

Global Optoelectronics Industry Market Report and Forecast

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7 Image Sensors

7.1 Market Overview

Worldwide image sensor sales continued to grow rapidly in 2006, reaching \$7.4 billion in revenue (Figure 7.1), due primarily to the continued growth of camera phones. Complementary metal-oxide semiconductor (CMOS) image sensors led revenue with small, low cost sensors ideal for the mobile phone market. Although CMOS imagers have in previous years been less expensive and consumed less power than charge-coupled devices (CCD), they were plagued by high signal-to-noise ratios. In 2005, CMOS imagers achieved an improved signal-to-noise ratio (SNR) as a result of research investment to address the emerging high-volume integrated mobile phone/camera market.

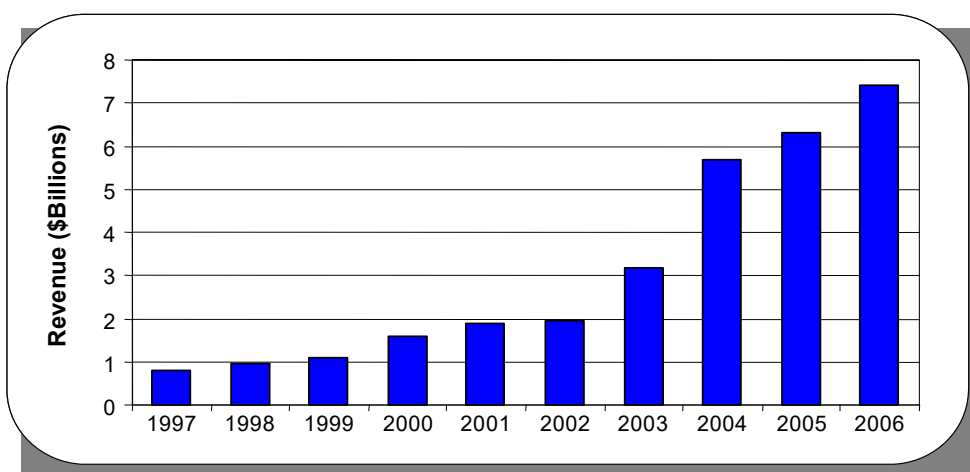


Figure 7.1: Worldwide Image Sensor Revenue, 1997-2006

Sources: Strategies Unlimited, Micron, IC Insights, NE Asia, OIDA

The image sensor market consists of two key contributing technologies: CCDs and CMOS-based image sensors. Until 2005, CMOS imagers couldn't compete with CCD's image quality—consisting of high pixel density and good brightness resolution (photosensitivity). CMOS imagers continued to improve in 2006 and were almost as good as the image quality of CCDs. With the lower price point and higher on-chip system integration, CMOS image sensors became the component of choice for integrated camera phones.

The rapid adoption of CMOS image sensors into the new mobile/camera phones increased revenue from image sensors in 2006. The steep, early-adoption revenue for CMOS imagers will be adjusted slightly in 2007 as price erosion comes into play from competition by manufacturers (Figure 7.2). Sensor revenue is projected to increase more strongly in 2008 as new CMOS image sensor designs, with additional features such as auto focusing, promise to increase average selling prices (ASP) of camera phone sensors. Price competition is expected to intensify further after 2008 as, unlike CCD sensors, the CMOS sensor manufacturing process is not difficult enough to present an obstacle to foreign competition.

