White Paper

Introduction to Intel's 32nm Process Technology

Intel introduces 32nm process technology with second generation high-k + metal gate transistors. This process technology builds upon the tremendously successful 45nm process technology that enabled the launch of the Intel® microarchitecture codename Nehalem and the Intel® Core™ i7 processor.

Building upon the tremendous success of the 45nm process technology with high-k + metal gate transistors, Intel is nearing the ramp of 32nm process technology with second generation high-k + metal gate transistors. This new process technology will be used to manufacture the 32nm Westmere version of the Intel® microarchitecture codename Nehalem. Westmere based products are planned across segments: mobile, desktop, and server. Intel is the first company to demonstrate working 32nm processors and is on track with their cadence of new product innovation – known as the 'Tick-Tock' model – that delivers new generations of advanced process technology and processor microarchitecture on an alternating 2 year cadence.

To understand the significance of 32nm, we must first take a look back at 45nm process technology and high-k + metal gate transistors:

To better understand the significance of the 32nm process technology it is helpful to look back and revisit the 45nm process technology introduction that occurred in 2007. The Intel internal process name for the 45nm generation is P1266 and is the process that enables Intel to launch the incredibly successful and high performing Intel® microarchitecture codename Nehalem. The P1266 process is the first to introduction high-k + metal gate transistors- a technological breakthrough that enabled higher performing transistors while simultaneously reducing leakage currents. At the introduction of the P1266 process technology Intel promised a fast and meaningful ramp of the 45nm technology. Intel has kept its promise and is today the only company with production 45nm with high-k + metal gate transistors.

In fact, the 45 nm production ramp has been the fastest in Intel history. 45nm processor unit production has ramped twice as fast as the 65nm process technology in its first year. Today, 45nm products are being manufactured across computing segments. Single core Intel® Atom™ processors, dual core Intel® Core™2 Duo processors, Intel® Core™ i7 processors with four cores, and even the 6 core Intel® Xeon® processor are all today manufactured on the 45nm process.

Intel takes another major leap ahead on the 32nm process technology with second generation high-k + metal gate transistors.

The foundation of the 32nm process technology is the second generation high-k + metal gate transistor. The improvements over the first generation's high-k + metal gate transistors are many. The equivalent oxide thickness of the high-k dielectric has been reduced from 1.0nm on 45nm to 0.9nm on the 32nm process while gate length as been reduced to 30nm. Transistor gate pitch continues to scale 0.7x every two years - with 32nm providing the tightest gate pitch in the industry.

32nm also uses the same basic replacement metal gate process flow as Intel's 45nm process technology enabling Intel to leverage an existing highly successful process. These improvements are critical for scaling the size of ICs and increasing transistor performance. 32nm process technology with second generation high-k + metal gate transistors enables designers to optimize for both size and performance simultaneously.

The decreased oxide thickness and reduced gate length enables a >22% transistor performance gain. These transistors provide the highest drive currents and tightest gate pitch reported in the industry. Leakage current can also be optimized for a >5x reduction in leakage over 45nm for NMOS transistors, and >10X reduction in leakage for PMOS transistors. These improvements combine to enable circuits to be designed that are both smaller and have improved performance/power. 32nm is also 4th generation of strained silicon technology for improved transistor performance – so Intel has had time and opportunity to make vast improvements.

32nm SRAM test chip demonstrates the health of the process as well as the health of Moore's Law

First demonstrated in September of 2007, the 32nm SRAM test chip is a testament to the health of not only the 32nm process, but also of the health of Moore's law. Moving to 32nm Intel was able to reduce the cell size from the $0.346um^2$ of the 45nm process technology, to $0.171um^2$ for 32nm.

Looking back over previous process technology implementations, Intel continues the trend of a 50% reduction in transistor size (i.e. capacity to double transistor density) every two years. The complexity and size of the test chip is also telling of the health of the process technology. The test chip is large (>1.9 billion transistors), comprehensive (291 Mbit), and fast (4 GHz operation), and has served as an excellent vehicle to improve process yield, performance and reliability in preparation for 32nm processor products.

32nm yield curve mirrors the rapid improvement Intel saw with its fastest ramping technology ever – 45nm

Intel is very proud of the ramp and yields achieved on the 45nm P1266 process. Intel was able to achieve a rapid defect reduction with 45nm technology. This was achieved despite revolutionary features and new industry leading technology. The 45nm P1266 process now represents Intel's highest yielding process ever.

The yield of the 32nm process is exactly in line with what is required to match or exceed the highly successful ramp of the 45nm process. Reduction in defect density is currently at the 2 year expected offset from 45nm and Intel fully expects to be at the low defect rates and high yields to be ready for Q4 2009 production.

Intel will be bringing four fabs online over the next two years to transition the processor lineup to 32nm. D1D in Oregon is currently in operation and D1C in Oregon will come online in Q4 of 2009 to meet demand for 32nm products. In 2010 Intel will add two addition manufacturing facilities to the mix: Fab 32 in Arizona and Fab 11X in New Mexico.

