22330

SOVIET PROGRESS IN THE PRODUCTION OF INTEGRATED CIRCUITS

(2-12 OCTOBER 1972)

~~Secret~~
COPY NO

WARNING

This document contains information affecting the national defense of the United States, within the meaning of Title 18, sections 793 and 794, of the US Code, as amended. Its transmission or revelation of its contents to or receipt by an unauthorized person is prohibited by law.

Foreword

This paper, prepared by [redacted] the Office of Economic Research, analyzes and assesses evidence concerning the output and quality of Soviet integrated circuits (ICs), and the apparent need of the USSR for Western IC production technology and machinery. This paper has not been formerly coordinated within the US intelligence community.

Soviet Progress in the Production of Integrated Circuits

Introduction

1. The USSR has a very active program to develop and produce integrated circuits (ICs).* IC production lines have been set up and apparently are operating in at least three plants. There are unconfirmed reports of production lines in six other facilities and of two additional plants wholly engaged in producing ICs. Moreover, the Soviets have exhibited IC devices at international exhibits each year since 1969, and each year the number of types of devices exhibited has grown larger. Beginning in 1970, some items of IC production machinery have also been displayed. These exhibitions have been interpreted by some observers as an indication of the growing sophistication and capability of the USSR in IC production.

2. On the other hand, US laboratory analysis of samples of Soviet devices that have become available indicates that the design of Soviet ICs is relatively primitive and that the quality is generally poor and inconsistent and is clearly inferior to counterpart devices produced in the United States. Soviet devices, even those with 1971 factory markings, appear to be prototypes. Laboratory analysis suggests that the USSR, as recently as 1971, still had not standardized its IC design. In addition, no Soviet series-produced civil electronic equipment is known to contain ICs, and there is no evidence that any military equipment being produced is using ICs. If the USSR is producing ICs on an industrial scale, it is unclear where they are going or how they are being used. Also puzzling, if the USSR has developed a large and viable IC industry, is

* Unless otherwise specified, the term <u>integrated circuit</u> refers to a "monolithically" structured device in which all components (active and passive) are diffused into the same (silicon) substrate.

the recent Soviet interest in purchasing IC machinery and technology on a large-scale from the West.

3. Because the USSR was very late in acquiring silicon planar technology, and because of persistent difficulties in producing high-quality silicon starting material in quantity, it is believed that ICs began to be produced in manufacturing plants only relatively recently, and that production is still on a very small scale.

Discussion

Planar Technology

4. IC technology is an outgrowth of advances in silicon epitaxial-planar transistor technology, and ICs are produced using essentially the same equipment and technology. It is not clear when the USSR first acquired a capability to manufacture silicon epitaxial-planar transistors. A few silicon diodes and transistors based on diffused junction technology may have been produced by 1965, but almost certainly epitaxial-planar transistors or other devices such as field-effect transistors (FETs) that are based on silicon planar technology were not being produced.* In fact, in 1965 the Soviet semiconductor industry was very small by US standards.** Relatively few types of semiconductors were in production, and most were simple germanium types based on point-contact, alloyed, and diffused junction technologies. Most of the

* According to the Soviet press, the first domestic consumer radio to use silicon transistors was the "Selga-402," manufactured in December 1970.
** It is estimated that the USSR, in 1965, produced 300 million to 350 million semiconductors (mostly germanium and largely diodes) compared to an output of more than 1.5 billion units in the United States. Actually, the level of output for the United States is much higher. Large US firms such as IBM manufacture large quantities of semiconductors for their own use which are not reported in US statistical data.

electronics equipment produced in the USSR at that time, both civil and military, was based on vacuum tubes.*

5. The first evidence that the USSR had manufactured transistors using planar technology was an official Soviet brochure published in 1967. As brochures on electronics hardware are frequently published when only experimental prototypes have been made, this evidence cannot be taken as proof that planar devices were in serial production at that time. Probably, the first limited production of silicon transistors based on planar technology took place during 1968-69.** The first Soviet planar transistor to become available for analysis by US experts was manufactured in 1968, and an actual Soviet production line for planar transistors was seen for the first time in 1969 by foreign visitors at the Svetlana plant in Leningrad.***

Silicon Materials Technology

6. It is believed that planar devices (transistors or ICs) could not have been in production on a large scale before 1970 at the earliest because of the limited availability of requisite high-purity monocrystalline silicon.† The evidence

---

* In contrast, in 1965, electronic component production in the United States was based almost entirely on semiconductors, a major shift to the production of silicon semiconductors had taken place, and the basic technology and industrial base for the large-scale production of monolithic ICs had been developed.