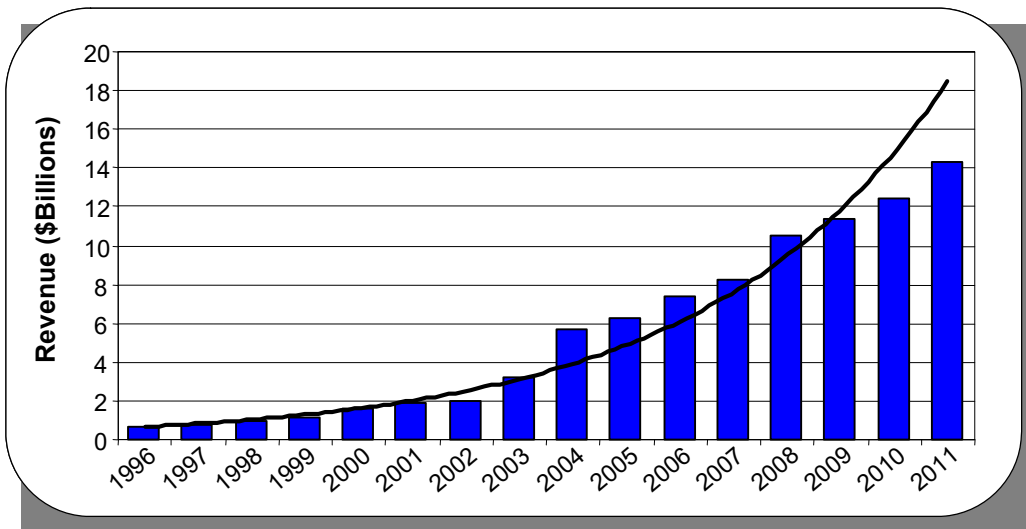


Figure 7.2: Maturing Image Sensor Revenue and Forecast, 1996-2011

Sources: Strategies Unlimited, Micron, IC Insights, NE Asia, OIDA

Figure 7.2 shows the exponential revenue growth of image sensors into 2007-2008, continuing to reflect the strong market adoption of camera phones in 2004-2006. Revenue growth is expected to continue through 2011 (Figure 7.3), with wireless device applications as the main driver for volume sales. However, a leveling of revenue is expected after 2008 owing to price erosion and market adoption curves. New applications, including image sensors for security devices, will further contribute to revenue. Automotive imaging is potentially the next consumer application on the horizon. Continued adoption of single and multiple camera chips in portable and wireless devices including mobile phones, cameras, portable media players, toys, and additional consumer products, are forecast to drive continuing growth in image sensor revenue through 2017 although revenue growth is expected to slow during the latter part of the forecast period (Figure 7.3).

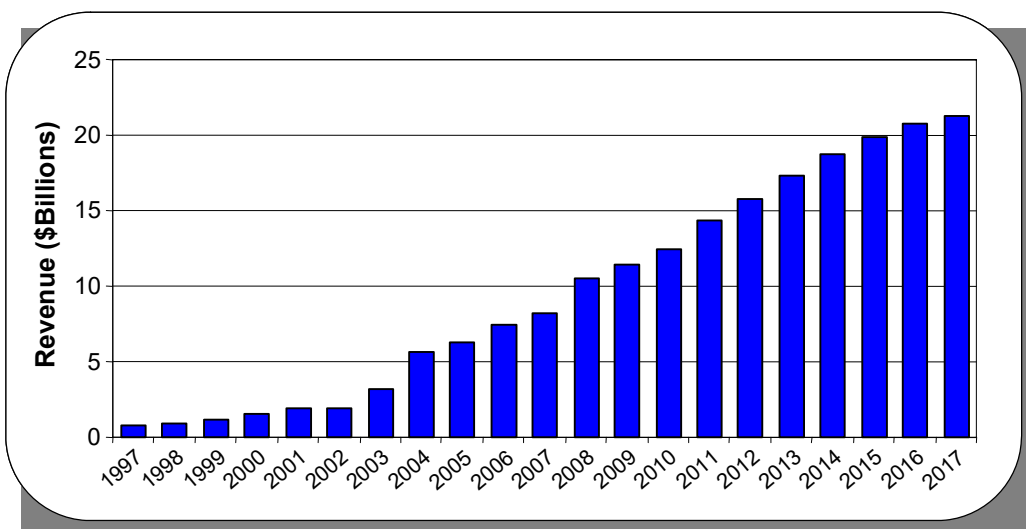


Figure 7.3: Image Sensor Revenue and Forecast, 1997-2017

Sources: Strategies Unlimited, Micron, IC Insights, NE Asia, OIDA

Worldwide image sensor sales (Figure 7.4) experienced 35% growth from 2005 to 2006, generating \$7.4 billion in revenue. This strong growth was led by camera phone sales. CMOS imaging technology helped fuel the market with small total component footprint, low power usage, improved pixel density, and acceptable image quality—all at a price that enabled adoption into the high- and mid-range consumer phone markets. Mobile phone sales are expected to remain strong into 2007, fueling image sensor revenue.

