

US PHYSICISTS PAY FIRST VISIT TO CHERNOGOLOVKA SOLID STATE INSTITUTE

This year for the first time, the Soviet Union's Institute for Solid State Physics at Chernogolovka was opened to a small but select group of solid-state physicists from the United States. The unexpected visit by ten physicists to Chernogolovka took place last June during a trip that included a four-day conference in Moscow and a week-long tour of several research facilities in Moscow, Novosibirsk and Leningrad.

The US group often was surprised by the sophistication of the equipment found in the labs at Chernogolovka and elsewhere, and the group returned with many impressions about Soviet experimenters, their equipment and their materials. Among the most important were some insights into Soviet work in silicon and gallium arsenide technologies.

In a nutshell: The visitors learned that the Soviet Union probably is lagging behind the United States, West Europe and Japan by five to ten years in research on gallium arsenide; but in silicon work the Soviets have produced metal oxide semiconductor structures of unmatched quality and used them to do exciting research. While the US physicists knew of this research before their visit, they now have a much more vivid idea of the circumstances under which it has been done at Chernogolovka.

The US visitors were treated with great hospitality and in general they were given remarkably free access to the facilities they wished to see and individuals they wanted to meet. They even were permitted to bring cameras into laboratories—which is not permitted at some major US labs such as AT&T. But of course they did not see everything or talk to everybody. In some cases they may have received an exaggerated impression of Soviet capabilities, in other cases too modest an impression.

Background

The occasion for the trip by the US physicists was a bilateral seminar in



US group and Soviet hosts at the Institute for Solid State Physics in Chernogolovka. Sitting on the steps, from left, are Frank Stern and V. B. Shikin (ISSP). Standing at the front is V. B. Timofeev, a deputy director of the institute; flanking him to the left is Alan Fowler and to the right Lu Sham. In the back row, from left, are John Worlock, Arto Nurmikko, Horst Stormer, Steven Girvin, Bruce McCombe, Gregory Timp, Aron Pinczuk, and two Soviet scientists who acted as guides.

Moscow on "electronic properties of two-dimensional systems," which convened on 30 May under the auspices of the Soviet Academy of Sciences and with sponsorship by the Institute for Solid State Physics. The seminar originated during an international conference in Santa Fe, New Mexico, last year, one in a regular series devoted to two-dimensional systems. The idea of holding such a conference in the USSR was broached with V. B. Timofeev, a leading Soviet solid-state physicist and a deputy director of the institute at Chernogolovka, but Timofeev said a large international meeting would be hard to arrange. Instead he suggested a small bilateral seminar, and John Worlock of Bellcore and Phillip Stiles of Brown University took it upon themselves to propose a list of physicists to be invited. They sought to include theorists and experimenters working at diverse institutions in the United States.

The solid-state physicists from the United States who attended were Horst Stormer and Aron Pinczuk of AT&T Bell Labs, Murray Hill; Gregory Timp of AT&T, Holmdel; Alan B. Fowler and Frank Stern of IBM, Yorktown Heights; Steven M. Girvin of Indiana University; Bruce D. McCombe of the State University of New York, Buffalo; Arto V. Nurmikko of Brown University; Lu J. Sham of the University of California, San Diego; and Worlock. Among those who were invited but could not attend were Daniel C. Tsui of Princeton, Sankar Das Sarma of the University of Maryland and Stiles.

All of the participants attended the initial conference at the Institute for Physical Problems—founded by Petr Kapitsa—in Moscow, along with about 50 Soviet physicists. Naturally all the US physicists took advantage of the opportunity to visit the solid state physics institute at Chernogolovka.



Academician Yuri Ossipyan, director of the solid-state physics institute.

lovka. After that the party split into groups of three, some going to Novosibirsk, some staying in Moscow and some proceeding straight to Leningrad. At the end of the tour, the groups reconverged in Leningrad for visits to the Ioffe Institute and the Science and Technology Corporation, a new organization that intends to make a profitable business of designing, building and selling advanced scientific instrumentation.

