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TERMINAL REPORT
ON
PROJECT : DP/DRK/79/003
ESTABLISHMENT OF
Digital Bi-Polar integrated Circuit plant
IN
DPR OF KOREA

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ET&T CORPORATION LIMITED

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TERMINAL REPORT ON PROJECT DP/DRK/79/003

I Introduction

1.1 Historical

In response to a request by Government of DPR Korea, the United Nations Development Programme (UNDP) decided to assist the country to establish a pilot plant and training centre for Digital Bi-polar Integrated Circuit technology. Since this plant was conceived as a pilot plant for devices to be used in the country's industrial development, the project was entrusted to the United Nations Industrial Development Organisation (UNIDO) by UNDP. The pilot plant was to be erected in the premises of the Institute of Electronics of DPRK Academy of Sciences in a district about 35 Kms from Pyongyang.

1.2 Contractual

As per the specification laid down by UNDP for this project a global tender was floated in August 1979 by UNIDO towards the execution of the project. The scope of work entrusted to ET&T under the Contract followed by instructions from time to time was as follows :-

1) Supply of fabrication equipment as out-lined in Annexure 1A of this report.
2) Installation commissioning and handing-over of the equipment procured
3) Supply of raw material necessary for trial production (Annexure IB).
4) Training of DPR Korean engineers (from the Institute) in India and at site in Academy of Sciences.
5) The plant performance will be carried out as :
   (A) Process of test chip to establish IC process.
   (B) Fabrication of two types of TTL IC of 74 series.
6) The contract also stipulated that the following services and facilities would be made available to ET&T:
   (1) Construction of buildings including material as per the operational requirement.
   (2) Plant erection personnel with adequate skills to be made available.
   (3) Plant erection outfit. eg. Workshop, special tools raw water etc. are to be made available.
   (4) Other facilities like, accommodation, transport, telephones etc.

7) As per the original Contract ET&T was to supply equipment to install the following process systems :-

   1) Crystal Pulling and Wafer System
   2) Mask Making System
   3) Wafer fabricating system
   4) IC Assembly system

The procurement of equipment items required for the first two process viz. Crystal Pulling and Mask Making were negotiated with a highly reputed vendor in Japan. A firm order was placed after comprehensive negotiations, as the equipment among other things, consisted of certain 'strategic' components in the 'Hi-tech' area. An inordinate delay, however, ensued on the part of vendor in Japan in getting the orders for these strategic items cleared through their Government. The vendors subsequently (in 1984) indicated, in writing, their inability to supply these 'strategic' components. It was also realised at this juncture that these 'strategic' items could not be procured from any other sources (other countries). The TAC appreciated this viewpoint of ET&T experts and decided, that the equipment shorn of its 'strategic' components would not serve any useful purpose. Therefore the committee advised that the orders for Crystal Pulling and Mask Making may be cancelled. This situation necessitated a revision for the project through the letter written to UNIDO on 21st December 1984. However, with a view to fulfil the objective of the project viz., to set up Wafer fabrication facilities, the TAC recommended the import of raw wafers and a set of masks required to produce two type of TTL circuits.

1.3 Project duration

The contract between UNIDO and ET&T Corporation stipulated a period of 30 months in which to complete the project in its entirety, commission checkout performance and handover the plant to DPRK authorities. However, a project of this complexity and sophistication would not permit the execution in a simple fashion (leaving alone the training requirement of DPRK personnel). Consequently, the period of completion extended to December 1986.

II PROJECT PLANNING

2.1 Site Considerations

2.1.1 Initial Survey

In May 1982, after initial survey, it was realised that, the most effective action for this time bound project called for a programme of competent logistical support

wherein reputed international vendors would supply material or equipment. It was noted, that, buildings and roads and stable power supply had to be made available for smooth working of the facilities, to be created. A detailed plan for the equipment layout was worked out with the authorities of the Electronics Institute and a tentative PERT Chart was prepared by ET&T expert. This PERT Chart was later revised and submitted to UNIDO (March 1983).

2.1.2 Logistical

As per the PERT Chart, the identification of competent vendors, assumed importance and utmost urgency. ET&T experts conducted surveys, lodged enquiries and appointed vendors on a firm basis. This complex task of indentification of systems and subsystems was accomplished by ET&T in a record time of six months. There were hundreds of items to be produced and orders for all the equipment was completed by June 1984.

2.1.3 Constraints

The initial survey as mentioned earlier revealed the following :-

1) Disabilities caused by some Government placing embargoes on their industries from supplying 'High Tech' 'strategic' or 'core' material to DPR Korea.
2) Long lines of communications such as from European ports to the project site, with transhipment at Hongkong or at Chinese port.
3) Disabilities caused even on well established routes et. between Port Dalian in China and Pyongyang by rail, for some inexplicable reasons.
4) Possible unilateral withdrawals by vendors (as was experienced later to a considerable degree) from mutually agreed supplies hit adversely at the schedule of completion.
5) The project site was far away from any metropolitan city.
6) Disabilities caused by stable power, water and adequate heating in the work areas.
7) Disabilities caused by the basic facilities like proper workshop and tools.

Anyone or combination of any two of the above was to affect the even flow of operations involved.

2.2 Technical Considerations

2.2.1 UNIDO Project Management

UNIDO appointed a 'Project Manager' at its Headquarters in Vienna to co-ordinate the various technical and logistical activities. A technical expert was also appointed at site to monitor the project, who gave suggestions to both ET&T and the Electronics Institute in its implementation, UNIDO also appointed a Committee of three members (Technical Advisory Committee - TAC) for higher direction of project implementation. These members, who had served with internationally known firms had vast experience in the semi-conductor technology and were highly accomplished in the state-of-the-art.

This committee, therefore, was highly capable of rendering advice to all concerned including ET&T and the Electronic Institute on matters of safety, design of buildings, systems, suitability of equipment procured for the project etc. This committee normally met once in six months to review the progress made and gave valuable suggestions so that project could be concluded sucessfully. The TAC was the ultimate in the project direction.

2.2.2 Design and Drawing of the Building

During the first visit to the site in May 1982, ET&T Engineers discovered that the main building, where semiconductor process equipment is to be housed, was already in an advanced stage of completion. This structure, as constructed, was prone to vibrations and it was not suitable to create 'clean room' conditions required for wafer fabrication (TAC Report 2-9 March 1984). ET&T engineers studied this problem carefully and gave several suggestions regarding the construction, and made several changes in the ventilation system so that clean air could flow in a particular fashion. The drawings for services building were also produced as per the Operational Requirements. These drawings were submitted to the authorities of the Electronics Institute (in DPR Korea) for action.

2.2.3 System and equipment specifications

Based on the Operational Requirements defined in the tender document, ET&T engineers drew out a Qualitative Requirement of each equipment or sub-system. After detailed computations detailed specifications were drawn to be adhered to by equipment vendors. Of necessity, these specifications had to be rigid and detailed as they pertain to some of the most highly sophisticated processes adopted in the production of digital Bi-polar ICs.

2.2.4 Pre-shipment Inspection

The inspection cover for the system and equipment was provided by the ET&T experts. Each equipment sub-system and system was inspected at vendors site as to its specifications and cleared. Special packing instructions were issued to the vendors. The possible routes for conveyance and problems at different ports in a large measure ensured the safe receipt of equipment at project site.