Image sensor revenue is expected to continue to grow into 2007, reaching \$8.2 billion. Although the growth rate may level somewhat owing to manufacturing competition and a maturing of the camera phone market, the introduction of new CMOS image sensor designs with additional features, including auto focusing, are forecast to increase the ASP of camera-phone sensors. This will help drive image sensor revenue to more than \$10 billion in 2008. The forecast compound annual growth rate (CAGR) for CMOS image sensors for 2008 is a robust 42%. The low price point of CMOS imagers will enable widespread deployment of new applications, such as fingerprint imaging and image sensors for vehicles, pushing expected revenue to \$12.2 billion by 2011.

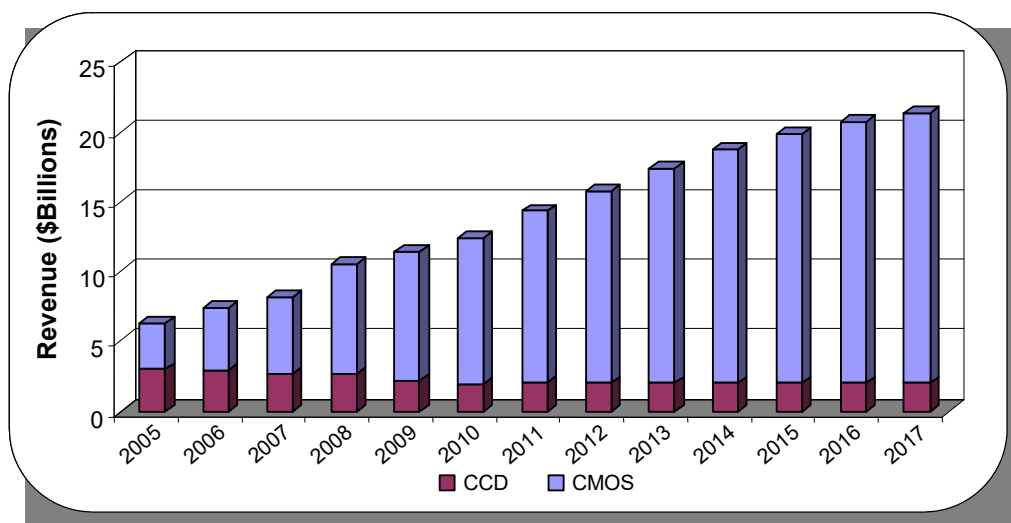


Figure 7.4: CCD and CMOS Image Sensor Revenue and Forecast, 2005-2017

Sources: Micron, IC Insights, NE Asia, TSR, OIDA

Sales of CMOS image sensors began to exceed CCD sales in late 2004, and surpassed CCDs in 2005, representing 52% of image sensor revenue. Historically, CMOS optical performance has been poorer than the more mature CCD technology that currently still offers comparatively higher image quality and has the advantage of supporting variable pixel pitch with excellent signal-to-noise ratio (SNR). Looking forward, many more CMOS imagers will be sold than CCDs, but the revenue will be tempered by pricing competition as a result of easy manufacturing and good yields. Premium, customized CMOS image sensors with additional features and designs for key applications will balance the price erosion.

