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Chapter 3: China's Science &Technology in Electronics, Microelectronics, and Nano-Technologies

Jingsong Xie, William Blanpied, and Michael Pecht

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Chapter 3: China's Science &Technology in Electronics, Microelectronics, and Nano-Technologies

Jingsong Xie, William Blanpied, and Michael Pecht

China has become increasingly committed to supporting scientific research and developing new technologies and innovations. To sustain its economic developments[2], science and technology (S&T) have played an important role in China's effort to improve its industrial business, industrial production, and labor productivity. Since the late 1970s, Chinese leaders have arrived at a reasonable consensus on how S&T can best serve the nation and how government might best support S&T development in the 21 century. A series of measures has been taken to make sure that S&T serves economic development. This chapter outlines China's S&T development policy and infrastructure as well as its latest S&T efforts and achievements with the focus on electronics, microelectronics, and nano-technologies.

1. History of China's S&T Development

China has had a long history of scientific discovery and technological progress. Well known are its inventions of gunpowder, pyrotechnics, seismic sensors, the magnetic compass, papermaking, movable type, fine porcelain and silk processing and weaving [Needham 1954, Yu 1999]. However, beginning in the 17th century, China increasingly lagged behind the West in science and technology (S&T). During the latter part of the 19th century, a handful of reform-minded Chinese recognized that the country would have to modernize and adopt Western scientific and technological practices and skills if it were to maintain its viability. Beginning in mid-century a few Chinese students, encouraged by Western missionaries, began to go abroad for higher education. At the beginning of the 20th century the Imperial Government itself began to sponsor foreign studies for selected students, even though it largely opposed many other reform measures.

Peking University, established in 1898, was the first institute of higher education created on a Western model. Following the collapse of the Qing dynasty in 1911 and the establishment of the Republic of China, several other Western-style universities were created. By 1922 almost 35,000 students were enrolled in the country's 37 national universities, provincial colleges, private Christian universities, and medical colleges. [Spence, 1990] These included prominent institutions such as Peking University, Peking Medical Union College, Tsinghua University in Beijing, Nanjing University, the Harbin University of Technology, and Northeastern University in Mukden (Shenyang). The development of higher education in China, as was the case of development in other areas, was largely arrested following the outbreak of the war with Japan in 1937. In 1952, the recently established Peoples Republic of China reorganized the recovering university system according to the Soviet system, assigning a specialty to each institution and

2 According to China's National Bureau of Statistics in 2003, China's economy experienced an annual growth rate of 9.1 percent and its GDP reached US$1.4 trillion in total and US$1,090 per capita [China News 20 Jan 2004].

limiting them primarily to instructional as opposed to research responsibilities, the latter being assigned to the newly created Chinese Academy of Sciences. It was not until the late 1970s that China once again began to make a concerted effort to become active in S&T development linked to a reconstructing of its economy. One of the reforms initiated during these years was to encourage the development of comprehensive universities that would engage in research as well as instruction. In 1983, the country awarded its first PhD degrees to students educated entirely at Chinese universities.

In the period of 1949-1978, China's S&T development and policies were directed by ideologies, the Cold War environment, and political conditions. With a highly centralized planned economy, China's S&T during this period focused primarily in military, defense, and national security areas, such as atomic energy, jet and rocket engines, electronics, and computers. China's development effort in electronics and computers started in 1955 during the first Five-Year National Development Plan (1953-1957). The first Chinese-made computer, a vacuum-tube computer named 901, was manufactured at the Institute of Military Engineering at the Harbin University of Technology in 1958.

In the 1960s and 1970s, several computer systems were developed and installed in universities, military laboratories, and industrial conglomerates, primarily to address national security issues such as navy command, missile launching, satellite control, geological data analysis, and production systems for oil fields [Zhang and Wang 1995]. Although its technology was outdated by the standards of the West, China was at that time one of the world's largest electronic producers, primarily of vacuum-tube devices. In 1976, for example, China was the world's second largest maker of radios [Tang 1984]. However, China's slow movement – at times stagnation or even backlash – in S&T development due to the political situation during this period further broadened its technological gap with the West. In particular, the ten years of the Cultural Revolution (1966-1976), a nation-wide political upheaval caused by power struggles and ideological confrontations among the top Chinese leadership, significantly impeded the evolution of S&T in the country [Wang 1993].

The ascendancy of Deng Xiaoping in 1978 ushered in a period of reform of China's domestic policies and institutions, as well as its international relations that, with occasional lapses, has largely persisted until the present. In particular, 1978 marked the starting point for China's transition from a Soviet-style planned economy to a market economy, with S&T assigned key roles in that transition. In March 1978 at the National Science Conference held in Beijing, priority areas for scientific development were announced, namely: energy sources, computers, lasers and space technology, high energy physics and genetics. At that same meeting a crash program to train 800,000 additional science workers was initiated, and the development of 88 key universities announced. [Spence 1990]. In December of that year the 3rd Plenum of the 11th Congress of the Communist Party of China (CPC) under the leadership of Deng Xiaoping, formally announced an historical shift in the Party's priorities from political revolution to economic development, and committed itself to upgrading agriculture, industry, military, and S&T known as the "four modernizations".

In 1978, China also formally adopted an open-door policy which permitted limited amounts of foreign direct investment and the entry of multinational corporations in the country. It also encouraged selected students to go abroad for advanced education. Following reestablishment of diplomatic relations with the United States in 1979, the two governments adopted formal agreements that initiated cooperative research programs and paved the way for significant numbers of Chinese graduate students to study in the United States. Realizing the importance of S&T in economic development, the Chinese government began to put forward detailed principles and policies to address S&T development. During the mid-1980s, a systematic S&T development policy took shape and was later continuously improved with the progress of economic reform. In 1982, the government issued a guideline for China's S&T policy, stating that economic development must rely on S&T and that S&T must be enhanced to serve economic development [Wang 1993, Yu 1999]. A pivotal 1985 document issued by the Central Committee of the CPC entitled "Decision on Reform of the S&T Management System", was intended to break down the barriers that separated the country's research and production sectors. Key provisions included sharp reductions in the budgets of the R&D institutes of the Chinese Academy of Sciences (CAS) with the objective of forcing them to supplement their funds by means of contracts with various enterprises. Subsequently, many inefficient R&D institutes attached to Ministries were either reformed or abolished, and several CAS institutes that focused primarily on development activities were converted into enterprises, thereby obliging them either to become primarily self sufficient, or to be shut down. [Suttmeier and Cao, 1999, Gu, 2003]

From the late 1970s to the early 1990s, China's economy gradually recovered with economic reform, and overall it enjoyed moderate growth compared with later double-digit expansion. Although self-reliance was one of the fundamental principles underlying China's S&T and economic development policy and remained China's official slogan for quite some time, China began to step up technology acquisitions through import from Japan and Western countries [Barnett 1981, Naughton 1997].

China realized its distance from the West in S&T development and the weakness in its economic infrastructure, and encountered serious difficulties in absorbing imported technologies [Barnett 1981]. As a result, its S&T development in electronics and computers focused on studying, absorbing, and duplicating existing Western technologies. China also began to strengthen its higher education system to solve the problem of skilled manpower shortages, starting with the March 1978 National Science Congress in Beijing.

In the United States, after the first transistor was invented at Bell Laboratories in 1947, Intel made the world's first integrated microprocessor in 1971 [About Intel 2004]. In contrast, China's effort to develop integrated circuits (ICs) began in the late 1970s. Factory 109, owned and operated by the Chinese Academy of Science (CAS), developed a medium-scale integration (MSI) bipolar high-speed transistor-transistor logic (TTL) and emitter coupled logic (ECL) circuit, and later also put in production a large-scale integration (LSI) circuit [Tang 1984]. Tsinghua University, one of the most important research centers for IC technologies in China, developed a 1,024-bit complementary metal oxide semiconductor (CMOS) memory using JK flip-flops. It also designed China's first digital voltmeter with liquid crystal display (LCD) [Tang 1984]. The country initiated its high-performance computer development programs in the 1980s. Its first supercomputer, "Yinhe" or "Galaxy," was developed by the University of National Defense Science and Technology during the sixth Five-Year Plan (FYP) period (1981-1985), and its first personal computer (PC), Great Wall 0520CH, was developed during the seventh FYP period (1986-1990). The birth of Great Wall 0520CH resulted in the formation of the Great Wall Group, a large state-owned enterprise (SOE), in December 1986 [About Great Wall 2004].