2.2.5 Site Management

The imperatives of close supervision at the project site on day-to-day basis were recognised at an early stage of project implementation. In August 1983, therefore, ET&T established an office at Pyongyang and qualified engineers were posted from time to time to help the appointed resident engineer from India. This resident engineer was available at project site for supervision of the work on site preparation. He was to receive, segragate and store the equipment (Consigned by vendors) and attend to queries raised by the Institute and UNIDO expert at site. Apart from liaising with DPRK authorities, the resident engineer would also keep in touch with ET&T Head Office in Delhi. He also had to render administrative services to the experts from ET&T deputed to the site from

time to time. The safe storage of the equipment posed its own problems. The built up shades were small and this resulted in the equipment having had to lie out in the open until the main building was ready and able to accommodate it.

2.2.6 Training of Institute's personnel

The Institute of Electronics in the Academy of Sciences assigned a batch of ten engineers to this project. These engineers were to assist ET&T experts in erectioning the equipment and were to take over the plant after commissioning. In order to give more exposure of this technology arrangements were made by ET&T to train these key personnel (from Institute) in India. The training programme was arranged at premier training institutions in India where instruction is imparted regularly on this technology. In addition, these engineers were also assigned to important Research Institutions in India. Following are the broad details of the training programme arranged by ET&T :

No. of Trainees		*Location*	*Duration*
	BATCH I		
03		IIT-New Delhi	2 1/2 months
		TIFR-Bombay	1/2 months
	BATCH II		
07		IIT-New Delhi	2 1/2 months
05		TIFR-Bombay	1/2 months
02		IIT-Kharagpur	1/2 months

Training - 30 manmonths

Subjects covered : Diffusions, Metalisation, Mask Making, Testing, Photolithography, Assembly and packaging, Crystal pullingThe technical knowledge of these engineers were low to start with, but they learnt fast and were very useful during the erection of the plant.

2.3 Plant erection plan

As adviced by TAC, schedule was prepared for the erection and commissioning of the plant:

2.3.1 Civil Construction

Construction of Buildings to house ancillary services equipment as well as the semiconductor fabrication equipment. This building had to be of high standard (as specified by TAC members). Also water, drainage and electricity had to be made available at site.

2.3.7 **Plant erection**

Erection and commissioning of systems in three phases:

Phase I Erection of ancillary services

Phase II Erection and commissioning of Assembly system.

Phase III Erection and commissioning of wafer fabrication facility.

This plan was rational and enabled effective utilisation of skilled, semi-skilled man power. ET&T readily accepted the TAC plan for implementation.

III PROJECT EXECUTION

3.1 Civil Construction

The construction of Building and roads commenced in 1980 and was well under way in May 1982, when ET&T experts visited the site. After making several suggestions for alterations (TAC Report May 6-13 1983), the building was modified & was made suitable for the equipment to be installed. The modifications and finish of the main building took a long time and finally only 2nd floor of the main building was available for the installation of assembly equipment by June 1985. The 1st floor, where wafer fabrication equipment was to be installed, was made ready by March 1986. The construction of roads continued through out the plan period.

3.2 PHASE I Erection of Ancillary Services

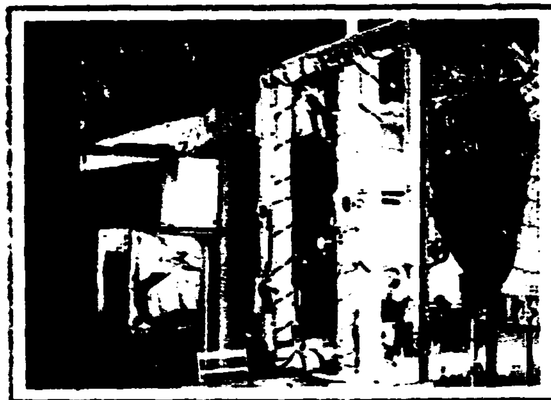
3.2.1 Erection of Power Sub-station

The pilot plant for Bi-polar Integrated Circuit requires a continuous, stable power supply of 1.3 MVA. The standard power supply available in DPRK was at 3.3 KV 60HZ. Therefore, a special transformer suitable for the power supply in DPRK was designed by ET&T and was installed at the Institute to provide a Voltage of 380V 3-phase 60 HZ at the site. All the material required to erect this substation was shipped by ET&T to project site and the substation was erected and commissioned in August 1984. However, it soon became clear that the available mains power supply needed considerable improvement in its smoothness and stability to be able to drive the sophisticated machinery and facilities installed. UNIDO appointed a special team of two experts in power engineering to advice the DPRK authorities

on the ways and means of improving the power supply. Another mains transformer was procured by DPRK authorities and was installed in 3.3KV line, which is feeding power to the Institute. Subsequent efforts under the guidance of the local expert team resulted in some improvement but only towards the fag end of the project. The Institute authorities have been briefed fully on the importance of a continuous, smooth and stable power supply.

3.2.2 **Air conditioning**

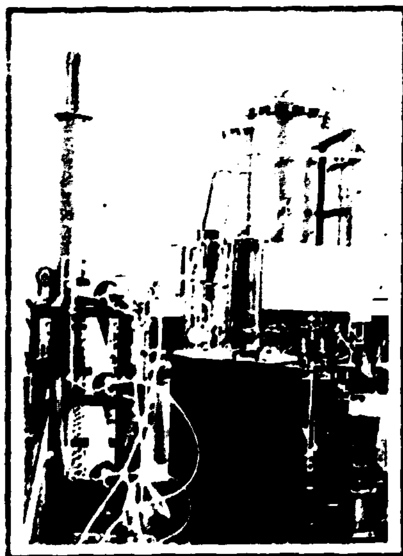
The activity commenced in April 1984, with the fabrication and fitting of ducts The process of fabrication of ducts was demonstrated by ET&T Engineers and was completed by DPRK engineers in June 1984. The 140 Tonne capacity plant was commissioned in a record time of six months (August 1984). This system can maintain following environmental conditions in the plant:



Temperature : 22°C $\pm$ 1

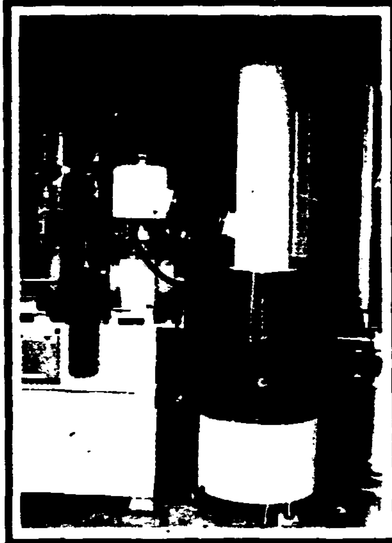
Humidity : 55% RH

3.2.3 **De-ionised Water**

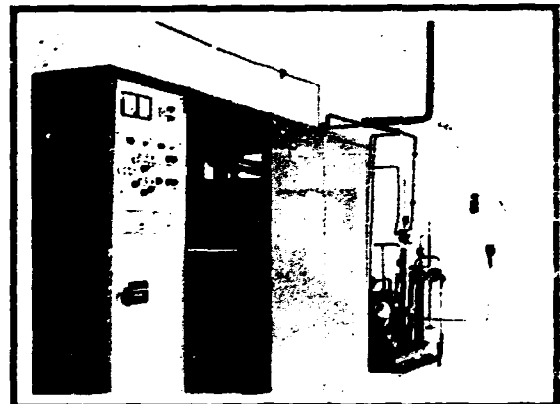


This system was installed and commissioned in December 1985. (This system works non-stop round the clock. Hence to effect economy; the commissioning was kept pending until there was need to have a continuous supply of DI Water). The system delivers high purity water at the rate of $2M^3/hr$. At the point of dispence the water conductivity is 18 M Ohm at 18° C.