From trip reports submitted by several of the participants and interviews with almost all of them, it is apparent that many impressions tended to confirm the stereotype that Soviet solid-state physics is strong in the theoretical tradition established by Lev Landau but that experimentation is hampered by a chronic weakness in equipment and materials preparation. "In our area of semiconductor electronics," said one participant, "there are a few stellar experimentalists in the USSR and a host of first-rate theorists." US participants were glad to meet and question theorists like Boris Altshuler, A. L. Efros, L. V. Keldysh, Boris Shlovskii and Boris Spivak, whom most of the US physicists had known previously only from their publications. A highlight of the seminar, several US participants said, was a talk by Altshuler in which he discussed time relaxation in disordered systems: Altshuler explored the possibility of an interference trap that would lead to anomalies in the time response of a mesoscopic disordered device.

It was obvious from the program, one participant reported, that "there is a great deal of concentration, particularly theoretical, in the area of electrical transport in confined sys-

tems, universal conductance fluctuations and mesoscopic effects on conductivity." On the other hand, "there was very little experimental work reported on quantum wells and superlattices."

Fowler observes that the Soviet experimenters who have managed to do outstanding work over a long period of time—Yu. V. Sharvin, for example, at the Institute for Physical Problems—have done so by "designing very simple, clean experiments." (One of Sharvin's most famous experiments, done with his son D. Yu., involved $e/2h$ oscillations in a magnetic ring and was one of the first in which mesoscopic or near-mesoscopic effects were observed.)

The US visitors found that most of the laboratories they saw "were crowded and filled with antiquated and home-built apparatus. Very rarely did we find any automation."

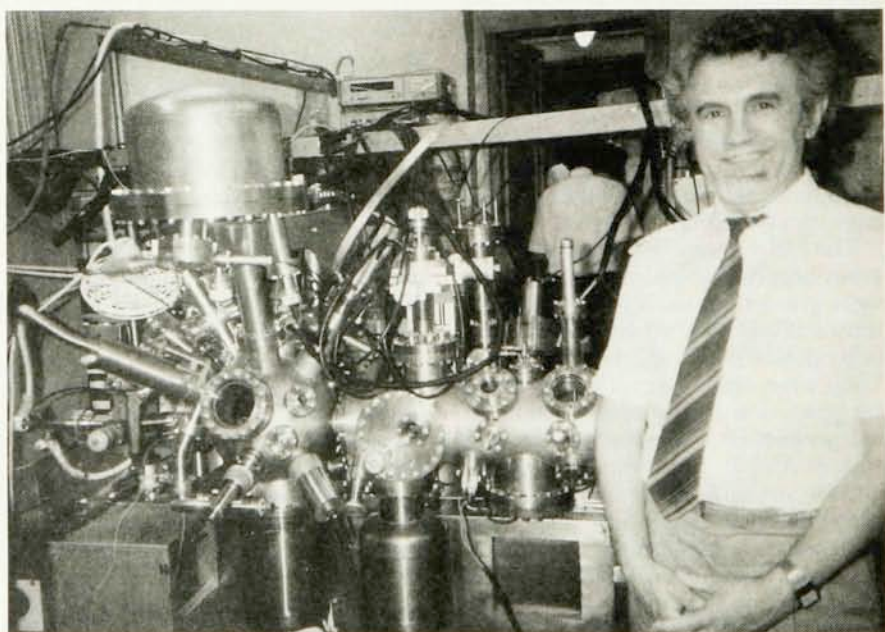
But there were exceptions. "The best laboratories were those of directors and associate directors of institutes, and some of these were almost up to date, as were many of the laboratories at Chernogolovka." Academician Zh. I. Alferov's personal group at the Ioffe Institute, which "has been among the leaders in the development of injection lasers," was found to be well equipped. V. A. Grazhulis, a deputy director at Chernogolovka, was found to be doing surface physics with excellent Soviet-built vacuum equipment—suitable for conversion to molecular beam epitaxy, in the estimation of one visitor. The director, Academician

Yuri A. Ossipyan, had a group studying stress and dislocation in crystals using, among other things, argon-ion lasers of US origin. A highlight at Chernogolovka was the work by Timofeev and his colleague I. V. Kukushkin involving observations of the fractional Hall effect using high-mobility metal oxide-silicon field-effect transistors.