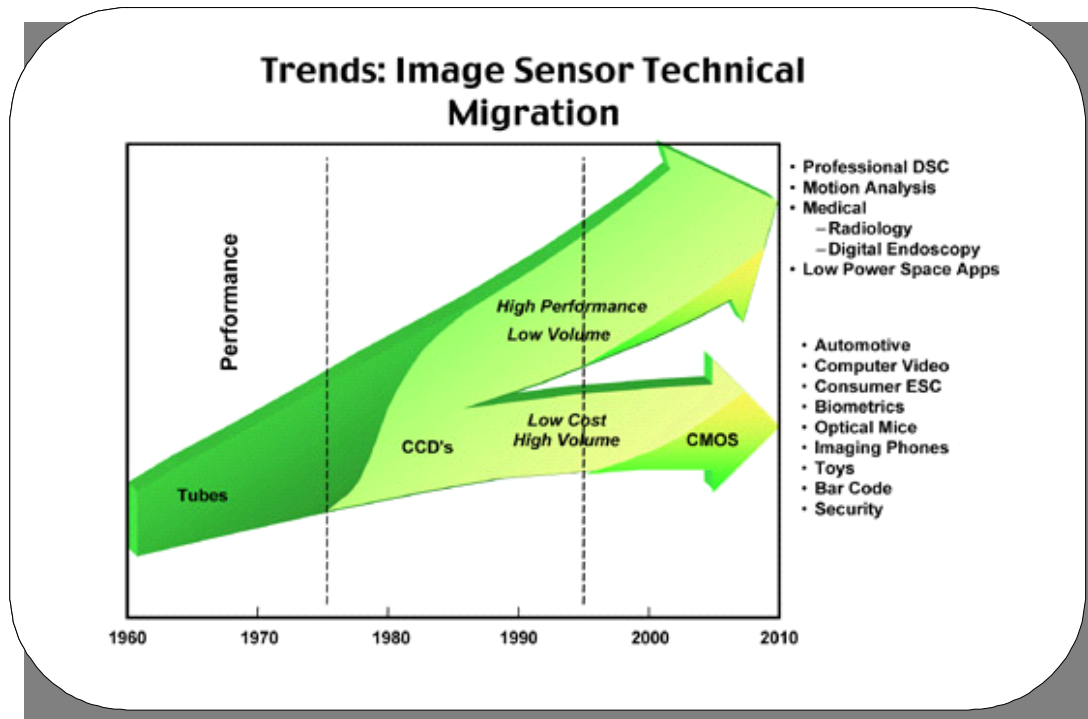


Figure 7.5: Image Sensor Migration and Materials

Source: Kodak

Image sensor products are differentiated not just by technology (CMOS vs. CCD) or pixel count, but by a variety of metrics and features. These include uniformity reduction, noise reduction, dark current, dynamic range, resistance to blooming, spectral range, ability to stitch lithographic fields into large arrays, and quality of associated integrated circuits (IC) including analog-digital conversion, color processing, and image processing.

CCDs will continue to be used for applications requiring very high quality imaging, such as medical imaging and professional cameras (Figure 7.5). CMOS has evolved into the high volume imaging sensor solution, using common silicon manufacturing processes. CMOS's integrated components, including analog-to-digital (A/D) converter and clock, combined with a small footprint and low power consumption, make CMOS the ideal solution for small handheld devices (Figure 7.6). CMOS imaging is also capable of tracking, necessary for video images; for CCDs, this requires even more circuitry.

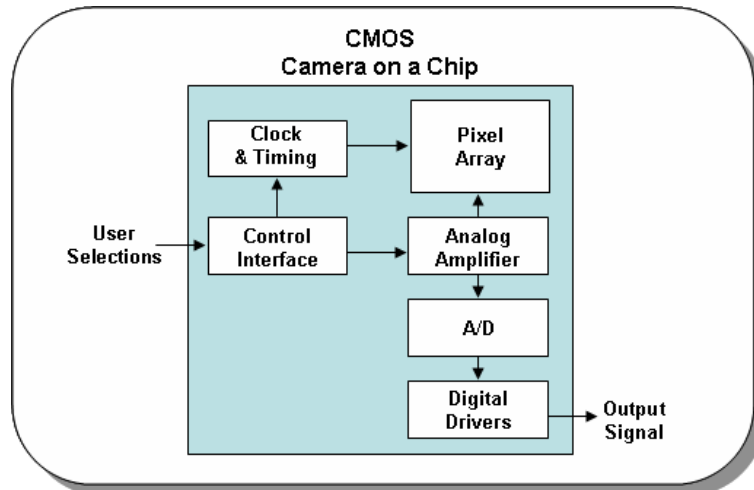


Figure 7.6: CMOS Camera Imager with On-Chip Supporting Components

Source: OIDA

In spite of their many advantages, CMOS image sensors have their drawbacks. Because CMOS chips include the associated circuitry, any changes or fixes to these components require a new chip design, which also renders them not as flexible for custom requirements. Also, in CMOS pixel arrays, each photodiode has an associated transistor(s) located next to it. This leads to decreased photo sensitivity of the CMOS array as a portion of the light hits the transistors rather than the photodiodes.

The individual photodiode transistors amplify the output of each pixel and can be individually addressed for analog to digital conversion. Since the output of each pixel is digitized, programs can be more easily applied to enhance or modify the image. However, the clocking of the decoder can interfere with the image signal readout and is one of the sources of poorer SNR (Figure 7.7).