3.2.4 Nitrogen Generator



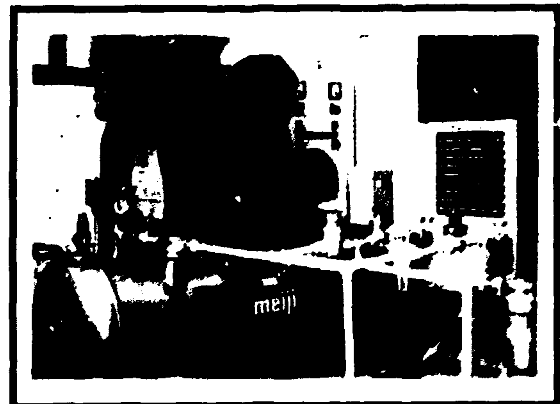
The installation of this system was taken up in August 1985. This system was affected adversely by malfunctioning of the controller in the Nitrogen Vapouriser. This component was replaced and the unit became fully operational in May 1986. There are two PLN 106 machines delivering 12 Litres of liquid Nitrogen per hour.



3.2.5 Hydrogen/Oxygen Generator

The installation of this system was taken up in April 1986. The performance of this unit too was adversely affected due to malfunctioning of the compressor unit. Subsequently, the oil and two high pressure valves were replaced and smooth production of Hydrogen and Oxygen commenced on 20th October 1986. The plant can produce 12M³ of Hydrogen at 172 Bar pressure and 6M³ of Oxygen at 172 Barr pressure.

3.2.6 Compresed Air



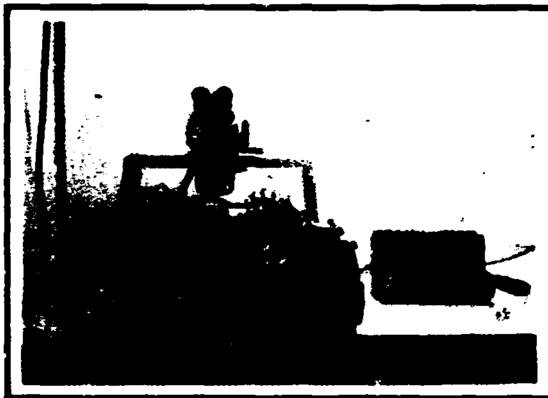
A special compressor was procured for this plant to supply dry, oil free compressed air to cater to the pneumatic part of the operations of various systems. This machine was made operational by end August 1984. The plant capacity is $1M^3$/min.

3.3 PHASE II Installation of IC Assembly System

3.3.1 Commissioning of Assembly Equipment

As s.ated earlier, alterations had to be incorporated into the main building so as to make it suitable for the semiconductor fabrication operations. The required standard was achieved with the right finishing materials and the building got ready in July 1985. The installation of the machines in the Assembly System was immediately undertaken. Following is the commissioning sequence of few important machines:

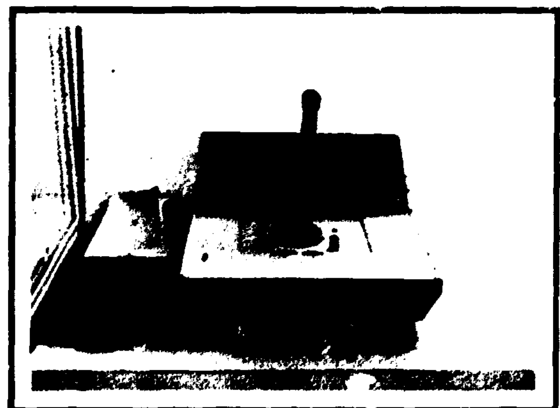
1) Wafer Prober:



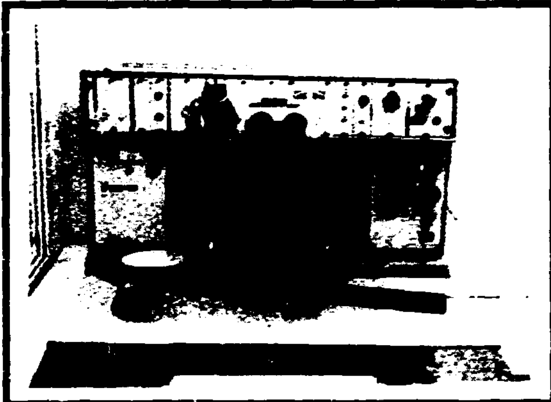
This machine was set up in July 1985. All probe connections were made and the machine was coupled with IC tester. For commissioning this system, a finished wafer was probe tested. This system was commissioned on 9/10/85.

2) Wafer Scriber & Expander

The commissioning of this system was affected due to power fluctations. A rectifier was replaced in the power circuit of the machine and the system was commissioned on 12/10/85.



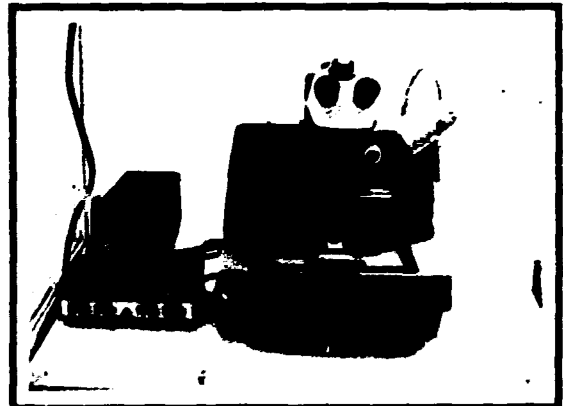
3) Die Bonder:



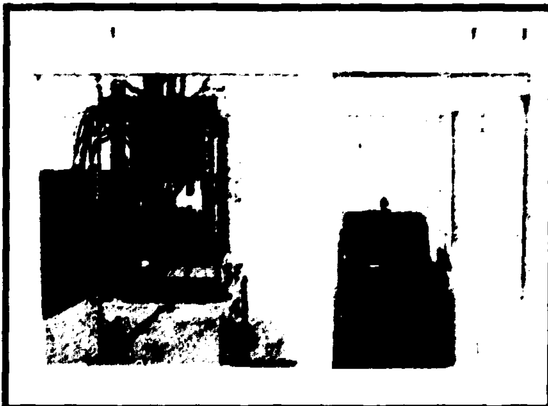
The installation of this machine was undertaken in July 1985. The system was commissioned in August 1985.

4) Wire Bonder:

Two machines were procured for this project. In August 1985 only one machine was installed and commissioned. The other one was commissioned in December 1985.

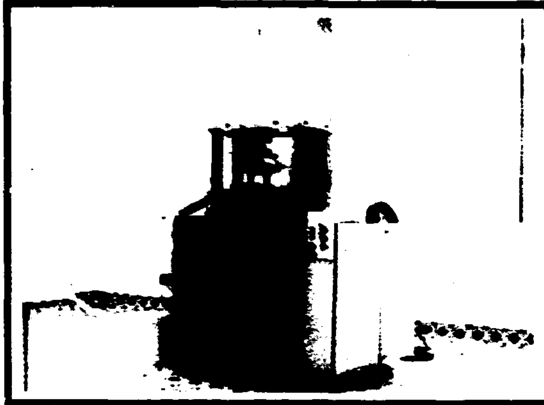


5) Transfer Moulding Press:



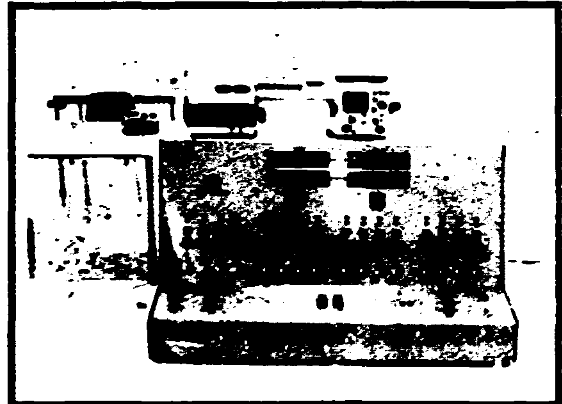
This is 50 Tonn. transfer moulding press used for encapsulation of bonded IC Chips. The commissioning of this machine was too adversely affected due to lack of some solenoid valves. The coils for these valves arrived in December 1985 and the machine was commissioned in January 1986.