Many other electronics and computer companies spun off from universities and research institutes in the same period. The most successful and famous are Legend (now Leveno, founded in 1984 at an institute of the Chinese Academy of Science) and Founder (founded in 1985, at Peking University). The latter reflected China's effort to build application-oriented S&T research and a market-oriented electronics and computer industry.

China's electronic research, development, and manufacturing relied on foreign technologies for high-performance electronics. National programs of economic reform in China that sought to upgrade the microelectronics sector had little success initially. China's promotional policies were pervasive and heavy-handed with respect to research, investment, and enterprise decision-making, and the measures taken were duplicative and poorly coordinated [Howell et al. 2003, Chinese Embassy 2004]. Under such circumstances, a higher profile was adopted in the 1990s to upgrade S&T policy for developing high technology and the high-tech industry.

To make China's S&T community more innovative, the government aimed to make competition for research funds more explicit and intense. In 1992, Deng put pressure on the S&T community and the government to accelerate market reform during his landmark "southern tour" to the south China cities of Shenzhen and Zhuhai to examine the results of more than a decade of economic reform. Although the government formally adopted reforms as early as the middle of the 1980s and re-affirmed this policy in the early 1990s, it was not until 1995 that a formal decision was made by the central committee of the CPC and the state council concerning the acceleration of S&T development. One year later, reform of the S&T system was specified in the ninth FYP (1996-2000) [Hsiung 2004]

2. Overview of China's S&T Policies

In May 1995, the Central Committee of the CPC and the State Council issued a "Decision on Accelerating Scientific and Technological Development," which built upon the 1985 "Decision on Reform of the S&T Management System" and established China's S&T development policy and strategy for the next several decades. It reiterated the decision that S&T research should be closely tied to the market and that institutions of higher education should seek to form joint ventures (JVs) with domestic and foreign capitalists to accelerate S&T transfer to China. The policy emphasized the need for China to use market forces to propel indigenous technologies. Realizing that China cannot compete with its foreign competitors in all areas, the State Council required concentration of limited resources in a few high technologies, such as electronics and information networks, which were considered key for delivering competitive products. In addition, the State Council called for management changes to consolidate research institutions, increase the mobility of personnel between organizations, improve the flow of information, encourage competition and open bidding on projects, protect intellectual properties, and allow talent to flourish through academic democracy. The 1995 Decision document focused on the need for the market to support applied research and discussed for the first time the role of venture capital in funding S&T research and development [Hsiung 2004, Chinese Embassy 2004].

One year later, in the ninth FYP (1996-2000), which was approved by the Eighth National People's Congress in March 1996, more details about China's effort to accelerate S&T development were published, based on the 1995 Decision. The following tenth FYP (2001-2005), which was jointly prepared by the State Development Planning Commission (SDPC) and the Ministry of Science and Technology (MOST) and made its official debut before the public in June 2001, addressed similar issues and set forth similar goals, reflecting China's long-term application of the S&T development policy. Both plans indicate that accelerating development of electronics and microelectronics is at the core of China's current S&T development policy. Some major development goals set forth in the ninth and tenth FYPs on electronics, microelectronics, and nano-technologies include [Yu 1999, MOST 2001] the following:

- focusing on the development of ICs, new devices, new computers, and telecommunication equipment to provide economic and social development with up-to-date information systems, and making preferential policies to support IC development;
- developing microchip devices, new displays, and photoelectric devices, and establishing production and export bases for computer and accessory devices;
- developing and producing digital programmed exchanges, mobile communications and optical communications equipment;
- improving the electronic industry's technical level and international competitiveness;
- achieving breakthroughs in basic and strategic high-tech studies;
- obtaining S&T personnel to meet development needs; and
- improving the nation's S&T infrastructure.

Based on the 1995 Decision and earlier official CCP documents from the 1980s on reforming and accelerating S&T development and the latest two FYPs, China's S&T development policies can be summarized in five aspects, as described below.

2.1 Tying S&T to Economic Development

The importance of S&T to a nation and its economic development was not unknown to Chinese leaders. During the latter part of the 19th century, with China's decline under its last imperial dynasty, the Qing, and the rise of the Western powers and Japan, many Chinese intellectual elites learned S&T from the West and Japan and tried to use it to rebuild the country. But their reform efforts failed, largely due to the opposition of the conservative Qing rulers who feared that such reforms would undermine their own power. A few Chinese students began to go to the United States and Europe to study from the middle of the 19th century, encouraged mainly by foreign missionaries. Japan, which at that time appeared to be modernizing and at the same time preserving its traditional character, also became a magnet for Chinese students. The numbers of those going abroad for study increased significantly at the very beginning of the 20th century as the dynasty, under pressure from foreign powers, began to sponsor selected students for foreign study. According to the terms of the so-called Boxer Remission agreed on during the last year of the presidency of Theodore Roosevelt (1908), the United States remitted $12 million of the $33 million annual indemnity resulting from the Boxer Rebellion of

1900 for the purpose of enabling Chinese students to study in the United States. A portion of this remission was used to establish an elite secondary school in Peking to prepare students for university life in the United States. This institution, created as Tsinghua School in 1911, became National Tsinghua University in 1928..

Despite the failure of the reform movements in the late Qing dynasty and the chaos that followed its collapse in 1911, many of the national universities and provincial colleges established between 1898 and the early 1930s were destined to reemerge following the years of Japanese occupation and civil war to provide a basis for China's modernization. After 1978, many of the Chinese students who had studied in the United States and Europe during the first half of the 20th century returned home and became leaders in the resurgence of Chinese S&T. Others, who had remained in the United States and who made important contributions to S&T in their adopted country, rapidly reestablished contact with their Chinese peers beginning in the late 1970s, thus contributing to the development of S&T in their native country as well.

After the foundation of the People's Republic in 1949, the Chinese leadership hoped to achieve swift improvement in China's S&T research and economic development using the Soviet-style, highly centralized planning system. Although this kind of planning system had some positive effect on China's development of its defense technologies, it has proven to be a failure in terms of the country's economic development. After experiencing almost three decades of economic experiments and occasional political upheaval, China eventually realized that it needs a market-oriented S&T system for its S&T research to support and promote its economic development. Chinese leaders have understood that "raising skills and productivity of peasants and workers is far different from developing several sophisticated technologies." [Song 1999]

Under this policy, the Chinese government encourages S&T research to be transferred from institutes to private enterprises and supports government research institutes creating joint ventures(JV) with domestic and foreign companies. As a result, the institutes themselves are officially given responsibility for determining their research directions and are also responsible for consequent profits or losses. The government also encourages government research institutes and universities to create their own high-tech companies and programs, with profits, if any, determined by the market [U.S. Embassy 1996].

2.2 Allocating Resources to High Technology Development

China remains a developing country and has limited resources available for S&T development. In 1999, for example, the total revenue of China's central government was US$70 billion, which was less than the budget for S&T technology development allocated by the U.S. government [Song 1999]. To deal with the insufficiency of available resources, the current S&T development policy requires that limited sources be concentrated on the development of selected high technologies that are key to the nation's economic development. In fact, this kind of policy and strategy has been applied to many other government-funded development programs, such as China's military modernization programs [Cox Report 1999].

It can be seen from both the ninth and tenth FYPs that electronics and microelectronics are among the key government-promoted development areas. Although nano-technology has not yet clearly appeared in the tenth FYPs, China's think tanks and the S&T community have called for putting together a unified plan for the strategic development of nano-technologies [**People's Daily**, 30 August 2000]. China has apparently accelerated the pace of building the infrastructure for its nano-technology development [**People's Daily**, 25 March 2003, 21 November 2002, 1 July 2001, and 29 June 2001]. It is likely that development of nano-technologies will become a focus in the next FYP for 2006 to 2010.