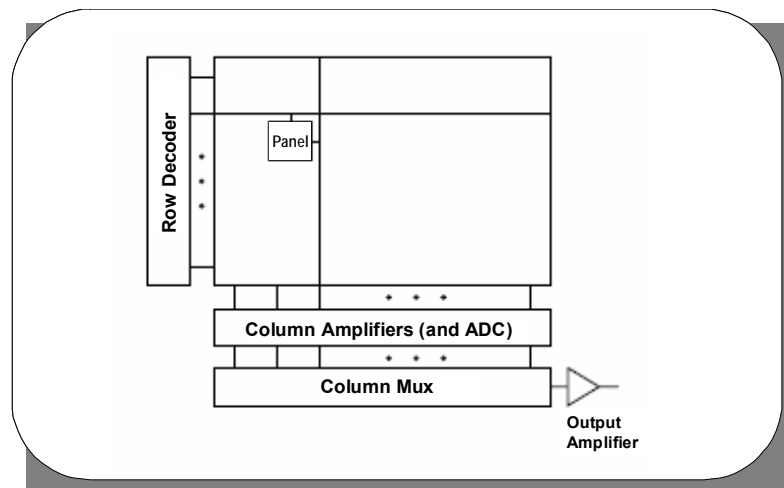


Figure 7.7: CMOS Basic Image Sensor Architecture

Source: DALSA Corporation

CCDs have historically been the dominant image sensors and have been very successful in high speed applications such as digital cameras, digital copiers, and flat bed scanners. CCDs are also appropriate for surveillance and manufacturing applications where high performance is a requirement. CCDs have traditionally had better light sensitivity as a result of their pixel architecture, where all of the light hitting the array can potentially be converted to signal.

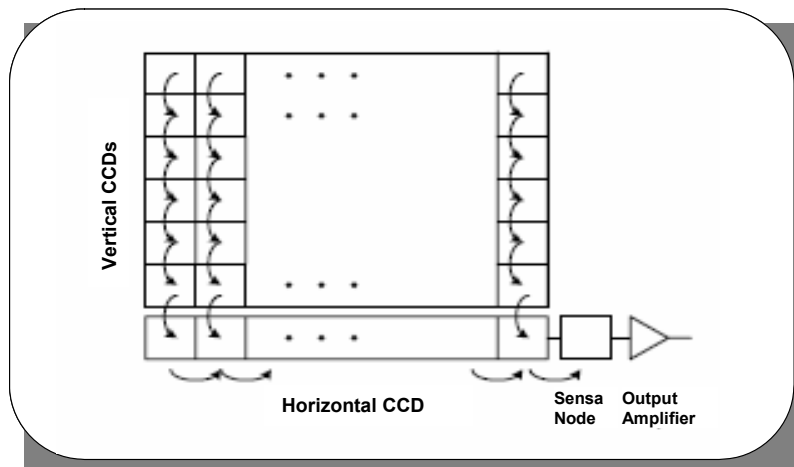


Figure 7.8: CCD Basic Image Sensor Architecture

Source: DALSA Corporation

Charge-coupled devices convert image information to an analog charge and are then read through a serial charge transfer. In a CCD, the charge is transported across the chip and read at one corner of the array. As a result, all of the readouts are processed by a common sense node and a single output amplifier (Figure 7.8). Unlike CMOS image sensors, the clocking with CCD imagers does not interfere or inject noise into the image signal. CCD also has an advantage when variable pixel pitch is required in that the charge from adjacent pixels can be binned together without the addition of noise. CCD time delay integration (TDI) devices can operate at extremely low light through their ability to sum the optical signal from multiple rows, further boosting the SNR ratio.