** As of December 1971, planar and epitaxial-planar transistors accounted for only about one-tenth of the total number of types of transistors carried in Soviet catalogues.

*** Visitors to Svetlana in 1968 did not report, and apparently were not shown, such a line.

† As a raw material, silicon is one of the most abundant substances in the earth's crust. However, in order to transform basic silicon to the state of very high purity required for the manufacture of advanced types of semiconductors, complex machinery, sophisticated controls, and critical processing know-how are required. Silicon material passes through several precision manufacturing steps to reach a single or monocrystalline state.

of Soviet shortages of this material abounds. For example, although the USSR had offered monocrystalline silicon for sale in the West in 1968, purchasers in Europe alleged that only very small quantities of electronic grade material were actually available for purchase. Moreover, the quality of silicon that was purchased was not uniform and varied from batch to batch. [redacted] complained in 1971 that they were able to acquire only very small quantities of Soviet high-purity silicon. [redacted] stated in 1971 that both germanium and silicon crystals produced in the USSR were of poor quality. In November 1971, [redacted] complained that the silicon they were receiving from the USSR was of very poor quality. During Franco-Polish negotiations in 1971 for the export of semiconductor technology and machinery to Poland, the French allegedly made it clear that they would not honor their contract commitments if Poland used Soviet silicon. At the Third International Conference on Crystal Growth held in Marseille, France, in July 1971, [redacted] Soviet hardware used in growing single crystals was very crude and that the material produced did not measure up to US standards. Moreover, Soviet officials in attendance indicated that they were dependent on West European sources for crystal pullers for both germanium and silicon and expressed keen interest in purchasing US crystal growth equipment.

7. Finally, there is some evidence that the USSR may not be producing enough high-purity silicon to meet its semiconductor needs. A West European firm was recently reported doing "substantial" business supplying electronic-grade silicon to the USSR and to other Communist countries in Eastern Europe. Sales were being made outside of legal channels to circumvent the embargo.

State-of-the-Art in Integrated Circuits

8. Soviet state-of-the-art in integrated circuits lags significantly behind that of the United States. Technical analysis of Soviet ICs by US experts indicates serious deficiencies in design, processing, and fabrication and suggests that, at least through 1971, ICs were still in developmental prototype production. By and large, the USSR is

manufacturing only small-scale integration (SSI) devices; transistor-transistor logic (TTL) and diode-transistor logic (DTL). To a much lesser degree, emitter-coupled logic (ECL) and metal-oxide semiconductors (MOS) are also being made. The production of medium-scale integration (MSI) and large-scale integration (LSI) devices is probably several years away at best, although development could be rapidly accelerated if Western know-how and processing technology should become available. State-of-the-art for individual types of ICs based on laboratory analysis of Soviet devices is discussed below.

<u>DTLs</u>

9. Three types of Soviet DTL ICs, manufactured in 1969,* have been evaluated by two major US producers of ICs. Both firms assessed the level of technology as pre-1965 by US standards. The most significant finding was the Soviet use of dielectric isolation, which suggests an attempt at radiation hardening. However, radiation protection was only partial, at best, since the Soviet devices had no compensating diodes for protection against photocurrent, and they used a gold-aluminum metal system which has a less desirable radiation tolerance than moly-gold or all aluminum. Both evaluations revealed a number of processing/design weaknesses in the Soviet devices. These included a lack of passivation protection over the metallization, oxide defects, very poor bonding and scribing, low device density per chip, poor control of the diffusion process (indicated by wide variation of breakdown voltages from device to device), and use of a poor photoresist as evidenced by pinholes, tears, and undercutting. The IC packaging (glass-metal flat packs) also contained weaknesses such as warpage induced during the molding process, leads flush with the bottom of the package (increasing the chances of shorting), poor thermal conductivity of the glass and a high expansion coefficient of the Soviet Kovar** and glass which implied potential

---

* This was the first year that the USSR exhibited IC devices.