2.3 Strengthening Basic Research

China regards basic research as a foundation of the development of future technologies, as well as a driving force for sustainable long-term development of its economy [Jiang 1997, **People's Daily**, 18 June 2000, Chinese Embassy 2004]. This perspective is consistent with long standing policies of most developed countries, including the United States. [Bush 1945]

Strengthening basic research has been a goal during the ninth and now the tenth FYP periods. Both FYPs called for efforts to make breakthroughs in selected areas [IOSC 1997, MOST 2001]. In 2002, CAS increased its spending on basic research to forty percent of its total outlay, aiming at Nobel-level fundamental research. It has also taken measures to increase its scientists' creativity [Huang 2004]. One of China's national-level efforts to strengthen basic research was the launch of its National Natural Science Foundation (NSFC) in 1986. NSFC's research budget increased over thirty times from US$9.7 million in 1986 to US$308.8 million in 2002 – much higher than China's GDP growth [Hsiung 2004]. Despite these impressive gains, many Chinese scientists argue that basic research is seriously under funded. In 2004, China's basic research funding in the country was 5.2 percent of total R&D expenditures, compared with a ratio of 16 to 20 percent in the United States, Western Europe and Japan. [Blanpied, 2004]

2.4 Insisting on "Self-reliance"

"Self-reliance" has been a long-term policy for China's S&T as well as its economic development since the foundation of the People's Republic in 1949. Until the late 1970s, with the highly centralized planning economy and in the Cold War environment, "self-reliance," basically exercised as "do-it-yourself," was nothing more than a natural consequence of China's several-decades-long closed-door policy [Barnett 1981]. During this period, there were some successes on some S&T development programs under this policy, such as the synthesis of insulin [Tong 1984] and the development of China's atomic weapons and space technologies, but not without outside assistance. A well-known example is the significant contribution of Qian Xuesen to the development of China's missile and space technology. Qian, also known as Tsien Hsue-Shen, is the father of China's missile and space program and a co-founder of the Jet Propulsion Laboratories. He was recognized as the world's foremost expert on jet propulsion in the U.S. before being allowed to return to China in 1955 [Cox Report 1999].

Since the 1980s, "self-reliance" has no longer been used as an official slogan for S&T development in China. As a policy, however, it remains, but with different meanings. With China's open-door policy as a long-term foundation for its economic development, foreign technologies have made a significant impact on China's S&T development. The focus of the "self-reliance" policy has shifted to mastering key foreign technologies and utilizing those technologies in indigenously developed technologies. In electronics and microelectronics, China's ongoing effort to develop its own core semiconductor technologies, particularly its own microprocessors, is a good real-life example of this policy.

With China's entry into the World Trade Organization (WTO), the international competitiveness of its industry becomes critically important to its survival in the global economy. China sees independent S&T development as essential to increasing its industrial competitiveness and survivability. Chinese leaders have reached a consensus on "self-reliance": "God would not help those who do not help themselves" [Song 1999].

2.5 Promoting Innovation and Creativity

Innovation has been an issue in China's S&T development, particularly in the area of applied research, which some leading Chinese scientists regard as mediocre, at best. [Blanpied 2004] To make China's S&T community more innovative, the government has made competition for research funds more explicit and intense, particularly in the case of basic research. Indeed, improvements in the country's basic research capabilities are regarded as an essential precursor to a viable applied research enterprise that can lead to greater innovation. NSFC still awards a relatively small number of grants but has increased their average size. For about twenty thousand proposals annually in recent years, they had only a success rate of sixteen percent. However, the average amount of a grant increased more than six times, from US$3,400 in 1986 to US$20,800 in 2000 [Hsiung 2000

China's performance in marketed-oriented applied research so far remains problematic. Three additional elements besides strong S&T capabilities need to be integrated to address the innovation issue: intellectual property (IP) protection, capital market development, and market access to competitive foreign products. Until China makes substantial progress in these three areas, the problem of creating a culture of innovation is unlikely to be solved. Protection of IP rewards innovators for their creativity; capital markets, particularly venture capital, support product development for the market; market access to foreign products spurs competition and innovation in Chinese companies. [Gu 2004] China has been notorious for its violations of intellectual property protection, although primarily in low tech areas such as pirating CDs or books. This has, of course, may well have discouraged some would be foreign investors in Chinese start up firms. Since joining the World Trade Organization (WTO), the Chinese government has vowed to crack down on intellectual property infringements. However, the extent to which the government in Beijing can prevail in this regard over provincial party bosses intent on protecting local enterprises remains to be seen.

China's Medium- and Long-Term Plan (2006-2020)

China is currently completing a Medium and Long-Range Science and Technology: 2006-2020, under the auspices of the Leading Group on Science and Technology and the Ministry of Science and Technology (MOST) and with the overall guidance of Prime Minister Wen Jiabao. The plan is to consist of 20 elements, each of them drafted by a committee composed of both government and non-government scientists, engineers, officials, and policy analysts. In February 2004, the US National Science Foundation was invited by the NSFC to cooperate in organizing a Forum in Beijing where a group of

Chinese scientists discussed features of the draft basic research element of the plan for discussion by a group of prominent, experienced US policy makers. [Blanpied, 2004]

According to State Councilor Chen Zhili, China hopes to quadruple its GDP over its 2000 level by 2020. Clearly, S&T will be critical if that goal is to be achieved, while maintaining sustainable, environmentally friendly growth. At a November 2003 International Conference on China's Medium and Long-Range Science and Technology Development MOST (Ministry of Science and Technology) Minister Xu Guanhua described the concepts that will underlie the plan as follows:

- The highest priority is to build up an all around well-off society, consistent with sustainable development.
- Highlight strategic development, with priorities set accordingly.
- Understand the links between scientific development and economic and social development. In other words, the plan must be consistent and integrated.
- Reinforce a national system of innovation within the socialist market economy. Stress the industrialization of science and technology achievement.
- Target imbalances among the country's regions so that the plan will be regionally-specific.
- Develop and implement the plan in an open atmosphere and with a global vision.
- Involve the general public in developing and implementing the plan.

3. China's R&D Expenditures

China currently has about 0.74 million people involved in R&D activities, compared with 1.3 million in the U.S. and about 0.65 million in Japan. Since the beginning of the ninth FYP (1996-2000), China has been stepping up its efforts to increase its overall R&D spending in key economic sectors. The ratio of its Gross Expenditure in Research and Development (GERD) to the Gross Domestic Product (GDP) was merely 0.6 percent in 1996 [Hsiung 2004]. The goal in the ninth FYP was to raise this GERD-GDP ratio to 1.5 percent by the end of 2000. Although the goal was not achieved in the ninth FYP and was again written into the tenth FYP (2001-2005), China's R&D spending first reached one percent in 2000.

