shipping such parts.

NEC and Toshiba, among others, have announced microprocessors using "0.35-micron" processes, but these chips have an effective gate length of 0.35 microns; we use the more standard measurement of drawn gate length, which classifies these processes as 0.5-micron or 0.45-micron. Fujitsu will manufacture the Hal processor in its new 0.4-micron CMOS-55 process, but this device is not expected to reach production until this fall.

Thus, Intel is the first company to ship a microprocessor in a true 0.35-micron (drawn) process. Contrary to earlier rumors, Intel continues to implement BiCMOS instead of pure CMOS, even at this feature size, claiming that the bipolar devices enhance performance.

The P54CQS continues to operate with a 3.3-V supply, although many vendors have proposed moving to voltages of 2.5–3.0 V for next-generation processes, and Intel's own P6 processor uses a 2.9-V supply in a 0.5-micron process. Intel says that its future 0.35-micron devices may move to lower supply voltages, but the P54CQS needs to retain compatibility with existing board designs.

Despite higher wafer costs and, at least initially, worse defect rates, advanced manufacturing processes tend to reduce manufacturing cost and increase output. Smaller transistors can also boost clock speed by up to 50% per generation. Thus, Intel's lead in process technology gives it a significant competitive edge in a market that it already dominates.

AMD plans to bring a 0.35-micron CMOS process on line in 1H96, about a year later than Intel. IBM, which builds x86 processors for Cyrix and NexGen as well as its own PowerPC chips, has not yet revealed plans to modify its 0.35-micron DRAM process for logic chips; it is unlikely to ship 0.35-micron processors this year. Motorola has not even put a 0.5-micron processor into production to date, and it is unlikely to move beyond that level until well into 1996, delaying the introduction of any 0.35-micron PowerPC chips. Thus, Intel appears to have a 9–12-month lead over its primary competitors, although some RISC vendors should begin shipping 0.35-micron processors later this year.

With the 486 fading fast, the market will demand 30–40 million Pentium-class chips per year by 1996. Intel's move to a next-generation manufacturing process will allow it to supply the lion's share of that volume. The higher performance of its new chips should surpass that of competitors' half-micron x86 processors and make it more difficult for PowerPC to open a significant performance gap. By investing some of its huge profits in manufacturing, Intel has found another advantage in the increasingly competitive microprocessor market. ♦

Price & Availability

The 120-MHz Pentium is available immediately from Intel. The list price is $935 in quantities of 1,000. For more information, contact your local Intel sales office or call Intel at 800.626.8686.