** A metallic alloy commonly used in making some of the metal parts of metal-glass IC packages.

problems with seal integrity at the Kovar-to-glass interface. The devices appeared to be prototypes.

Hybrid Thin Film*

10. Samples of two Soviet hybrid devices, believed to have been manufactured in 1971 and apparently designed for computer application,** were acquired and evaluated by a leading US producer of semiconductors. Both were thin-film devices with discrete transistors added. The transistors were ordinary NPN silicon devices with electrical characteristics comparable to those found in common US commercial applications. However, these hybrid devices were adjudged extremely large for their intended function (each package would take up 0.80 square inch of printed circuit board space), and both the workmanship and the quality of part of the thin-film network were poor. The packages were poor also in terms of hermetricity integrity, thermal expansion, and mechanical strength. These devices were believed to be prototypes.

MOS ICs

11. Two Soviet digital MOS devices*** manufactured in 1971 have been examined [ ] The devices were packaged in glass ceramic (molded borosilicate) flat packs. Such packaging is relatively expensive and may suggest a military application. One MOS chip contained corrosion products indicating that it was nonhermetic at one time or that contaminants were sealed in. Both chips showed numerous scratches in the metallization, oxide defects, and much foreign material attached to or in the oxide. Bond wires were in close proximity to the edge of the chips, and there was

---

* "Hybrid thin film" devices are not strictly speaking integrated circuits. However, they are fabricated by advanced techniques, are commonly used together with ICs in high reliability military/space applications in the United States and may be considered illustrative of Soviet state-of-the-art in IC technology taken in the broad sense.

** An unmarked dual flip-flop with two NOR gates, and a quad NOR gate marked 2LB111.

*** Three input NAND NOR gates, marked 8PMD16A.

no passivation protection over the metallization.* Scribe lines were very rough, mask misalignment was evident, and gate oxide was exposed. The diffusions were very large. Chip size varied because of irregular scribing; the average size was 70 mils by 70 mils. Given the same size chip, current US MOS capabilities would permit a density about one order of magnitude greater. In sum, these MOS ICs exhibited very poor workmanship by US standards and were probably prototypes.**

<u>TTLs</u>

12. A few TTL devices manufactured in 1970 and 1971 have been evaluated in [redacted] In general, [redacted] experts found that the Soviet devices for both years compared favorably in all aspects with counterpart Texas Instruments (TI) devices*** and that they are in "intensive" production. In contrast, US experts in their analysis of the data [redacted] reports have concluded that the Soviet devices compared very poorly with US devices and that the design of the devices suggests an experimental or pilot line, rather than commercial-scale production. The following major deficiencies in design and processing technology were noted:

* No Soviet ICs examined to date exhibit the use of passivation protection over the metallization.

** The poor quality of Soviet MOS ICs is not surprising since MOS transistors have themselves been developed only recently. To date, no samples of MOS transistors have been acquired, and no MOS transistor production has been observed by Western visitors to the USSR.

*** For example, the Soviet device (a quad-2 input NAND gate marked 1LB553) was said to have a speed of 14 nanoseconds (ns) compared with a "typical" speed of 13 ns for the TI device (SN 7400). The speed of the TI device appears to be incorrect. The TI catalog (CC 201 -- Integrated Circuits from Texas Instruments, dated 1 August 1969, p. 2-5) lists a typical value of 7 ns for this device. US experts state that if the TI device had a "typical" value of 13 ns it would be non-competitive in the United States.

(1) Chip size was very large -- more than twice that of TI devices. The larger size means that less than one-half as many units per wafer can be produced, and the reject ratio will be more than twice as high.

(2) Input leakage was high -- about ten times that of TI circuits -- indicating poor surface processing and passivation techniques, as well as poor emitter diffusion techniques.

(3) The power (current) consumption of the Soviet devices was about 50% higher than in the TI devices, indicating relatively higher operating temperatures and potentially degraded reliability.*

(4) The Soviet chips included redundant transistors and resistors, suggesting that the Soviet devices were in a relatively early stage of design.** In addition, the insertion of one such extra resistor in the "totem pole" output structure indicates the use of poor gold doping technology.