China's R&D spending has been accelerating in recent years. In 2001, for example, R&D spending, in terms of the total expenditure based on purchasing power parity exchange, climbed to third place in the world behind the U.S. and Japan. R&D spending accounted for 1.1 percent of the GDP, according to the Organization for Economic Cooperation and Development (OECD), a Paris-headquartered economic analysis and policy-making organization with membership from virtually all the world's developed countries. [*Xinhua,* 3 November 2003]. Assuming this ratio is based on internationally agreed on definitions, the country's GERD-GDP ratio would be comparable to that of Italy. As shown in Figure 1, since 1997-1998, China's GERD growth has been slightly higher than the GDP growth, reflecting the government's accelerated effort in S&T development. At this rate, China's GERD is likely to reach US$21 billion by the end of

2004. However, China's R&D spending remains at a low level in terms of the GERD-GDP ratio compared with several scientifically-important developed countries, and this situation is unlikely to change significantly in the near future. Compared to China's goal of 1.5 percent of GDP spending on R&D by 2005, Germany and France both have GERD-GDP ratios between 2.0 and 2.5 percent. The ratio for the United States is somewhat greater than 2.8 percent, with Japan's slightly less than 3.0 percent. [National Science Board 2004]

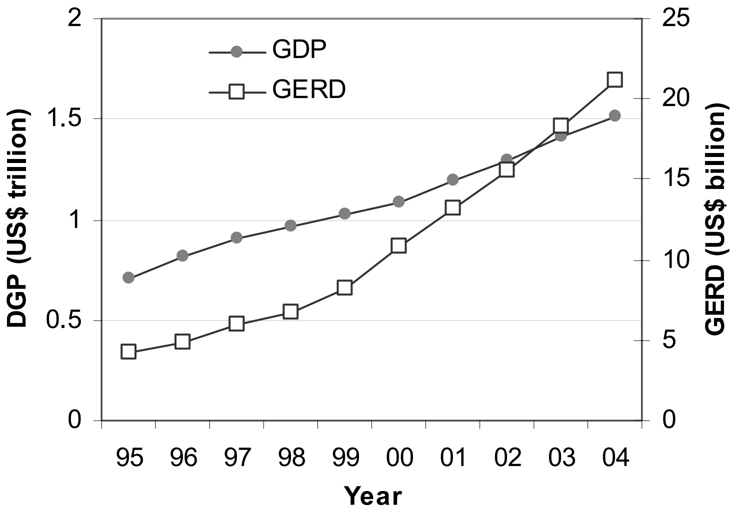

Figure 1. China's GDP and GERD (GDP ′04, GERD ′02-′04 estimated)
Source: China S&T Statistics 2002, Data Books 2000-2001, MOST 2004, OECD 2003

To make S&T contribute to its economic development, China has been encouraging product-development R&D activities. For example, in 2002, 77.8 percent of the nation's R&D spending went to product development and another 17 percent to applied research. The spending on basic research was only 5.2 percent, compared with an average of approximately 18 percent for the United States, Japan and Western Europe [Blanpied, 2004]. At the end of the ninth FYP (1996-2000), enterprises accounted for 60.4 percent of the total R&D performed in the country, R&D institutes 27.7 percent, and universities 9.8 percent. [Hsiung 2004] China (like most developed scientific countries, including the United States and Japan) also encourages non-government sectors themselves to support R&D from their own funds. Funding by enterprises has begun playing a significant role in China's S&T development, although firm data are difficult to obtain. In 2000, governments (central and provincial) were estimated to have contributed 33.3 percent of total R&D support in China, enterprises 57.6 percent, foreign sources 2.7 percent, with the balance accounted for by unspecified "Other" sources. [MOST 2002] On the other hand, approximately half of enterprise expenditures for R&D were estimated to have come from State Owned Enterprises (SOEs) and thus indirectly from the central government. If so, then 62.7 percent of China's R&D expenditures in 2000 came either directly or indirectly from government and only 28.8 percent from private enterprises. (In the United States, private industry accounts for over 65 percent of all R&D support with government accounting for somewhat less than 30 percent. In Japan, private industry accounts for a slightly higher percentage of total R&D support than in the United States and government slightly less. [National Science Board 2004])

4. China's S&T Organizational Structure

The State Council of the central government is the highest administrative body of China. There are six major ministry-level administrative organizations directly under the State Council that handle the nation's S&T development activities. A Leading Group on Science and Technology, chaired by the Prime Minister, is located organizationally between the State Council and these administrative organizations. However, most observers agree that it is relatively ineffective in setting R&D priorities, primarily because it is composed of representatives of the latter organization who devote the bulk of their attention to guarding their own turf and budgets. These administrative organizations are the Ministry of Science and Technology (MOST), the Ministry of Education (MOE), the Commission of Science, Technology and Industry for National Defense (COSTIND), the Chinese Academy of Sciences (CAS), the Chinese Academy of Engineering (CAE), and the National Natural Science Foundation of China (NSFC) (see also Figure 2) [*China in Brief* 2004, Hsiung 2002]. Among those organizations, MOST, COSTIND, and MOE have policy-making authority, in addition to varying degrees of funding authority; CAS (which receives substantial funds from the government as a budget line item to support its research activities) and CAE have advisory power; and NSFC provides research funds. Below is a brief introduction to each administrative organization.

4.1 Ministry of Science and Technology (MOST)

The predecessor of the Ministry of Science and Technology (MOST) was the State Science and Technology Commission (SSTC), which was responsible for managing and organizing China's S&T activities within a centralized planning economy. After losing its original centralized authority, SSTC's name was changed to MOST in March 1998 [Hsiung 2004]. With its basic functional shift from research activity control to policy-making and administrative management, its employees were also reduced about half during the transition.

Some key functions of MOST include:

- formulating strategies and policies for S&T development;
- conducting research on major S&T issues related to economic and social development;
- administering national technological industry development zones;
- promoting international S&T cooperation and exchanges; and
- managing and publishing S&T information.

MOST also provides substantial support for research, primarily through special large scale programs such as 863, 973 and Torch. [MOST 2002.]

4.2 Ministry of Education (MOE)

The Ministry of Education (MOE), founded in 1949, is the highest administrative organization in China responsible for education policy making, education-related laws and regulations, educational development strategies, management of higher education institutions, and vocational and adult education and occupational training. Its major functions in S&T development include [About MOE 2000]:

- promoting commercialization and application of scientific research achievements, especially on high and new technologies;
- providing guidelines to universities undertaking major national scientific research projects; and
- overseeing key state laboratories and research centers at higher education institutions.

MOE provides indirect research support by virtue of its role as the principal government supporter of the national universities.

4.3 Commission of Science, Technology and Industry for National Defense (COSTIND)

The Commission of Science, Technology and Industry for National Defense (COSTIND), formed in August 1982 by merging the National Defense Science and Technology Commission, the National Defense Industries Office of the State Council, and the Office of the Science, Technology, and Armaments Commission of the CPC Central Military Commission, is China's top national defense administrative organization. It incorporates some administrative functions of the Department of National Defense and various military-industrial corporations. Its functions in S&T include military research and development and military application of commercial technologies [About COSTIND 2000, Mulvenon and Yang 1999].

4.4 Chinese Academy of Sciences (CAS)

The Chinese Academy of Sciences (CAS), founded in November 1949 on the model of the Soviet Union, is China's premier natural science and technology research organization (see Figure 3 for its organizational structure). CAS operates over a hundred research institutes nation-wide and has over five hundred private S&T enterprises spun off from its institutes. Baseline support for these activities is provided by a line item in the central government's budget. However, CAS institutes are also obliged to seek additional support through contracts with enterprises and frequently obtain revenue from their own spin off enterprises as well. CAS has over six hundred academicians elected as the foremost experts in their fields from over a million scientists and engineers in China. In addition to its primary role in scientific research and technological development, CAS also offers graduate programs in natural sciences and applied research.

CAS is headquartered in Beijing, with a number of administrative offices throughout China. There are five divisions in CAS, forming China's highest advisory bodies on S&T development. They are mathematics and physics, chemistry, biological sciences, earth sciences, and technological sciences. CAS members and institutes serve as consultants to the government, providing S&T policy advice [Hsiung 2004].

4.5 Chinese Academy of Engineering (CAE)

The Chinese Academy of Engineering (CAE), founded in 1994, is China's premier advisory institute of engineering. It consists of seven divisions including:

- mechanical and vehicle engineering;
- information and electronic engineering;
- chemical, metallurgical, and materials engineering;
- energy and mining engineering;
- civil engineering, hydraulic engineering and architecture;
- agriculture, light industries, and environmental engineering; and
- medicine and health engineering.

It also has over six hundred academicians to provide advice and guidelines on China's engineering development [*Xinhua,* 6 January 2004, Hsiung 2002]. However, unlike CAS, CAE does not have its own research institutes. Instead, research is carried out in engineering departments at universities throughout China.