While some personal computers generally were available at labs, they were relatively few and far between and often were built by Western or East German manufacturers. One of the visitors was interested to see a Russian-built computer—but upon looking through an open portal he discovered its innards consisted of Motorola chips. Another was amused to see a Bulgarian version of an Apple II. More than one of the visitors concluded from the paucity of computers that resources have been heavily committed to the military and to the space program. And their Soviet hosts observed more than once that many solid-state physicists doing basic research in the USSR have little or no contact with military R&D, in contrast to the characteristic situation at major research laboratories in the United States or even at US universities. The leaders of the Soviet labs, on the other hand, may have more contact with military research.

Chernogolovka

The invitation to visit the Institute for Solid State Physics came after the conference had begun in Moscow, and on 2 June the ten US participants



V. A. Grazhulis, deputy director of the solid state physics institute, with high-vacuum equipment for surface studies.

piled into a bus and were driven by a somewhat circuitous route to a spot about 50 km east-northeast of Moscow. The standard explanation for why no previous visit by Westerners had been allowed was that Chernogolovka is situated in the first ring of ballistic-missile defenses that surround Moscow. Another explanation was that an institute doing work on high-power chemical lasers may be situated at Chernogolovka.

Chernogolovka is a kind of solitary science city of some 20 000 inhabitants surrounded by forest. It is thought to house about eight institutes, including (in theory) the Landau Institute of Theoretical Physics, which actually has only a few rooms there and uses them only once a week for a seminar. Ossipyan is mayor of the whole town as well as director of the solid-state physics institute and, incidentally, the new president of the International Union of Pure and Applied Physics (PHYSICS TODAY, December 1987, page 76).

As described by various of the US visitors, Ossipyan is "a person who would be equally excellent at IBM, Bell Labs or as a university dean" and "a very charming, amusing and worldly man." One visitor was struck, listening to Ossipyan's welcoming talk at Chernogolovka, by the similarity between the problems he described and the ones facing anybody responsible for managing research: How do you allocate resources between basic and applied research? How do you make the case for basic work? Given constant pressure to fill all available slots with professional scientists, how do you obtain an adequate ratio of qualified technicians?

Ossipyan and associates founded the Institute for Solid State Physics about 25 years ago. It currently has about 1500 employees and supports itself largely from sales of advanced materials and metallurgical technology to Soviet industry. About 200 of the employees work in solid-state physics, and the rest in materials science. Technical support for those doing basic science is perhaps not quite what the managers would wish. A typical scientific group seems to consist of about 15 individuals, and on average only about two of them are technicians.

"The basic work," as one visitor described it, "comprises studies of electronic properties of metals and nonmetals, dielectrics, x-ray investigation, surface science, high-pressure physics and, recently, a large effort on... high- T_c superconductors—their effort involves approximately 30



INSTITUTE FOR SOLID STATE PHYSICS/CHERNOGOLOVKA

A festive tea during the afternoon at Chernogolovka. Worlock is playing the guitar.

equivalent full-time scientists." The visitors were impressed by the quality of the superconducting samples the Soviets were working with at Chernogolovka, and also by work at the Lebedev Institute in Moscow, where a group associated with Victor Bagaev and Dima Basov studies infrared properties of high- T_c materials.

The materials science at Chernogolovka includes work on refractory metals, amorphous alloys and crystal growth—mostly bulk dielectrics—the visitor said. "We were given a demonstration of the production of long thin foils of high-strength amorphous metals by splat cooling and were also shown some really fascinating examples of single-crystal sapphire grown into some very complex shapes with rather good tolerances for certain applications."