6) Back end Line:



The installation and commissioning of this machines was carried out in December 1985. However, the commissioning report was signed in June '86. The machine was in operation since January 1986.

7) Test Equipment:



Other test equipment like manual IC testers, baking ovens, Oscilloscopes etc. were all commissioned in July August 1985.

3.3.2 Training

After commissioning of the assembly system, the DPRK technicians were imparted on-the-job training for four months. For each machine one technician was trained. In all ten technicians were trained by ET&T for a total period of one month. These technicians in turn gave training to others and thus a work force of 20 technicians were created.

3.3.3 Performance Test

The Moulding press in the Assembly system needed repairs (replacement of two coils of hydraulic valve). These coils arrived at project site on 25th December 1985 and the press was made opreational on 30th December 1985. The performance test of the entire assembly system was completed by January 15th 1986. A significant feature of the Overall Performance Test was the high degree of skill exhibited by the technicians

from the Institute who accomplished the task in 7 days against an originally planned schedule of 15 days. This success of the Performance test was mainly due to intensive training programme arranged by ET&T. The results were very impressive as can be seen from the following figures:

1)	Total number of devices scribed	=	6941
2)	Devices selected for assembly	=	5841
3)	% rejection after gold wire bonding & testing	=	28.4%
4)	Overall yield after mould and testing	=	71.6%

The overall yield of 71% achieved in the assembly line as against an accepted yield figure of 50% laid down by TAC members. (TAC Report October-November 1985 & 10-17 May 1986).

3.3.4 Handing over Assembly System

The results of the Performance Test carried out in January 1986 were accepted by UNIDO and UNDP (TAC Report 8-15 July 1985 and October-November 1985 Report) and so, the system was handed over to the authorities of the DPR Korean Institute on 15th March '86 for further operation. The ET&T on their part continued to afford support to this line until 31st December 1986.

3.4 PHASE III Installation of Wafer fabrication facility

3.4.1 Commissioning of Equipment

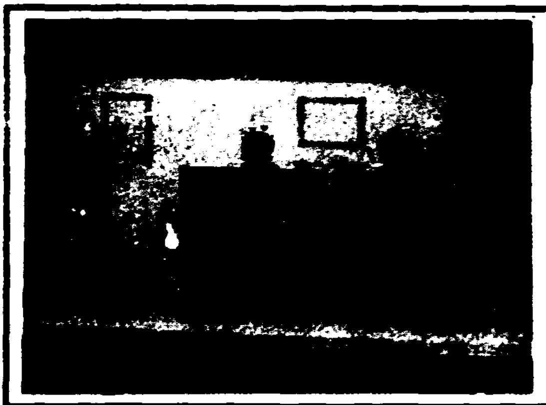
ET&T experts commenced the installation of wafer fabrication equipment only after the building was made available in May 1986. The installation of exhaust system lay along the critical path of the PERT Chart. UNIDO awarded the contract for installation of this system to a firm in Ireland. This firm completed the erectioning of exhaust system only in August 1986. This meant, that the commissioning of Diffusion furnaces, Epitaxial system and Silox Equipment could only be undertaken after August 1986 as these systems require a proper exhaust system to expel toxic gases. By July 1986 all chemical benches were connected to DI Water supply and chemical drains. At this point it became necessary to train the Institute technicians in the basic but vital procedure of cleaning the silicon wafer. The photoresist process room (Yellow Room) was ready with proper exhaust system and gas supplies in July 1986. ET&T engineers immediately commissioned all the equipment in the Yellow Room and started training of the DPRK personnel in the technology. The technicians, became familiar with the photoresist process within a month. They could print out and etch successfully the patterns from the mask. This was an important landmark in the execution of the project. The remaining equipment like Epitaxial Deposition System, Diffusion furnace, Metal Evaporator etc. were commissioned by 15th September 1986. Initial trials for diffusion oxidation and

metalisation were undertaken during the later part of September 1986. Following is the sequence of the work carried out on commissioning of major equipment or system:

1) Mask Aligner:

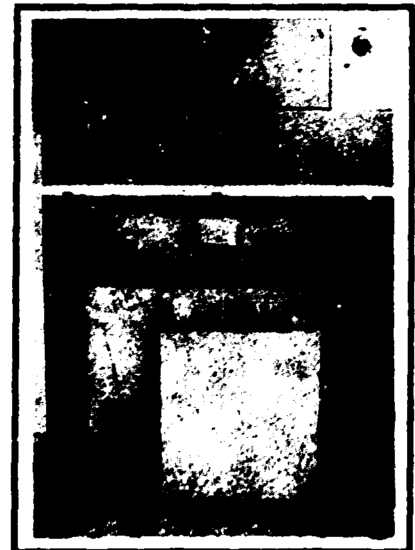
This machine was installed and was made operational in July 1986. Initial experiments on photoresist coating were carried out successfully towards the end of July 1986. This is a very critical equipment in the farbrication of Integrated Circuits. The machine can print out fine features of 5 u lines on the wafer.

2) Resist Spinner :



This machine has an automatic resist dispencer unit and the controler can control both acceleration and RPM of the machine. The coating thickness of the resist is very uniform (±1%). The system was commissioned in July 1986.

3) Wafer Developer

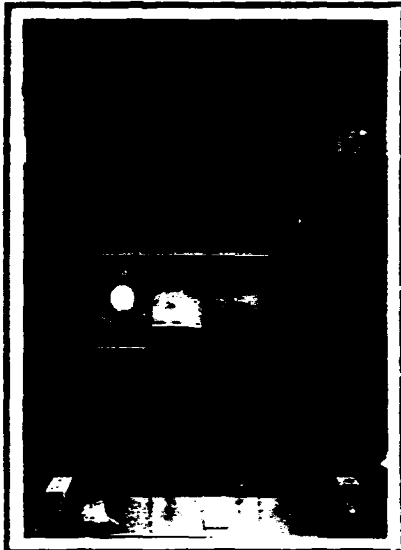


This machine is used for developing the exposed wafers. The commissioning of this machine was adversely affected for the lack of spare components. The machine was made operational in July 1986 and handed over to the Institute for future use. However the commissioning report was signed in August 1986.

Other systems in the Photolithography room e.g. Microscope, baking ovens etc were commissioned in July 1987 and the Yellow room

was made operational. The initial trial runs on the photoresist work were carried out successfully in August 1987.

4) Diffusion Furnaces:

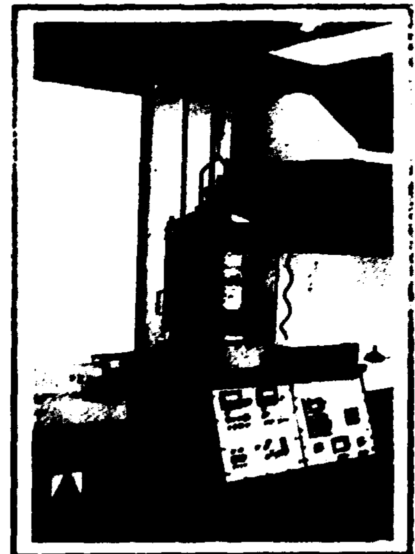


Diffusion furnaces were installed in March 1986. The commissioning of this system was undertaken only after the exhaust system was erected. The equipment was made operational in July 1986 and the system was commissioned in August 1986. In all 12 diffusion furnaces have been supplied. These furnaces can take upto 4" diameter wafers and are capable of maintaining temperature within ± 1/2° C at set point temperature. The gas distribution panel with gas filteration system was provided with the furnaces.