4.6 National Natural Science Foundation of China (NSFC)

The National Natural Science Foundation of China (NSFC), headquartered in Beijing, was founded in 1986 to promote and finance S&T research. Unlike the National Science Foundation (NSF) of the U.S., NSFC only funds the natural sciences, leaving the funding of social science and education to other organizations. [About NSFC 2004, Hsiung 2004]. It consists of seven major departments: mathematical and physical science, chemical science, life science, earth science, engineering and materials science, information sciences, and management science.

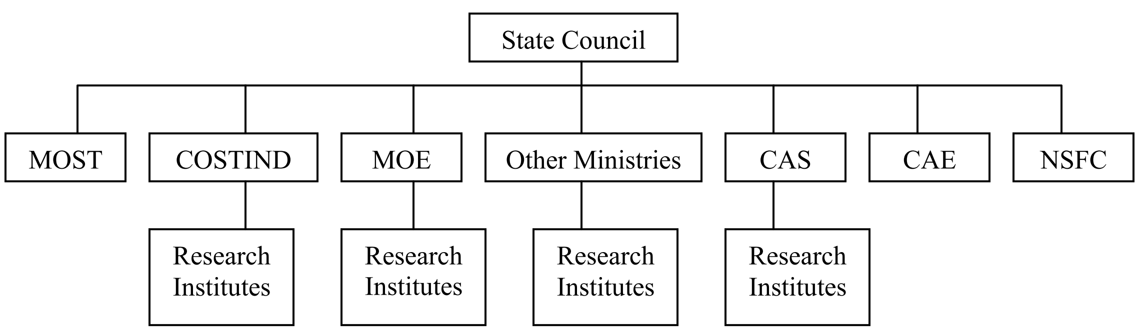

Figure 2. Organization of China's S&T management system [Hsiung 2002]

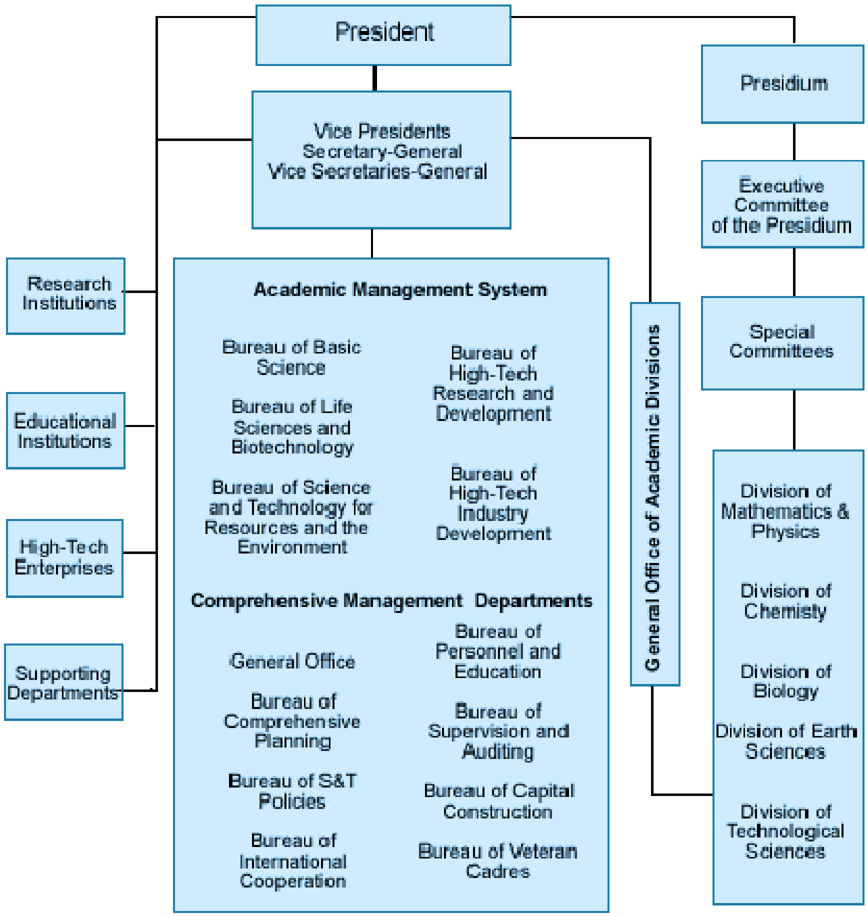

Figure 3. Organization chart of CAS [CAS Fact Sheet 2003]

5. China's S&T Infrastructure

China's national network of S&T research consists of about fifty-four hundred R&D institutions under the supervision of the central or lower-level governments, about thirty-four hundred research institutions affiliated with universities and colleges, about thirteen thousand research institutions operated by major state enterprises, and about forty-one thousand non-government research-oriented enterprises. In addition, there are more than hundred and sixty national academic societies under the jurisdiction of the Chinese Science and Technology Association, with branches across the country. In general, six major R&D resources can be identified in China:

- CAS-operated institutes and laboratories;
- R&D institutions under the various ministries and administrative agencies;
- institutes and research centers of industrial enterprises;
- universities and colleges;
- local R&D institutions; and
- R&D institutions affiliated with defense.

5.1 CAS-operated Institutes and Laboratories

As the premier research organization in China, CAS operates one hundred twenty-three research institutes and employs about sixty thousand scientists and engineers. Among these institutions, those related to electronics and microelectronics include the following:

- Institute of Computing Technology (location: Beijing, founded: 1956, technical personnel: 123)
- Institute of Semiconductor (location: Beijing, founded: 1960, technical personnel: 430)
- Institute of Electronics (location: Beijing, founded: 1956, technical personnel: 434)
- Microelectronics R&D Center (location: Beijing, founded: 1986, technical personnel: 310)
- Changchun Institute of Optics, Fine Mechanics and Physics (location: Changchun, founded: 1999, technical personnel: 1,615)
- Shanghai Institute of Microsystem and Information Technology (location: Shanghai, founded: 1999, technical personnel: N/A)
- Shanghai Institute of Optics and Fine Mechanics (location: Shanghai, founded: 1964, technical personnel: N/A)
- Institute of Optics and Electronics (location: Chengdu, founded: 1970, technical personnel: N/A)
- Xi'an Institute of Optics and Fine Mechanics (location: Xi'an, founded: 1962, technical personnel: 414)
- Hefei Institute of Intelligent Machines (location: Hefei, founded: 1979, technical personnel: N/A)

In addition to its own institutions, CAS also jointly builds research facilities with domestic and foreign enterprises and universities. In 1998, for example, CAS and its most successful spin-off, the Legend Group (now also called Leveno), established the Legend Central Institute for the development of computing technologies. In March 2003, CAS and China's two top universities, Peking University and Tsinghua University, announced the setup of a national nanoscience research center in Beijing, with a first-stage investment of US$30.2 million from the central government [**People's Daily**, 25 March 2003].

5.2 Universities and Colleges

As of 2001, China had 1,911 colleges and universities (including colleges for professional training), among which 728 offer graduate programs. In China, most of the top-level or first-tier universities are operated by either MOE or other ministries and/or agencies of the central government. Control of most universities formerly supported by other ministries has now been removed from those jurisdictions and in most cases transferred to MOE. Regional colleges and universities are under the management of local governments. Among all the universities and colleges, the most prestigious are Peking University (PKU) and Tsinghua University. PKU was founded in 1898. It has twelve key national laboratories, with information technology, nanoscience, and nanotechnologies among its most popular research areas. It also has a nanotechnology research center jointly established by its biology, physics, and microelectronics departments. Tsinghua University, on the other hand, founded in 1911, is home to fifteen key national laboratories, with the nation's strongest programs in engineering research. In addition to its main campus in Beijing, it also recently opened a campus in Shenzhen, the most developed city in southern China (adjacent to Hong Kong), to enhance its technology transfer and professional training to meet the increasing demand for new technology and technical professionals in the region. Other important research universities include Fudan University in Shanghai, Nanjing University, and the Harbin University of Technology.

In 1998, the central government initiated The World Class University Program (985 Program) providing special funds to selected national universities in order to bring them up to international standards. [Cao 2004] The accompanying table provides some statistics on these universities. [NB: The designation SCI papers refers to peer reviewed papers published in journals included in the Philadelphia-based *Science Citation Index,* considered to be the world's premier scientific journals. Engineering journals are not included in the SCI.]