Crystal growth could be oriented in the A and B axes, the visitors learned, and possible applications of such crystals could include crucibles for use in molecular beam epitaxy. The visitors also learned that the lab has produced boron nitride, a material embargoed by the United States that is used for crystal growing in MBE systems; it is widely used in the semiconductor industry and has military applications.

The laboratory has no MBE devices as such. The standard explanation was that they are too expensive, but the lab had other pieces of equipment, some imported, that are far from cheap: for example, a Bruker Fourier-transform infrared spectrometer "with all the bells and whistles," manufactured by a company in West Germany; an ESCALAB-5, a photoemission spectrometer that is produced by Vacuum Generators in Great Britain and probably sells for more than \$500 000; and ultrahigh-vacuum surface analysis equipment produced by

RIBER in France. Soviet-built equipment included static helium cryopumps that "are capable of 10^{-13} torr and hold a 10-liter charge of liquid helium for over four months."

MOSFETs, MBEs and III-Vs

Impressions were complex and somewhat contradictory as regards the Soviet Union's status in research involving silicon and gallium arsenide technology.

It is generally agreed that the Soviets have produced "the best silicon and MOSFET samples that anybody has made." As early as 1984 Kukushkin and Timofeev were reporting on research employing silicon samples with mobilities as high as $40\,000\text{ cm}^2/\text{V sec}$, while the highest mobilities in silicon reported outside the USSR at that time were in the vicinity of $20\,000\text{ cm}^2/\text{V sec}$. Even now the highest mobilities attained outside the USSR are around $30\,000\text{ cm}^2/\text{V sec}$.

It is not clear what the source of the Soviet samples is and how characteristic they are of general Soviet capabilities. Several visitors came back with the impression that the samples were from "an industrial line"; one thought they came from some kind of industrial lab at Novosibirsk. The best guess seems to be that they are from a closed laboratory, probably in the Moscow area, that does not publish its research—in other words, a military lab. In any event, it is considered highly improbable that the Soviets produce these MOSFETs by the thousands. "They don't do anything differently than we do with silicon wafers," one visitor concluded; "somebody just went through many samples and picked out the very best ones." Another visitor concluded that the samples were random exceptions and that Soviet physicists had

no idea what accounted for them; samples with mobilities of 12 000–15 000 $\text{cm}^2/\text{V sec}$ are “their routine and ours too,” he said.

The US group found no MBE devices at Chernogolovka, as noted, and the two early models seen at Novosibirsk were unsatisfactory. “They were all built in-house and gave the impression—well, ‘outdated’ is not even the right word—of being built out of equipment that is just unsuitable for building MBE machines.” At the end of the tour the US group was told during its visit to the Science and Technology Corporation, the new instrument manufacturer in Leningrad, that the company’s first MBE device had been not very successful. The next-generation machines, the product of a joint venture with Vacuum Generators, were said to be up to snuff. “We asked to see one, but they are being manufactured in Chernogolovka (Hmmm), not in Leningrad.”

Largely because molecular-beam epitaxy is so important in the production of gallium arsenide materials, one member of the US group concluded: “In the area of semiconductor materials, especially III-Vs, the Soviet Union is simply not in the game. We saw one, repeat one, MBE machine, at the Ioffe Institute, dedicated to growing AlGaAs lasers. Maybe there are half a dozen others elsewhere in the USSR.” In the US, in contrast, any modern lab doing semiconductor physics will have several MBE machines, and even five years ago you had to have at least one.

Members of the group got somewhat different impressions about the quality of the gallium arsenide samples produced in the USSR. One says that the mobilities the Soviets have attained are an order of magnitude below those achieved in the US. According to another, the Soviets routinely achieve mobilities of about 100 000 $\text{cm}^2/\text{V sec}$ —“about where we were five years ago.” According to yet another, the best mobility the Soviets have achieved is about 1 million $\text{cm}^2/\text{V sec}$, compared with 5 million here.