13. [redacted] believe that computer-aided design (CAD) techniques were used in the design and lay-out of the Soviet TTLs. For example, as evidence that masks were generated using CAD, they observe that the metallization mask contained a number that was "apparently in computer typescript." [redacted] believe that this CAD association is highly tenuous. The numbers are not symmetrical (blocked) which is typically the case with computer print-outs and could have been formed by a variety of hand methods such as overlay hand printers or simply hand-cutting during conventional

---

* A ceramic substrate (rather than metallic) is used in the Soviet devices, apparently to lower the chip's high operating temperature.
** For example, TI used redundant components in its early approach (master slice). When processing techniques were perfected, however, the redundant elements were no longer included.

rubylith slice and peel. Moreover, close examination of Soviet ICs indicates that masks probably were hand-cut to obtain the metallization pattern. The configuration of some of the slopes in this pattern could not have been generated by CAD, according to US experts in computer-aided design technology. Finally, the rather primitive design of the Soviet devices seems inconsistent with the sophisticated capabilities of CAD.

Production

14. ICs reportedly are being produced at the Lenin Electrical Engineering Works in Bryansk, at an unidentified plant in Voronezh, and at the Svetlana plant in Leningrad. In addition, a facility at the scientific research complex in Zelenograd (suburb of Moscow) may be producing ICs. [redacted] that plants in Borispol', Kiyev,* Minsk, ~~Moscow~~, Novosibirsk, and Riga also are in IC development and/or production. [redacted] IC production appears to be poorly organized, inadequately equipped, and grossly inefficient.

15. Some output data has been reported by visitors to Bryansk, Voronezh, and Leningrad. Output of ICs (DTLs and TTLs) at the Bryansk plant has been estimated by [redacted] who visited the plant [redacted] at 2.5 million to 3 million units per year based on 24 hour operation, 6 days per week. Production technology was said to be "5 years to 10 years" behind that of the United States. Western production machinery appeared to be in wide use. [redacted] some ICs at the final test stage appeared to carry the brand mark of a major US producer of ICs, although he was unable to examine the devices closely to confirm that suspicion.

16. An IC production line is installed and operating at the Svetlana plant. Output of ICs is less than, and possibly substantially less than,

* Possibly Borispol' and Kiyev are references to the same facility.

100,000 units per month.* Some Western-made equipment is in use. ICs being produced include some ECL devices. The speed claimed for these devices is 7 ns, well below average US state-of-the-art for ECLs (2 ns), and even below US state-of-the-art for TTL ICs (3 ns).** The relatively slow speed of the Soviet ECLs suggests that these are still under development and probably in experimental production.***

17. In [redacted] 1972 [redacted] visited an IC production facility at Voronezh. He estimated total annual output of ICs at about 2 million to 3 million units. The plant produces dielectrically isolated SSI TTL and MOS ICs in a flat pack configuration.† He also estimated the size of the TTL chips at 75 mils by 100 mils and the MOS chips at 100 mils by 125 mils.†† Density (number of elements per chip) of both chips was very low. All of the production machinery observed appeared to be of Soviet design. The plant had a large number of diffusion furnaces (80 single tube models); however, only 20 were in use. In contrast, there were only about 40 wire bonders.††† It is possible that the plant is scaling up but has not received all of its machinery.

18. The evidence indicates that the USSR could be producing 5 million to 7 million devices in the three plants known to have IC production lines.

---

* According to [redacted] who visited Svetlana in [redacted] 1972, the output of ICs and high-frequency transistors combined amounted to about 100,000 units per month.

** Schottky TTL devices.

*** It may be noted that the speed of ECLs being produced at Svetlana is far slower than the 3 ns speed claimed by the Soviets for ECLs more than three years ago.

† The use of dialectric isolation and flat pack encapsulation for the TTLs strongly suggests military/space applications.

†† Both chip sizes are very large for their functions by US standards.

††† This is a very low ratio of bonders to diffusion tubes by US standards. Generally, US firms have a very high ratio of bonders to diffusion tubes, anywhere from 5:1 to 20:1.

Soviet yields are probably very low, however, and the output of high-quality, useable devices is probably substantially less than 7 million. If production is also under way in some of the other facilities mentioned, gross output of ICs (including rejects) could be greater than 7 million units per year. In any case, it may be concluded that current levels of output are inadequate to meet domestic needs. A volume of output of about 50 million ICs annually would be needed merely to meet the requirements of the Soviet third-generation "RYAD" computer program. Probably, the USSR will have to import a great deal of machinery and technology from the West over the next few years if production of ICs is to be equal to rising demand.