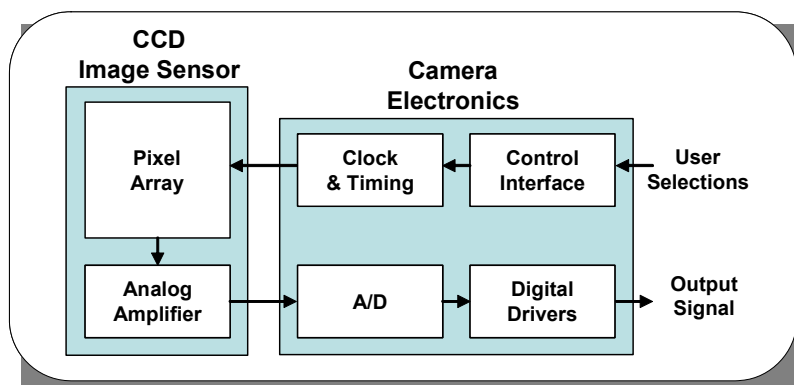


Figure 7.9: CCD Image Sensor with Off-Chip Supporting Components

Source: OIDA

Although CCDs offer high imaging performance, they are expensive to produce. Unlike CMOS, CCDs require a special manufacturing process in order to create components capable of transporting the charge across the chip without distortion (Figure 7.9). CCDs also require additional supporting components, increasing the footprint of the total solution. Power consumption is significantly higher with CCDs compared to CMOS imagers. Voltage requirements also run higher, typically over 10 volts; in some instances two different voltages are required. Lastly, current CCDs require additional components in order to support both still images as well as video.

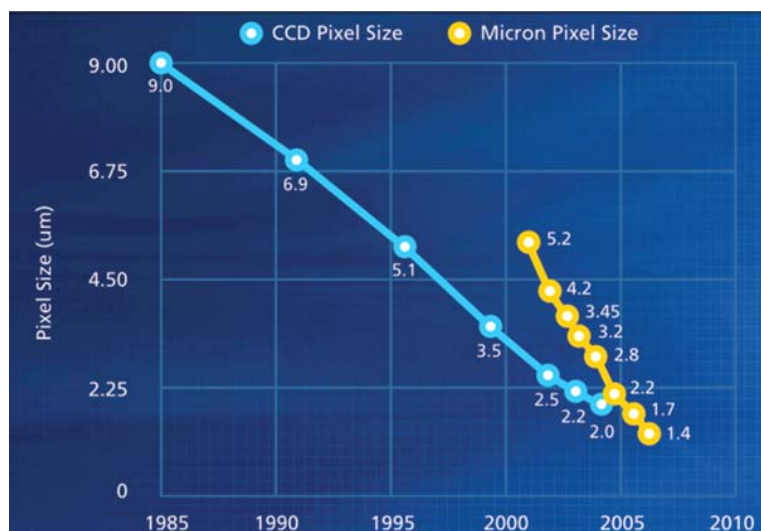


Figure 7.10: CMOS Pixel Size Developments

Source: Micron Technology, Inc.

Traditionally, a key difference between CCDs and CMOS image sensors has been the pixel pitch and the resultant pixel density. CMOS devices, due to their low signal-to-noise ratio, had faced limitations in reducing the pixel-to-pixel distance because of cross-talk between adjacent pixels. But new developments have CMOS pixel sizes achieving the CCD sub $3\mu\text{m}$ size. CMOS pixel pitch has dropped from $5.2\mu\text{m}$ pixel pitches in 2002, to $2.8\mu\text{m}$ in 2004, and $2.2\mu\text{m}$ and below in 2005, as shown in Figure 7.10. CCD pixel pitches also continue to improve. An FT-type CCD imaging device, presented by Sanyo Electric Co, Ltd of Japan at the International Solid State Circuits Conference (ISSCC) in 2005, has a pixel pitch of $1.56\mu\text{m}$ (Figure 7.11). CMOS pixel resolution is now arguably running neck-to-neck with consumer CCD devices.

Table 1 Performance Increases in CMOS and FT-type CCD Imaging Devices The table summarizes the major characteristics for current imaging devices with a pixel pitch of 3µm or less. Items changing in the last year or two are marked with >.

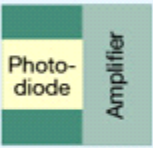

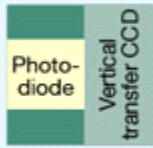
Imaging device type	CMOS (including MOS)	FT-type CCD	IT-type CCD
Major application	Spreading from camera-equipped mobile phones to general photography	Camera-equipped mobile phones	Digital cameras, camcorders, camera-equipped mobile phones stressing high pixel counts
Top view of pixel			
Aperture ratio	Max 20% > max 30%	Max 70%	Max 30%
Output signal level	Fair > Good	Very good	Good
Lower noise	Fair > Good	Fair	Very good
Resistance to smear during video photography	Very good	Fair > Good	Good
Power consumption (relative)	1	3	5
Parts count when used in camera	Very good	Good	Fair
Manufacturability on depreciated line (memory, etc)	Very good	Good	Fair
Manufacturer	Many Japanese companies (Sony, Toshiba, Matsushita Electric, etc) and foreign firms (Micron Technology, etc)	Most manufactured by Sanyo Electric	Most manufactured by Sharp, Sony, Matsushita Electric and Fuji Photo Film