At least one visitor characterized the GaAs/AlGaAs samples he saw at the Ioffe Institute as “very good quality.” “I was surprised,” he says. “I would not have expected it.” He would not agree that the Soviets are not in the game in III-Vs.

Profits and politics

The US group was impressed that the Soviets have set up the Science and Technology Corporation with a staff of some 17 000 to make a success of instrument manufacturing capitalist-

style. “Many of the usual Soviet bureaucratic rules have been eliminated, especially on foreign trade and hard money. Disemployment [that is, firing employees] is allowed.” STC operates under the aegis of the Soviet Academy, which partly accounts for its special status.

Instruments made so far by STC include the first (unsuccessful) MBE device, a Mössbauer spectrometer, and cryogenic pumps using liquid helium and liquid nitrogen. The corporation hopes this year to build a device for focused ion beam lithography at 10–100 keV, 50-nm resolution, 2 A/ cm^2 and a field of 150×150 micrometers.

The US group was impressed by the invigorating effects that new rules permitting retention of earnings are having at the STC and Chernogolovka.

The group also was impressed, more generally, by the freedom with which their Soviet counterparts talked about politics and expressed critical opinions in public. “Most striking... is the new freedom of people to know and speak the truth. For us, this removes several layers of barriers in our relationships with Soviet scientists,” Worlock observed.

The US group found that the Soviets, from lab technicians to experimenters to theorists, have been achieving remarkable results considering the circumstances under which they have been working and the

materials at their disposal. “It is a general property of Soviet labs that you can’t buy a lot of equipment off the shelf, and so you have a remarkably elaborate machine shop and foundry and impressive technical skills,” Girvin said, referring to Chernogolovka. Referring to the MBE machines at Novosibirsk, Stormer said, “It is just extremely impressive what these people get out of this kind of equipment.” Sham, a theorist, found that the Soviet solid-state physicists “tend to think very deeply about problems, which to some extent compensates for the weakness of their tools.”

The US visitors detected a general eagerness for more contact with physicists in the West, a desire to get US physics publications more promptly and a yearning for greater recognition of their work in the West. Fowler said that at all sites they visited questions were raised about the possibility of young Soviet scientists visiting labs in the United States.

With the winds of *perestroika* and *glasnost* transforming Soviet society, as well as relations between the US and USSR, the visit to Chernogolovka may not figure very big in the greater scheme of things. But for the Soviet solid-state physicists who engineered the visit, it was a “triumph,” as Worlock sees it. “The meeting had the feeling of a real celebration.”

—WILLIAM SWEET

KLEIN TO BE NAMED SENIOR EDITOR OF EINSTEIN PAPERS

An announcement is expected early this month that Martin Klein of Yale University is to be named senior editor of the Einstein papers, a joint publishing venture of Princeton University Press and the Hebrew University of Jerusalem. Klein will be assisted by two coeditors, Robert Schulmann and Jürgen Renn, who already are connected with the Einstein project. The project will continue to be headquartered at Boston University.

Klein will have overall responsibility for mapping out future volumes and for seeing to it that they meet standards, but he will stay at Yale and will not be much involved in day-to-day editing.

A theoretical physicist turned physics historian, Klein has been an adviser to the Einstein papers project from its inception. He has done research as a historian in the papers

and has published a number of articles about Einstein, mainly on Einstein’s work outside relativity.

John Stachel of Boston University, the first editor of the Einstein papers, announced his retirement earlier this year. Stachel will continue to pursue his research interests—mainly general relativity and the foundations of quantum mechanics—as a professor at Boston University, and he may continue to work as a consulting editor on the Einstein papers.

Stachel became project editor in 1977. During his tenure the project was troubled by many difficulties, including a lawsuit between Einstein’s executor and Princeton University Press. Nevertheless, the initial volume in a projected series of 40 was published last year and attracted considerable attention, especially because of the newly disclosed correspondence it included between Ein-