5) Silox System:

This equipment was procured by UNIDO as this was not part of ET&T supplies. The system is capable of depositing silox on 2" or 3" wafers with 10% uniformity. Both dopped and undopped silox could be deposited and system was proved to be very useful in passivation of finished wafers.

6) Metalisation system:

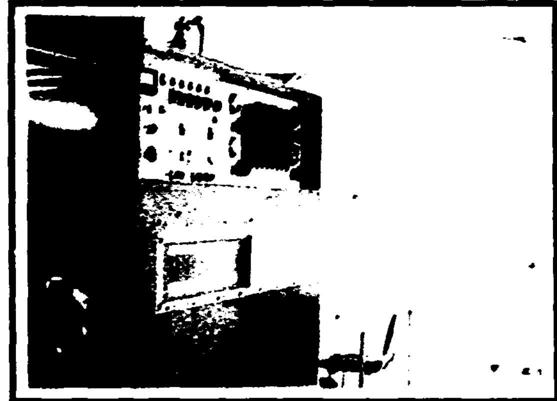


An Electronic beam metalisation system was provided for this project. The planetary motion system to achieve uniformity within 1000°A is also provided with this unit. The system can have vacuum of 10^{-7} Torr in 30 mins. The electron beam unit of 10KV can coat Aluminium on 3" diameter within 5 minutes. This system was commissioned on 25/11/86.

The Gold metalisation system consisting of planetary motion system and filament evaporation fixture, was commissioned on 10/12/86.

7) Epitaxial System:

The system consists of three different kinds of equipments namely :



(A) Induction heater

(B) Gas distribution panel

(C) Reactor chamber

The system was made operational on 26th July '86 and initial trial runs were made to get epitaxial layer parameters as required. The system was commissioned on 2/10/86. After commissioning this system, a leak developed in the reactor chamber and on 5/10/86 the reactor tube was exploded during the heating cycle. This fault was analysed by ET&T and within a week the fault was corrected.

Other small equipment like Microscopes, moisture meter, lapping machine, spin dryers etc. were made operational in July 1986. The wafer fabrication system was made operational on 20th October 1986.

3.4.2 Implementation of Fabrication Process

The implementation of the fabrication process by using a test mask was undertaken by 28th October 1986. A total involvement of the Institute's engineers was achieved inspite of severe difficulty in communication in English. The first batch of wafers was divided into two sub-groups to speed up the implementation of all process steps in the wafer fabrication. This excercise was completed by 25th November. Again, during the first week of November another batch of wafer for the est mask was processed, primarily,to demonstrate all masking and diffusion steps to simulate the fabrication of actual IC devices. This exercise was completed by 30th November 1986. The IC Component fabricated on this batch exhibited the following characteristics:

BV_{ISO}	=	35-40V AT 10 uA
H_{FE}	=	80-100 on large transistor structure
BV_{EB}	=	4V at 10 uA
X j (Base)	=	3.0 u Base Junction depth
X j (Emitter)	=	2.4 u Emitter Junction depth
t_{Epi}	=	7.8 - 8.2u Epi thickness
R_{Epi}	=	220 (555 with gold diffusion)
Rs	=	Resistor values - 20 / ohms/aquare

The Chips fabricated exhibited excellent junction characteristics. Low junction leakage indicated an excellent capability of the plant to produce high quality Integrated Circuits. Appendix III shows the photograph of various IC Components thus fabricated.

3.4.3 Handing Over

The Technical Advisory Committee met at site in DPR Korea between 2-8 December 1986, to assess the progress of the project and to determine the extent to which objectives of the project have been met. The committee noted the completion of installation of the plant in all respects. Further an assessment of the training and skills of DPRK engineers at the Electronics Institute was made. The TAC members assured themselves of the skill and competence acquired by DPRK engineers and saw themselves that they have become conversant with the plant system, machine installation and their maintenance and operation. In their view, the time was ripe for handing over the plant to the authorities of the Electronics Institute, who could run the plant on their own.. They, however, advised ET&T authorities to extend a technical support till end of December 1986, to ensure that there are no dark or grey areas in the operation of the plant. Besides, ET&T experts, had already started the wafer fabrication of 7400 TTL IC which was unfinished at the time of TAC visit to the institute. Considering the skills acquired and the confidence shown by DPRK engineers, TAC recommended to handover the plant to the authorities. This recommendation of the committee was accepted by the Institute authorities, ET&T, UNIDO and UNDP and accordingly the plant as a whole was handed-over (Appendix II) to the authorities of Electronics Institute on 5th December 1986. At this point of time, a list of some actions to be taken by ET&T authorities was drawn up. These follow up action points relating to the equipment were of minor nature and not affecting the functioning of the equipment. The present status of these action points is given in Appendix. IV.

IV EXTENDED TECHNICAL SUPPORT

4.1 Special considerations

As mentioned earlier, ET&T authorities agreed to extend the technical support to the Institute with a view to fabricate two TTL ICs. This way, the capability of the plant could be established

4.2 Fabrication of TTL 7400 Device

A new batch of wafers for the fabrication of 7400 TTL Circuits was undertaken on 25th November 1986. This batch, consisted of 10 wafers, was processed upto Epitaxial deposition stage and then split up into two groups First group of 3 wafers were processed under the close supervision of ET&T engineers and the rest of the wafers were processed by the Institute engineers as per ET&T instructions. The batch of wafers processed by

ET&T engineers, when probe tested gave 83% yield. The other group processed by the Institute engineer yielded 25%. The low yield was due to poor gains at the time of Emitter diffusion. At this stage, ET&T experts gave further training to the Institute engineers and it is hoped that in future the Institute's process engineers would take a corrective action. Combining the yields of two groups of wafers the average yield of the batch was about 30% which is much more than 5% acceptance criteria set out by TAC. These wafers were scribed and assembled and functionally tested to give 7400 TTL circuit. On the three good wafers processed by ET&T engineers, it was difficult to probe any bad device. One wafer out of this lot was scribed and 80 devices of 7400 were randomly selected for functional testing, 65 passed the functional test indicating 65% overall yield.

Following is the comparison of dynamic testing carried on 7400 ICs. This test was compared with commercial 7400 IC device by Texas Instrument company :-

	TTL Spec.	*Typical Comml.*	*ET&T Processed*
Propogation delay (nano sec.)			
t_{PHL}	15n.sec.	10n.sec.	22n.sec.
t_{PLH}	22 "	15 "	16 "
t_{RR}	10 "	8 "	8 "

These tests are compared very well with the commercially available devices. This in itself indicated successful device fabrication in the plant.

4.3 Fabrication of TTL 7476 IC

After the successful fabrication of 7400 ICs, the Institute engineers became very keen to undertake the fabrication of 7476 Integrated Circuit Chip. A first batch of 5 wafers were processed fully. One wafer out of this batch was scribed and assembled. The testing of this circuit was carried out by testing 7473 IC with altered pin connections, However, out of 84 assembled devices tested, 28 passed full functional test indicating 30% yield. This indicates a very good success for the process step of the fabrication of this chip carried out by the Institute engineers.

Appendix III shows the photographs of 7400 & 7476 TLL Circuit processed successfully in this pilot plant.