	Graduate Students (2002)	**Undergraduate Students (2002)**	***SCI* Papers (2001)**	**R&D Funding from Government (%) (1999-2001)**
Beijing	12,075	14,212	1,427	80.31
Tsinghua	9,063	12,625	1,209	61.32
Harbin Univ of Tech	7,777	24,692	307	54.93
Shanghai Jiaotong	8,193	13,421	648	53.83
Fudan (Shanghai)	7,437	14,397	589	31.05
Nanjing	7,463	12,880	937	64.92
Zhejiang	13,900	27,000	868	22.76
Univ. of S&T (Heifei)	3,211	8,854	880	92.23
Xi'an Jiaotong	5,504	19,375	229	35.68

5.3 National Engineering Research Centers

Since the beginning of the eighth FYP (1991-1995), MOST has started to establish a series of National Engineering Research Centers (NERCs) to accelerate China's S&T development in electronics and microelectronics, computers, communications, automation, electronics product and process development, and other high-technology areas. Many of the centers also operate companies for quick commercialization and transfer of new technologies. The objectives of establishing those engineering centers include the following:

- converting significant scientific research results into useful, economically viable products;
- solving engineering problems related to key areas of industrial development; and
- exploring ways to integrate science and technology into the economy.

Through 2001, more than US$2 billion has been invested and over a hundred national engineering research centers have been established in China, with over one-third dedicated to the development of electronics and information technology. The major NERCs related to electronics, microelectronics, and nanotechnologies in China are these:

- NERC for Application Specific Integrated Circuit Systems (Southeast University)
- NERC for Application Specific Integrated Circuit Design (The Institute of Automation, CAS)
- NERC for Data Communications (The Research Institute of Data Communications of the Ministry of Posts and Telecommunications)
- NERC for Flat Panel Displays (The Nanjing Electronic Devices Institute)
- NERC for Parallel Computers (The Institute of Computing Technology, CAS, and the Jingnan Institute of Computing Technology)
- NERC for Mobile Satellite Communication (The Panda Electronics Group Company)
- NERC for Digital Switching Systems (The Information Technology Institute of the People's Liberation Army
- NERC for Computer Integrated Manufacturing Systems (Tsinghua University)
- NERC for Solid State Lasers (The North China Research Institute of Electro-Optics)
- NERC for Power Automation (The Nanjing Automation Research Institute of the Ministry of Electric Power)
- NERC for Specific Pumps and Valves (The 11th Research Institute of the China Aerospace Corporation)
- NERC for Industrial Control Devices and Systems (The No. 502 Institute of China Aerospace Corporation)
- NERC for Optical Instrumentation (Zhejiang University)
- NERC for Polymer Matrix Composites (The Harbin Fiber Reinforced Plastics Research Institute)
- NERC for Fiber Reinforced Moulding Compounds (The Fiber Reinforced Plastics Research and Design Institute, the State Administration of Building Material Industry)

5.4 Science Parks

Science parks have played a significant role in China’s S&T development. These allow enterprises and R&D institutes to cooperate and interact in close proximity. Among all the science parks across the country, Zhongguancun Science Park (ZSP), located in

Beijing close to both Peking and Tsinghua Universities, is the largest, with the highest concentration of scientific, educational, and research institutes in China. The GDP output of ZSP was about US$5.5 billion in 2003 and is expected to reach US$7.2 billion in 2005. In addition to Beijing, other metropolitan cities, such as Shanghai and Xi'an, have also begun building science parks funded by the Torch Program.

6. China's Major S&T Development Programs

Setting up and funding a set of national research programs is a major feature of China's efforts to promote its S&T development and raise its overall technological level. It affects mid- to long-term S&T as well as economic development goals aimed at achieving advances in consecutive FYPs. Each program may support thousands of projects in a variety of areas. MOST is the top administrative organization responsible for the management and coordination of these programs [MOST 1998, Hsuing 2004].

China's S&T development programs are implemented in three different tiers. In the first tier are those aimed at tackling major S&T snags encountered in the nation's economic development, such as the Spark Program and the National Program for S&T for Sustainable Development, which are designed to renovate China's traditional industries and agriculture and to improve labor performance. In the second tier are programs for developing emerging technologies and the high-tech industries. Typical programs in this tier are the National High-Technology Research and Development Program (the 863 Program) and the Torch Program. In the third tier are those programs for basic and applied research, such as the National Basic Research Priorities Program [Chinese Embassy 2004].

In the areas of electronics, microelectronics, and nanotechnologies, China plans dozens of high-tech projects, ranging from high-speed broadband information systems to new materials development, to boost industrial sectors in the tenth FYP period (2000-2005). The projects focus on new technologies and products such as the third generation of mobile telecommunications, high-definition color television, satellites for live broadcasting, and digital products.

The following sections provide an overview of the high-technology development programs with a focus on the development of electronics, microelectronics, and nanotechnologies.

6.1 National High-Technology Research and Development (863) Program

The National High-Technology Research and Development Program, also referred as the "863" Program, was initiated in March 1986 at the beginning of the seventh FYP period (1986-1990). The program focused on cultivating the younger generation of S&T researchers and finding a niche in the world's high-tech industries for China. By the end of the ninth FYP (1996-2000), about US$1.9 billion had been invested to fund over five thousand projects in the program, with about one-third of this from direct government funding and the rest from enterprises and other sources. The projects funded by the program cover six major fields: information technology, biology, modern agriculture, new materials, advanced manufacturing technologies, and energy and environment. The development of a super-large-scale IC, a large-scale parallel processing computer, key optoelectronic components, and modern communication technology is included in the projects.

6.2 National Basic Research Priorities Program

The National Basic Research Priorities Program, also known as the "Climbing Program" or the "973" Program, was initiated in March 1997 during the ninth FYP (1996-2000). This program focuses on basic research that is relatively mature but still plays an important role in S&T development. During the first five years since it was initiated, this program funded about sixty projects, at a cost of US$14.5 million, in mathematics, life sciences, information science, materials science, energy, and the environment. Due to the fundamental research nature of this program, MOST also coordinates with other top administrative bodies, such as MOE, CAS, and NSFC, on project selection and management. Major projects in electronics, microelectronics, and nanotechnologies include the following:

- research on high-temperature superconductivity;
- physics of new semiconductor materials and devices;
- nano-size materials science;
- research on structure, property, molecular design, and manufacturing process of photoelectrical materials;
- research on femtosecond ultra-fast lasers;
- micro-electromechanical systems (MEMS); and
- high-performance computing.

6.4 Torch Program

The Torch Program, launched in 1988, seeks to

- develop new high-tech industries by establishing High-Technology Development Zones (HTDZs);
- help to market high-tech products;
- promote international cooperation with China's high-tech industries; and
- train and attract a talented workforce.

By the end of the ninth FYP (1996-2000), the Torch Program had supported over twenty-seven hundred projects with US$3.5 billion. Among those, the greatest number were information technology and electronics projects, with over a thousand projects totaling over US$ 1.8 billion.

The setup of HTDZs is the primary approach used by the Torch Program to accelerate the development of China's high-tech industries. In August 2002, an agreement was reached for a U.S.-China Science and Technology Innovation Park, to be established on the University of Maryland's College Park campus, and officially signed by MOST and the Technology Administration of the U.S. Department of Commerce. This will be the first overseas research park initiative to be undertaken by China. China's principle partners in the initiative are the Torch High Technology Industry Development Center of MOST and the Administrative Committee of Zhongguancun Science Park, the largest research park in China [Technology Administration 2003]. According to Professor Mote, the President of the University of Maryland, "the purpose of establishing the U.S.-China Overseas Science & Technology Innovation Park is to attract more Chinese enterprises coming to the U.S., accelerating their R&D and business expansions, promoting their innovations mutually with American enterprises" [*Jiefang Daily,* 5 November 2003].