32nm process technology with second generation high-k + metal gate transistors will deliver world class processors and computing products.

Westmere is the family of processors where the 32nm process technology will first debut. These processors (32nm versions of the highly successful Intel® microarchitecture codename Nehalem) will be available across computing segments. This "innovate, then shrink" strategy is known as Intel's Tick Tock development model. The 45nm Nehalem-based products (Tock) represented a major new processor architecture and design and were deployed on the already in production 45nm process technology. Westmere-based processors (tick – production Q4 '09) are set to follow, shrinking the existing microarchitecture to the smaller, faster, and lower power 32nm process.

Westmere-based processors will bring the Intel® microarchitecture codename Nehalem to the mainstream client. Westmere-based processors will enable clients with increased performance (vs. 45nm Intel® Core™ microarchitecture family), smaller processor core size, and will enable the introduction of a Multi-Chip Package (MCP) with graphics integrated in the processor.

Great 32nm process and product health is enabling Intel to accelerate the ramp of 32nm products for desktop and mobile processors.

Intel® processors based on Westmere will ramp into mobile, desktop, and server segments over time, as the 32nm process ramps. On the client roadmap, 45nm Intel® Core™ i7 processors and Intel® Core™ i7 Extreme processors with four cores supporting eight software threads will be followed by 32nm versions codename Gulftown to meet the needs of the high end desktop computing segment. For the performance and mainstream desktop segments, 45nm processors codename Lynnfield (4 cores with 8 threads) will be augmented by 32nm processors codename Clarkdale (2C/4T), with the Clarkdale processors including integrated graphics capability.

For mobile computing, the Mobile Extreme Segment will remain on the 45nm process technology with processors codename Clarksfield (4 cores/8 threads) with the performance and mainstream segments transitioning to 32nm processors codename Arrandale (2 cores/4 threads) that are targeting production in Q4'09.

We have plans to transition to 32nm process technology in all of the key Intel® Xeon® server segments. The 'Entry' segment will support Clarkdale processors coincident with release in desktop. The 'Efficient Performance' segment (Intel® Xeon® processor 5000 sequence) moves from 45nm Nehalem-EP to a 32nm Westmere-based processor in the future. The 'Expandable' segment (Intel® Xeon® processor 7000 sequence) will also transition from 45nm Nehalem-EX to a 32nm Westmere-based version in the future.

A dramatically repartitioned mainstream client: greater performance and lower power via higher integration.

32nm client processors will see more than just improved performance headroom and smaller die sizes. The Clarkdale and Arrandale mainstream client platforms will undergo a dramatic repartitioning with these new processor products.

Today, mainstream PCs are segmented into a 3-chip solution with a processor and a "Northbridge" (GMCH) containing integrated graphics, a memory controller, display, and the Manageability Engine behind Intel® vPro™ Technology. The third chip is the "Southbridge" (ICH) which primarily controls the I/O functions.

Moving to Westmere based clients, the integrated graphics and the memory controller will now reside in the processor in a multi-chip package. The graphics and the memory controller will be a 45nm chip in a package with the 32nm processor core die. The second chip moving forward will comprise the manageability engine for Intel® vPro, the I/O controller, and the display capabilities. This new chip for upcoming 45nm and 32nm based processors will be known as the Intel® 5 series chipset.

32nm Westmere – New instructions make Westmere more than just a smaller Nehalem.

The intention of a "Tick" in the Tick-Tock manufacturing model is to move an existing processor microarchitecture to a smaller processor core size. Typically, few (if any) enhancements are made to the processor when shrinking the die to the new process. Westmere based processors deviate from this rule by adding both new microcode instructions, as well as new hardware features to improve power management capabilities.

Westmere processors will introduce new instructions for accelerating encryption and decryption algorithms. These 6 new Advanced Encryption Standard (AES) instructions will find a variety of usages in corporate computing. As an example, software can be written to take advantage of AES to enable full disk encryption.

The 32nm process with second generation high-k + metal gate transistor era begins!

Intel is poised to bring 32nm to the compute industry via the Westmere family of processors – which are the 32nm version of Intel's highly successful Intel® microarchitecture codename Nehalem. Production is expected to begin in Q4 2009. 32nm will usher in faster and lower power second generation high-k + metal gate transistors that will enable higher performing and lower power processors that continue Moore's Law.

The first products based on Westmere will launch in the client segment and will include the Clarkdale (desktop) and Arrandale (mobile) 2 core / 4 thread products. Server products will follow to enhance the Nehalem-EX and Nehalem-EP products on the roadmap. These new products will enable higher performance in the same thermal envelope, improved power management features, and new instructions for accelerating encryption and decryption.

Intel's 32nm process technology is on track for production readiness in Q4 2009.

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All data is based on comparisons of engineering data sheets or measurements using actual hardware or simulators.

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