V SUGGESTIONS FOR THE FUTURE

During the implementation of this project which lasted for five years, ET&T experts had a close interaction with the Institute personnel and observed the style of working in DPRK. From this experience ET&T experts would like to draw attention to the following:-

1) It is advisable to have precision workshop to support this facility.
2) It is hoped that there would be channelisation of engineers in the areas of Specilisation e.g. Air conditioning experts, Diffusion expert, photolithography expert etc.
3) The plant requires a smooth and stable power supply.
4) The existing system of cooling water could be improved.
5) Arrangement to procure raw material in future.

VI CONCLUSION

The implementation of the project started in 1982. The site office was opened in November 1983, and the ET&T Resident Engineer at site received the equipment and took care in storing at a proper place. The commissioning of ancillary and the assembly system was completed by December 1985. The performance test for assembly plant was carried out successfully in January 1986. The installation and commissioning of wafer fabrication equipment was complete. The process trials and the training of DPRK engineers was completed by November'86. ET&T engineers demonstrated performance of the plant by fabricating - two actual TTL circuits. Thus ET&T has fulfilled all contractual obligations as stipulated in the contract.

VII ACKNWOLEDGEMENT

ET&T wishes to express its deep gratitude to UNIDO for giving a chance to implement this project. ET&T also would like to express the sincere thanks to Mr. T. Chavez-Chief Technical Advisor - UNDP Head quarters New York for making the implementation of the project smooth and easy. Thanks are also due to Mr. H. Ali, Mr. R. Nuttall and Mr. J. Gourgout the three TAC members, who spared their valuable time to assess the progress of this project periodically. These members also gave valuable suggestions without which the implementation of process would have been difficult. Since the initiation of this project till its completion, UNDP New York deputed Mr. F. Marusic (Res.

Rep.) Mr. R. Miller (Dy. Res. Rep) Mr. S. Ristic (Res. Rep.), Mr. Long (Dy. Res. Rep.), Mr. C. Wiberg (Res. Rep.) and Mr. Melder (Dy. Res. Rep.) at their field office at Pyongyang. The kind help rendered by these officers to ET&T personnel is Sincerely acknowledged E.T & T also like to thank Mr. G. Putnam Dr. M. Delos and Mr. S.S. Morozov of UNIDO-Vienna. The UNIDO project manager stationed at site monitored the project constantly. The valuable help of Mr. J. Gyimesi and Mr. R. El Hadidy is duly acknowledged. The most important help rendered by the Director of the Institute - Dr. Ro, Director - Mr. Kim and Vice Director Mr. Han. of 5th Department - DPRK Government is sincerely acknowledged. Dr. Ro was instrumental in making ET&T engineers stay in Pyongyang a memorable one. ET&T also wishes to express deep gratitude to engineers at the Institute and other officers of 5th Department in DPR Korea for helping the implementation of this project successfully.

—*—

BAR CHART
PROJECT IMPLEMENTATION

SL. NO.	ACTIVITY	1982	1983	1984	1985	1986
1.	Equipment Order					
2.	Equipment Delivery					
3.	Building Completion					
	IInd Floor					
	Ist Floor					
4.	Commissioning of Services					
	1) Liquid Nitrogen Plant					
	2) D/I Water Plant					
	3) A/C System					
	4) Power Substation					
	5) O2/H2 Plant					
5.	Commissioning of IInd Floor					
	1) Assembly System					
	2) Performance Test					
	3) Handing Over					
6.	Commissioning of IInd Floor					
	1) Yellow Room					
	2) Diffusion Room					
	3) Metalisation					
	4) Gold Room					
	5) Epitaxial Room					
	6) Performance Test					
	7) Handing Over.					

ET&T PERSONNEL RESPONSIBILITIES FOR THE IMPLEMENTATION OF THE PROJECT

	Name		Responsibility
1)	Dr. S.M. Deval	-	Project Incharge GM (Tech.) ET&T Corpn.
2)	Mr. P.R. Apte	-	Diffusion & Fabrication Process Expert TIFR-Bombay
3)	Mr. A.V. Joshi	-	Epitaxy, Gas Plant Expert TIFR-Bombay
4)	Mr. S.P. Pai	-	Photolitohgraphy Expert TIFR-Bombay
5)	Mr. H.C. Aggarwal	-	A/C Power Sub-Station Expert ET&T Corpn.
6)	Mr. M.L. Gupta	-	Procurement of Equipment Material & Inspection ET&T Corpn.
7)	Mr. A.T. Sambandam	-	Assembly & Metalisation Expert ET&T Corpn.
8)	Mr. T.S. Ramanath	-	DI Water, Gas Installation Material Procurement ET&T Corpn.
9)	Mr. R.M. Joglekar	-	Back Lapping, Silox Expert ET&T Corpn.
10)	Mr. V.V. Rama Rao	-	Electronics Expert maintenance and Assembly Operation ET&T Corpn.
11)	Mr. N.J. Deshmukh	-	Testing ET&T Corpn.
12)	Miss. T.P. Narayani	-	Head Office - Site Office Liaison ET&T Corpn.

EQUIPMENTS SUPPLIED BY ET&T UNDER THE CONTRACT AND DATE OF COMMISSIONING

Sl. No.	EQUIPMENT	QUANTITY	DATE OF COMMISSIONING
	FACILITY		
1.	Air conditioning	01	I - 27/8/84, II- 3/5/85 III - 28/12/86
2.	DI Water Plant	01	23/1/86
3.	Power Sub-station	01	27/8/84
4.	Air Compressor (oil free)	01	27/8/84 (Report signed on 12/2/84)
5.	Diesel Generating Set	01	26/08/84
6.	Liquid Nitrogen (Automatic)	01	I-20/09/85, II-25/4/86 III-12/05/86
7.	Oxygen/Hydrogen Generator with Compressor	01	20/01/86
8.	Chemical Benches (Cleaning stations)	01	12/07/86
9.	Dry Benches	12	12/07/86
10.	Air Showers	04	12/07/86
	ASSEMBLY SYSTEM		
11.	19 position wafer Prober	01	09/10/85
12.	Wafer Scriber	01	12/10/35
13.	Wafer fracturer & Matrix expander	01	12/01/85
14.	Eutectic die bonder	01	12/01/85
15.	Thermosonic ball bonder	02	14/10/85, 03/12/85
16.	Transfer Moulding Press with moulds	01	03/01/86
17.	Back end line machine	01	20/06/86
18.	IC Testers		
	a) Automatic	01	04/01/85
	b) Non-Automatic	02	09/01/85 10/02/86
19.	Pull Tester	01	19/10/85
20.	Oscilloscope	01	25/09/85
21.	Baking Ovens	06	24/09/85
22.	Curve Tracers	03	21/10/85
23.	Digital Multimeter	02	26/10/85
24.	Pulse Generator	01	26/09/85
25.	Power Supplies	06	21/10/85

Sl. No.	EQUIPMENT	QUANTITY	DATE OF COMMISSIONING
	WAFER FABRICATION		
26.	Diffusion Furnace	12	06/10/86
27.	Epitaxial Reactor	01	02/10/86
28.	Aluminium Evaporator	01	25/11/86
29.	Gold Evaporator	01	10/12/86
30.	Four Point Probe (FP100)	01	16/10/86
31.	Gas Driers	04	28/11/86
32.	Photoresist Spinner (With pressurising-tanks)	01	20/09/86
33.	Photoresist developer	01	11/10/86
34.	Mask Alinger	01	11/10/86
35.	U/V Intensity meter	01	05/11/86
36.	Spin Drier	02	12/07/86
37.	Visco Meter	01	26/11/86
38.	Manual Driven plotter (Micro Plotter)	01	28/03/86
39.	Particle Counter	01	03/11/86
40.	Microscopes		28/11/86
41.	Ultrasonic Cleaner	02	16/09/86
42.	Hot Plates	02	16/09/86
43.	Manual Prober	01	04/11/86
44.	XY Recorder	01	28/11/86
45.	Moisture Meter	01	28/11/86
46.	Lapping Machine	01	29/09/86