7. China's Major S&T Development Efforts and Achievements

After almost another decade of development since 1995, when China formally adopted the policy to accelerate its S&T development process and launched several national programs to support high-tech research and development, the country has now begun to enjoy unprecedented although uneven prosperity in S&T. In 2003, China's patent applications grew twenty-two percent and domestic patent applications for the first time surpassed foreign ones [*China News,* 26 January 2004]. China has made noticeable achievements in high-tech areas that are keys to economic development, and has begun to gain ground in the world's S&T community.

On the other hand in the opinion of many Chinese scientists, basic research remains significantly, perhaps even dangerously under funded, and with the exception of less than a dozen universities, research facilities are unimpressive. [Blanpied 2004] In 2001 China's ranking in the number of scientific papers in journals listed in the *Science Citation Index* had risen to sixth place, behind the United States, the UK, Japan, Germany and France. [MOST 2002] However, the number of highly cited papers remained disappointingly small.

Despite these caveats, the country's progress in several high tech areas has been impressive. The sections below highlight the country's major development efforts and achievements in electronics, microelectronics, and nanotechnologies.

7.1 China's Indigenous IC Development

Complete dependence on foreign imports for core technologies has been a long-term bottleneck in China's electronic development. At the top of the list are the design and manufacturing technologies of high-performance ICs, particularly microprocessors and digital signal processing (DSP) units. Therefore, development of indigenous ICs has been a top priority in the national development plan and national S&T development programs since the beginning of the seventh FYP (1986-1990).

In recent years, China has made noticeable progress in the area. In December 2003, China's BLX IC Design Corp., a CAS spin-off, started marketing its 32-bit 266-MHz central processing unit for China's domestic manufacturers of set-top boxes, smart televisions, digital video recorders, and thin-client personal computers [USITO, 5 December 2003, Clendenin 2003]. The development kicked off in 1999. After three years of work, BLX first introduced the 266-MHz standard cell CPU in 2002. A next-generation of the CPU is also under the development.

Also in December 2003, China officially announced the market launch of the United-863 chip, a CPU touted as the first China-developed system-on-a-chip (SOC) and designed to be used with the Linux operating system. This CPU was distinguished from its predecessors by being developed from scratch using Chinese intellectual property rights. It was also the largest CPU China had produced to date, with each processor holding at least eight million transistors [USITO, 19 December 2003; Xinhuanet, 8 December 2003]. The United-863, also known as the MPRC-863 processor, was developed by the Micro Processor Research and Development Center (MPRC) of Peking

University with support from the 863 Program, with the aim of making China the world's second largest designer of integrated circuit products by 2020.

About the same time, a group of Chinese scientists announced the launch of two chips for 3G handsets based on Chinese-owned technology. Growing out of seven years of research conducted at the Institute of Super-large-scale Integrated Circuits in Tongji University, a Shanghai-based University, these two microchips, named the Shenxin I and Shenxin II, enabled a variety of services including digital video recording, transmission, and playback. According to the Institute, the chips, which can be used in conjunction with W-CDMA, CDMA2000 or TD-SCDMA networks, constitute a core mobile technology that will boost the domestic handset industry and reduce reliance on foreign imports. The Institute was seeking a manufacturing partner to commercialize the technology, which had been awarded seventeen patents in the U.S. and thirteen in China [USITO, 26 December 2003].

7.2 China's Avionics

China's history of aviation development dates back to the 1950s, during the Cold War. Although China developed several fighter and passenger jets from the 1950s through the 1980s, mostly based on old Soviet designs, China's aviation industry has so far not been as successful as its space programs.

In recent years, however, with an accelerated process for acquiring foreign technologies, China has developed and launched several fighter jets, all using the state-of-the-art, so-called flight-by-wire technologies. With a gradual technological buildup, China launched its first passenger jet program aimed at the commercial market, ARJ-21 (Advanced Regional Jet in the 21st Century), in February 2000. After only three years of work, China completed the design and started manufacturing on December 20, 2003. This seventy-eight to ninety-eight passenger jet was fully developed under the international standard and is expected to get off the ground in 2008 [*Shanghai Star,* January 9 2003].

To meet the stringent standards on commercial airplanes, ARJ-21's key systems will still be provided by top international companies. For example, Rockwell Collins, the U.S.-based company, has been selected as the avionics provider for ARJ-21 [Rapids, 28 April 2003; Dolven and Neuman 2004]. However, China has formed multiple task forces and companies to design and manufacture advanced avionic systems. With the help of China's preferential policy for technology transfer and the world's tough market environment for the aviation industry, China is likely to see noticeable progress in avionics development in the near future.

7.3 China's Development of the Global Positioning System

The global positioning system (GPS) is a satellite navigation system that uses multiple geosynchronic satellites to determine the location of a target on the ground. Currently, the U.S. is the only country in the world that owns the system and is able to locate an object at any time on the globe.

Because of the significant value of the GPS system in both civilian and military applications, China has been actively studying and developing GPS technologies since the 1990s. To break up the U.S. monopoly of the GPS system, the European Union (EU) and the European Space Agency first kicked off development of the Galileo satellite navigation system in 2002, despite opposition from the U.S. In September 2003, it won China's backing for the program, just several months after China successfully shot a man into orbit [*EU Business,* 18 September 2003; *SpaceDaily,* 27 September 2003].

In addition to cooperating with the EU, China has been actively developing its own GPS system independently. In October 31, 2000, it successfully put its first GPS satellite, BNTS-1 or Beidou Navigation Test Satellite-1, into orbit [Wei, 31 October 2000]. The second one, BNTS-1B, was launched on December 21, 2000 [Wei, 8 January 2001], and the third on May 25, 2003 [Ang, 25 May 2003]. With three GPS satellites in orbit, China has gained some preliminary GPS positioning capability of objects within Chinese territory and some peripheral areas.

7.4 China's Supercomputers

Since the 1980s, China has developed several series of high-performance computer and server systems to meet its needs in scientific research, space programs, weapons development, weather forecasting, and many other areas. Since the development of China's first supercomputer, "Yinhe-1" or "Galaxy-1", with a peak computing speed of 100 million Floating Point Operations per Second (MFLOPS) in 1983, several models with reduced size but enhanced performance have been developed. Yinhe-2, released in the early 1990s, was capable of 1,000 MFLOPS, and Yinhe-3 reached a computing capability of 13,000 MFLOPS in 1996 and 30,000 MFLOPS in 1998.

During the nation's Eighth Five-Year Development Plan (1991-1995), China began a major effort to advance its supercomputer technology. In 1995, the National Research Center for Intelligent Computing Systems (NCIC) and CAS' Institute of Computing Technology (CAS-ICT) announced success in the development of a super-server system, Dawning 1000, which reached 2,500 MFLOPS. In 1998, an enhanced model, Dawning 2000-I, became capable of operations at a speed of 20,000 MFLOPS. In 2000, its successor model, Dawning 2000-II, reached 110,000 MFLOPS or 110 billion FLOPS (Giga-FLOPS or GFLOPS) in peak computing speed. The latest model of the Dawning-series computer, Dawning 3000, was released in February 2001 with a peak operational speed of 402 GFLOPS.

In 2003, China's Dawning Information Industry Corp., a joint venture of CAS-ICT, NCIC, and the National Research Center for High Performance Computers (NCHPC) funded by the 863 Program, released Dawning 4000A, a supercomputer capable of operations at 10,000-GFLOPS or 10-Tera-FLOPS (TFLOPS). This computer was built with over two thousand AMD and Intel processors. On the other hand, the National Institute of Advanced Industrial Science and Technology will combine 1,058 IBM Opteron™ servers with about 520 Intel Itanium® 2 boxes to create a Linux computing cluster that will be capable of more than 11 TFLOPS. That level of performance should put the cluster near the front of the "Top 500" List. Chip giant Intel has teamed with China's MOE to build a national computing grid – a network of computers harnessed to work together. When the grid is completed, MOE expects it to operate at more than 15 teraflops, making it one of the world's most powerful high-performance computing grids [**People's Daily**, 24 July 2003; Wang, 6 January 2004].