Soviet Interest in Western Technology

19. Since 1969 the USSR has tried repeatedly to purchase technology and machinery in the West for the production of ICs and semiconductors across-the-board. The Soviets have shown interest in complete production lines for both bipolar and MOS ICs, thin-film substrates, lead frames, printed circuit boards (double-sided, multi-layer, and flexible types), transistors, diodes, and silicon-controlled rectifiers. In addition, the Soviets continue to try to purchase bonders, diffusion furnaces, thin-film deposition systems, evaporation equipment, photo plotters and pattern generators, step and repeat cameras, complete CAD systems, crystal growth furnaces, IC testers (digital and linear), reflow and flat pack soldering machines, probe testers, in-line auto coaters, photographic plates for masks, molding compounds, slicers, and high-purity silicon. It may also be noted that the Soviets, reportedly, continue to purchase large quantities of semiconductor devices.

20. In the past, the USSR has sought to buy individual items of equipment in small amounts usually from one item to five items. Piecemeal purchases of this type have been successful and apparently fairly extensive. More recently, however, the USSR has been seeking very large quantities of equipment. For example, a 1972 Soviet shopping list included 1,000 diffusion furnaces, 1,000 IC testers, and 150 probe testers.[ ]

[redacted] indicate that the Soviets may have been successful in acquiring two complete plants -- one [redacted] for bipolar DTL and TTL circuits [redacted], and the other an MOS/MSI plant [redacted]

21. In past years, the Soviets have purchased semiconductors and individual items of production machinery through third countries. More recently, however, they have been attempting to deal directly with Western firms. Probably the Soviets have found that purchases of small orders of machinery through third parties is expensive, but seldom (if ever) includes installation and technical training, creates serious maintenance problems, and is a very inefficient way to build a highly advanced and viable semiconductor industry.

22. On the basis of evidence of Soviet interest, the potential sales of semiconductor technology, production machinery, and related items by the West to the USSR over the next several years could be very large. Soviet interest in large-scale purchases of Western equipment and know-how tends to belie the suggestion that the Soviet semiconductor sector is a large, highly diversified, and technologically advanced industry.

Conclusions

23. The USSR is engaged in an intensive program to produce monolithic ICs. Some successes have been achieved, but ouput is still very small -- experimental or pilot scale by US standards. It is estimated that output of useable monolithic ICs in 1971 (in facilities known to be manufacturing ICs) probably was less than 7 million, compared to more than 400 million in the United States.*

24. The USSR is believed to be producing only SSI devices, mostly TTLs and DTLs. Some ECLs and MOSs also are being made. Hybrid ICs are under

* More than 500 million units if hybrid IC devices are included. In addition, this figure does not include large quantities of ICs produced by firms such as IBM which are for internal use and not reported.

development but apparently not in series production. MSI and LSI devices apparently are still several years away.

25. Soviet devices are of uncertain and widely varying quality and reliability. Soviet IC state-of-the-art is significantly behind that of the United States, and Soviet devices are substantially inferior to US counterparts in design and performance characteristics.

26. The USSR does not produce enough ICs to meet its civil requirements. For example, to produce third-generation RYAD computers at the rate of 3,000 per year -- apparently the rate originally planned for the current five-year plan -- an annual output of about 50 million ICs would now be needed. Such a level of output is far beyond present Soviet capabilities.

27. Little is known about the production and use of ICs for military purposes. However, no Soviet military equipment is known to contain integrated circuits, and it is believed that if such equipment exists, it exists in prototype form only.

28. Even the limited IC manufacturing capability that the USSR now has is the result, in large part, of Soviet success in acquiring crucial items of production equipment from the United States, Western Europe, and Japan. However, failure to acquire at the same time the know-how needed to set up, operate, and maintain these equipments has retarded IC production efforts.

29. The USSR is interested in purchasing IC and other semiconductor production machinery and technology on a very large scale, including whole plants on a turnkey basis. Potential sales could be very substantial over the next few years. Unless machinery and technology to produce ICs is imported on a very large scale, the USSR will continue to lag behind the United States, and the West generally, in state-of-the-art and will probably not be able to produce quality ICs at the level needed to meet civil and military needs for at least several years.