CHEMICAL & COMPOUNDS SUPPLIED BY ET&T FOR THE PROJECT : DP/DRK/79/003

Sl. No.	Name	Quantity	Date of Delivery
1.	Spray adhesive Wax	20 Sticks	10-11-84
2.	Polishing Compound	20 Solid Comp. 06 Slurry	10-11-84
3..	Polishing Cloth	20 Nos	10-11-84
4.	Methenol	250 Lit.	07-12-84
5.	Tri-Chloro-ethelene	300 Lit.	07-12-84
6.	Glassware (Beakers, Petridish etc.)	Lot (350 Pcs)	29-04-84
7.	Polythene Carriers (Fluoroware)	302 Pc.	04-09-85
8.	Tissue paper	300 pcs	
9.	Tweezers	50 Nos	
10.	Quartz tubes & boats	6 + 24 Nos	
11.	Dopant gases with gas controllers	01 cylinder each with regulators	07-12-85
12.	Dopant Liquid POCL3 BBr3	40 x 25 40 x 25 ml } 1 Lit.	07-12-84
13.	Aluminium Evaporation material	200 Gms	07-06-84
14.	Gold Wire	300 Gms	13-01-85
15.	Photoresist	1 gal -ve 1 gal +ve	19-12-84
16.	Photoresist Developer	4 gal + 4 gal + 4 gal	19-12-84
17.	Photoresist Striper	150 Lit.	07-12-84
18.	Buffered HF	2500 Lit.	07-12-84
19.	Nitric Acid	250 Lit.	07-12-84
20.	Sulphuric Acid	1250 Lit	07-12-84

Sl. No.	*Name*	*Quantity*	*Date of Delivery*
21.	Bonding Wire	4000 Metres	25-09-84
22.	Lead Frames	300,000	25-10-84
23.	Epoxy	440 lbs Powder	
		400 lbs Pillet	22-02-85
		+ 440 lbs Melamine	
24.	Timers	3 Kodak	29-04-85
		4 Electronic	
25.	Silicon Wafers	2000 + 1000 Check	17-09-85
		+ 400 device wafers	
26.	Masks Test Chip 1 Test		
	7400 & 7476 TTL device	+2 device	16-10-85
27.	Hydorchloric Acid	300 Lit.	07-12-84
28.	Acetic Acid	250 Lit.	07-12-84
29.	HF 50%	400 Lit.	07-12-84
30.	Hydrogen Peroxide	1500 Lit.	07-12-84
31.	Phosphoric Acid	500 Lit.	07-12-84
32.	CP4 Silicon etch	200 Lit.	07-12-84
33.	Xylene (Developer)	300 Lit.	07-12-84
34.	N. Butyle Acetate (Rinser)	700 Lit.	07-12-84
35.	Acetone	400 Lit.	07-12-84
36.	Proponol	300 Lit.	07-12-84
37.	KOH Pottasium Hydroxide	100 kg.	07-12-84
38.	$K_2Cr_3O_4$ Pottasium Chromate	1 kg.	07-12-84

DP/DRK/79/003 - INTEGRATED CURCUIT PILOT PLANT
HANDING OVER DOCUMENT

We, the undersigned, agree to the following :

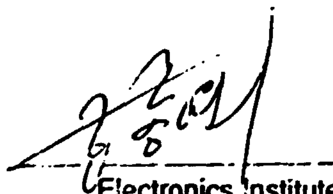
- all items of equipment supplied in connection with this project have been individually commissioned and were operating satisfactorily at the time of their commissioning;
- process sheets describing each process step and the use of all equipment have been supplied by ET/T to the Electronics Institute;
- key personnel from the Electronic Institute have been adequately trained in the operation of this equipment, familiarized with its maintenance and the processes described in the process sheets mentioned above;
- from the date of signing this document the Electronic Institute agrees that it will assume responsibility for the operation and maintenance of the entire integrated circuit pilot plant including the wafer processing area and the assembly test area together with all the auxiliary service buildings and installations;
- from the date of the signing of this document until 31 December 1986, ET/T will continue to carry out work on the IC plant on the basis of the conclusions and recommendations of the project's Technical Advisory Committee in order to finalize the responsibilities vis-a-vis UNIDO and the Electronic Institute. ET/T will have daily access to the IC plant for the purposes of providing further training, continuing to assist in the stabilization of process and providing consulting services. Also, the UNIDO project manager will continue to function in his oversight and coordinating role until the project's completion on 31 December 1986.

Signed:

Electronics Trade and Technology Development Corporation Limited (ET & T)

5/12/1986

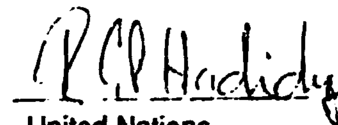
(Date)



Electronics Institute of the Academy of Sciences, DPR Korea Pyongsong

5/12/1986

(Date)



United Nations Industrial Development Organization (UNIDO)

5/12/1986

(Date)

The TAC recommendations are attached.

TAC RECOMMENDATION ON THE PROJECT COMPLETION

The TAC considers the services for the IC plant to be acceptable for handing over to the Electronics Institute since it meets the process requirements and is consistent with the practice of the industry, subject to:

1. ***Hydrogen/Oxygen Plant***

   Moisture sensors have arrived and will be fitted. The spare valve plungers have also been delivered. The original compressor motor will be repaired with new bearings and fitted to compressor. The above will be carried out by ETT and the H2/O2 plant will then be complete and operational.

2. ***Nitrogen Plant***

   The additional fitting of the N2 purifier will be done by ETT. This will complete the N2 plant.

3. ***Deionised Water Plant***

   New water tanks will be delivered in the new year to replace the present leaking tanks. This replacement will be carried out by the Institute. The plant would then be fully operational.

4. ***Air Conditioning***

   The air intake duct will be restored to the original construction by the Institute. ETT will then insulate all cold surfaces on ducting around heat exchangers sufficiently to avoid surface condensation. The condensed water drain on the heat exchangers will also be checked by ETT. ETT will then rebalance the air conditioning system relative to air extraction within the processing areas by 30 December 1986.

5. ***Power Supply***

   KW hour meter will be repaired by ETT.

6. ***Extraction***

   The ductwork will have additional permanent supports fitted as necessary to prevent strain on duct and joints. All joints will be examined and reinforced as necessary. Any leaks will also be repaired.

   All this work will be carried out by the Institute.

The Assembly and Test Area (2nd floor) of the IC plant is considered to be acceptable based on the practice of the industry and responding to the terms and conditions agreed upon between UNIDO and ETT, and it has already handed over to the Electronics Institute on 15 March 1986.

It is noted that :

1. *Expander*

   The process was demonstrated by ETT and observed by the Institute and TAC. TAC found

that the equipment and process operated satisfactorily. The problem was in the expansion plastic tape which was the wrong quality. These has been supplied with the equipment. The TAC recommends that "expandable sticky blue tape" be used instead of present tape. This would cure the problem. ETT would supply the new tapes.

2. *Die Bonder*

The die bonder is faulty in operation and is well out of the guarantee period. It was also commisssioned 12.01.85. This fault would be classed as a maintenance problem and therefore should be repaired by the Korean engineer in charge.

The Wafer Processing (1st floor) of the IC plant is considered to be acceptable for handing over to the Electronics Institute based on the practice of the industry and responding to the terms and conditions upon between UNIDO and ETT, subject to:

1. *Diffusion Furnaces*

There are 12 furnaces total, 9 of which are fully operational. The 3 furnaces non-operational have controller problems and these are to be rectified by ETT and supplied as follows:

a) Deliver and fit new circuit boards to controller.

b) Provide additional spares for controller.