7.6 China's Telecommunications Effort

Driven by huge domestic market demand, China's development in telecommunications technologies has been moving rapidly and has begun to lead the world's development efforts in some areas. China is the only country in the world that is constructing both the next generation, also known as third-generation (3G), mobile networks, and one-more-generation-ahead 4G mobile networks.

In November 2003, China announced plans to build the world's largest IPv6 (Internet Protocol Version 6) network. Backed by eight major ministries and commissions, the "China Next Generation Internet Project" is estimated to cost US$170 million and was scheduled to be completed by the end of 2005 [USITO, 5 December 2003; Xu 2003].

In December 2003, Japan's Ministry of Posts and Communications disclosed plans to cooperate with China in testing 4G mobile phone technologies. Employing Internet Protocol Version 6 technology, the advanced networks will be capable of transmitting data at speeds of up to 100 Mb per second, instead of 2.4 Mb per second with the 3G technology. China has invested over US$12 million in 4G research, most of which is being conducted at Mobile Communication Research (MCR), a Shanghai branch of CAS-ICT [USITO, 5 December 2003].

On the other hand, China's deployment and development of 3G mobile networks has quickened its pace. In December 2003, Datang Telecommunications, the owner of the core technology of the Chinese-backed TD-SCDMA, a 3G wireless network standard, signed a landmark agreement with Putian and Zhongxing to cooperate on the development of TD-SCDMA network equipment. The TD-SCDMA standard was initially developed by CAS and backed heavily by MII.

This agreement is not the first to promote TD-SCDMA. In October 2002, Datang joined hands with seven local vendors, including Putian and ZTE, to establish an industry alliance around the fledgling standard. What distinguishes this new agreement from its predecessor is the extent of the promised information sharing. One reason the aforementioned TD-SCDMA industry alliance has stalled over the past year has been Datang's refusal to disclose details of its TD-SCDMA IPR to other members of the alliance. In contrast, this new agreement commits Datang to IPR sharing [USITO, 12 December 2003].

Government and market pressure combined to affect the about-face. MII has been asking companies to speed up their production of TD-SCDMA equipment, and has even explicitly directed that local alliances and patent exchanges should be used to promote 3G businesses. A second reason is the spectra of increased competition in the TD-SCDMA market. In August 2003, Siemens and Huawei formed a joint venture with the intention of engaging in TD-SCDMA business. Foreign vendors in the CDMA2000 and WCDMA markets have also recently made movement toward the new standard. Ericsson and Motorola have expressed interest in investing in TD-SCDMA, while Samsung currently plans to introduce its first TD-SCDMA handset in mid-2004 [USITO, 12 December 2003; Reuters, 19 December 2003].

7.7 China's Development on Wi-Fi

In 2003, China developed its own wireless fidelity or Wi-Fi encryption technology, a wireless communications standard first developed by the Wireless Ethernet Compatibility Alliance (WECA) to make products from different manufacturers interoperable. The Chinese government began prohibiting the import, manufacture, and sale of Wi-Fi gear that does not use this new security specification, which is unfortunately incompatible with other standards and technologies [Shim, 2 December 2003]. China made this technology available to only eleven Chinese firms, including Legend, Huawei, and Zhongxing [USITO, 12 December 2003; Shim, 11 December 2003].

7.8 China's Effort in Audio-Visual and DVD Development

Due to royalty disputes between Chinese DVD manufacturers and international patent consortia, including the groups called 6C (Toshiba, Mitsubishi, Hitachi, Panasonic, JVC, and AOL Time Warner), 3C (Phillips, Sony, and Pioneer), 1C (Thomson), and the Motion Picture Experts Group (MPEG), which administer patent licensing for data-compression standards, China has accelerated the development process of its own audio-visual and DVD encryption technology and standards. In December 2003, a technical working group charged with developing new standards for audio-visual data compression submitted to MII for review a new Chinese Audio Video Coding Standard (AVS 1.0), which will likely be approved in 2004. Earlier in November 2003, the Enhanced Versatile Disc (EVD) standard with Chinese IPR was already announced and adopted by a consortium of Chinese DVD manufacturers. As a result, Chinese DVD manufacturers can cut their royalty payments from roughly US$12 per unit down twelve cents [USITO, 5 December 2003].

8. Summary

China has made noticeable progress in the development of electronics, microelectronics, and nano-technologies. China is rapidly moving ahead in a race to become the technological powerhouse it has dreamed of becoming for decades. The country's economic development has become the primary driving force for its S&T advances. In some areas, such as telecommunications and semiconductor technologies, China has made breakthroughs.

In other important areas not directly related to economic development, progress in S&T remains more problematic. As one significant example, the country's health care delivery system has deteriorated badly, particularly in rural areas, as formerly government-managed hospitals and clinics have been privatized. Moreover as the SARS crisis indicated, the government appears ill equipped to deal rapidly and effectively with emerging infectious diseases. As another example, there remain a number of severe environmental problems in the country, including air and water pollution, deforestation and desertification. [Economist 2004] While neither China's health care nor its environmental problems can be solved solely by means of science and technology, neither can they be solved without them. Although the government certainly recognizes the severity of these problems, thus far it has given little indication that it is prepared to divert any substantial resources away from R&D more directly related to economic development to address them. It remains to be seen how China's Medium- and Long-Term S&T Development Plan (2006-2010) will deal with them.

Despite these caveats, there is no doubt that China is emerging as a significant high tech country. It has started to gain the capability of independently developing its own medium-to-high performance chips. The huge domestic telecom market has also helped China advance quickly on telecom technology development. After two decades of government efforts to raise the nation's S&T level, China's S&T in electronics, microelectronics, and nanotechnologies in general has significantly improved. In the development of electronics and microelectronics technologies, China is gradually closing its gap with the West in some key areas, such as wireless communications, video processing, and IC manufacturing.

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Appendix A. Acronyms

3G	third generation
BNTS	Beidou Navigation Test Satellite
CAE	Chinese Academy of Engineering
CAS	Chinese Academy of Sciences
CAST	Chinese Association for Science and Technology
CMOS	complementary metal oxide semiconductor
COSTIND	Commission of Science, Technology, and Industry of National Defense
CPC	Communist Party of China
CPU	central processing unit
ECL	emitter coupled logic

EU	European Union
EVD	Enhanced Versatile Disc
FYP	Five-Year Plan, also Five-Year National Development Plan
GDP	Gross domestic product
GERD	Gross Expenditure in Research and Development
GFLOPS	giga Floating Point Operations per Second
GPS	Global positioning system
HTDZ	High-Technology Development Zone
IC	integrated circuit
ICT	Institute of Computing Technology
IP	intellectual property
IPR	intellectual property rights
IPv6	Internet Protocol Version 6
JV	joint venture
LCD	liquid crystal display
LSI	large scale integration
MCR	Mobile Communication Research
MEMS	Micro-electromechanical System
MFLOPS	mega Floating Point Operations per Second
MII	Ministry of Information Industry
MOE	Ministry of Education
MOST	Ministry of Science and Technology
MPRC	Micro Processor Research and Development Center
MPEG	Motion Picture Experts Group
MSI	medium scale integration
NCIC	National Research Center for Intelligent Computing Systems
NCHPC	National Research Center for High Performance Computers
NSF	National Science Foundation
NSFC	National Natural Science Foundation of China
NERC	National Engineering Research Centers
OECD	Organization for Economic Cooperation and Development
PC	personal computer
PKU	Peking University
PLA	People's Liberation Army
R&D	Research and Development
SDPC	State Development Planning Commission
SETC	State Economic and Trade Commission
SOE	state-owned enterprise
SSTC	State Science and Technology Commission
SOC	system-on-a-chip
S&T	Science and technology
TFLOPS	tera Floating Point Operations per Second
TTL	transistor-transistor logic
USITO	United States Information Technology Office
WTO	World Trade Organization
WECA	Wireless Ethernet Compatibility Alliance

Wi-Fi	Wireless fidelity
ZSP	Zhongguancun Science Park