Figure 7.11: CMOS vs. CCD Comparisons

Source: Nikkei Electronics Asia Magazine May 2005

In 2005, CMOS and IT-type CCDs generated the vast majority of image sensor revenue. Key manufacturers include (in no particular order) OmniVision, Micron, Sharp, STMicro, Sony, Toshiba, Matsushita, DALSA, Kodak, and Sanyo Electric. Many Japanese companies that previously dominated the CCD market are now moving into CMOS imagers, as well. The image sensor market is extremely competitive at this point: a lower-ranking manufacturer one year can dominate the market the following year. IC Insights, for example, reported significant shifts from 2004 to 2005 for the CMOS image sensor producers, as detailed in Figure 7.12. IC Insights reflects one perspective on the dynamic nature of the current image sensor market.

Top CMOS Sensor Makers (Sales*, Millions)							
2006 Rank	2005 Rank	2004 Rank	Company	2006	2005	2004	2005-2006 % Growth
1	2	8	Micron	845	439	159	92%
2	3	4	STMicro	540	415	290	30%
3	1	1	OmniVision	520	450	370	16%
	4	2	Toshiba		375	340	NA
	5	5	Sharp		290	260	NA
Top 5				NA	1969	1419	NA
Others				NA	1244	1175	NA
Total				4450	3213	2594	38%
* Sensors-only revenue; excludes camera module sales							

Figure 7.12: Top CMOS Image Sensor Manufacturers, 2004-2006

Source: IC Insights

In addition to CCD and CMOS imagers, there are other image sensing technologies that contribute to small niche markets and applications, such as x-ray imaging. Technologies include charge injection devices (CID), hybrid CCD-CMOS structures, and a-Si (amorphous silicon) designs. Contact image sensor (CIS)-based products are yet another type of sensor module and may be used with either CCD or CMOS linear arrays. However, these alternative technologies represent only a small fraction of the image sensing market segment.

7.2 Image Sensors Market Applications

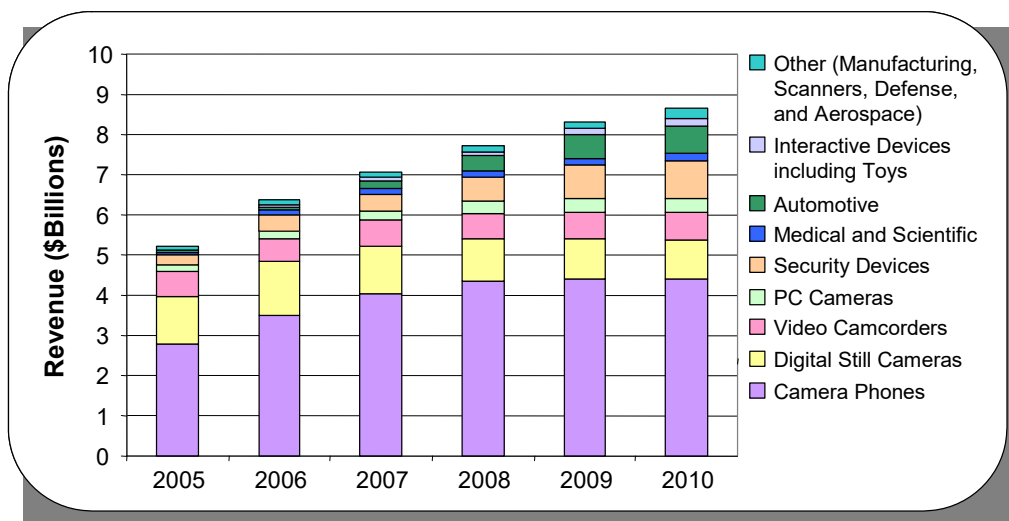


Figure 7.13: Image Sensors Market and Forecast, 2005-2010

Sources: IC Insights, OIDA