In addition:

c) 2 ceramic furnace liners have buckled and will be replaced by supplier.

d) 5 new temperature ramping system are to be delivered in the new year by furnace supplier for fitting by the Institute.

ETT will be responsible for delivery of the above and Institute will install them as required.

2. *Epitax Equipment*

A new quartz tube will be provided by EGS in the new year to replace the one broken during process stabilization.

3. *Aluminium Evaporator*

ETT to provide suitably strong vaccum insulated containers for liquid nitrogen transport from N_2 plant to evaporator by 30 December 1986.

4. *Gold Evaporator*

This is in position and complete. Commissioning will commence on 5th December and be carried out by an Edwards high vaccum engineer. Successful commissioning is anticipated during the week 15-20 December 1986.

These conclusions are based on :

1. Satisfactory commissioning documents for all equipment units which include :
   a) the review of 13 commissioning documents for all the service units
   b) the review of 19 commissioning documents for the wafer processing area
   c) the review of 23 commissioning documents for the test and assembly area
2. Availability of appropriate operating instructions for all units of equipment
3. Availability of appropriate maintenance instructions for all units of equipment
4. Availability of staff who were associated with the commissioning of the different units of equipment
5. Inspection of all facilities and consideration of all comments made by the Institute, ETT and UNIDO.

Furthermore, it was ascertained that the capability of the process lines has been demonstrated since 7400 series devices are being processed as a joint activity between ETT and the Institute with some degree of sucess. The skills of the Korean staff was shown to have sufficient promise to be followed by the production of 7400 series and subsequently 7416 series devices.

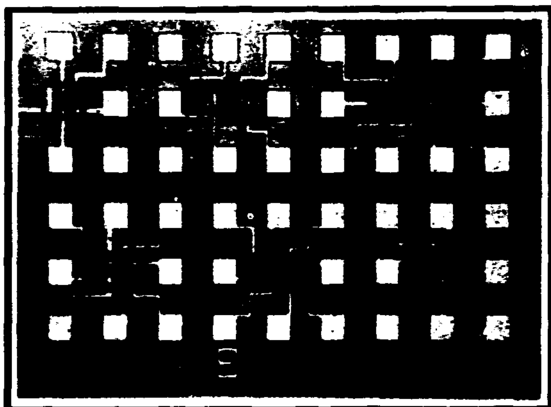
On the basis of the above conclusions, the TAC recommends the handing over of the entire IC plant from ETT through UNIDO to the Electronics Institute. Furthermore, it recommends that the technical assistance to the project be completed as scheduled by 31 December 1986.

Hassanuddin Bin Ali
TAC

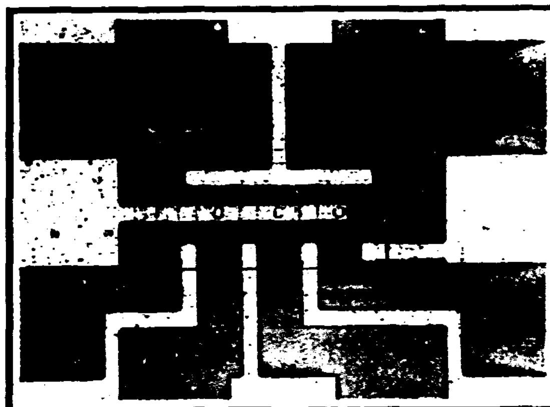
Roy Nuttall
TAC

Pyongyang, DPR Korea
5 December 1986

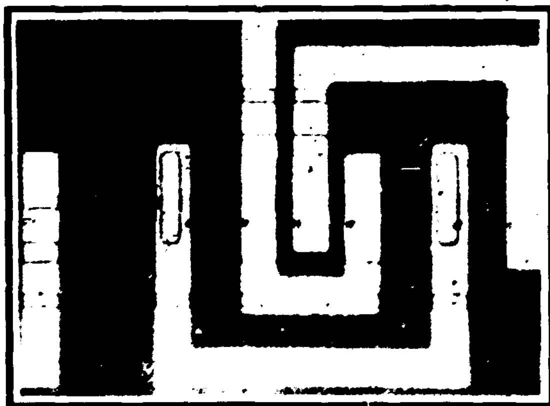
PHOTOGRAPHS OF TEST CHIP SN7400 AND SN7476 ICS PROCESSED AT THE PLANT



Test Chip showing IC Transistor

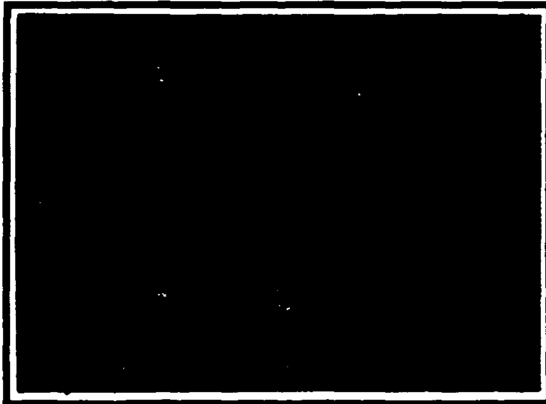


Test Chip - 4 Input Transistor

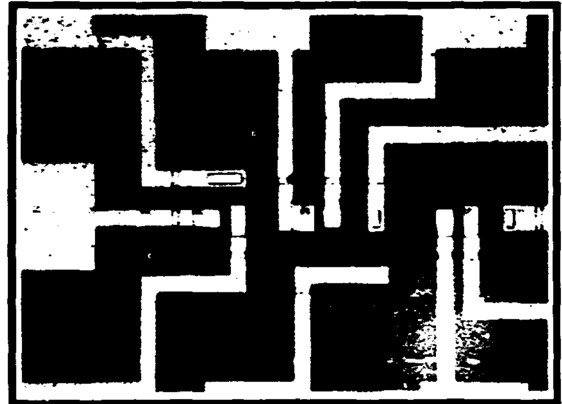


Test Chip - Large Transistor structure

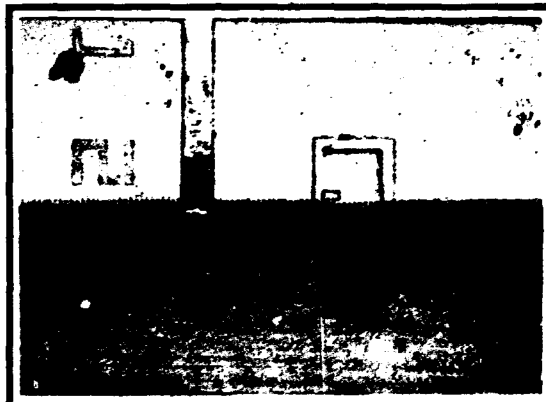
Test Chip - Base Resistors of different values



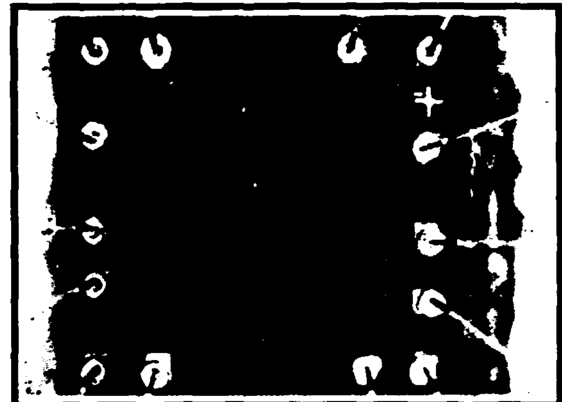
Test Chip pinched Resistors



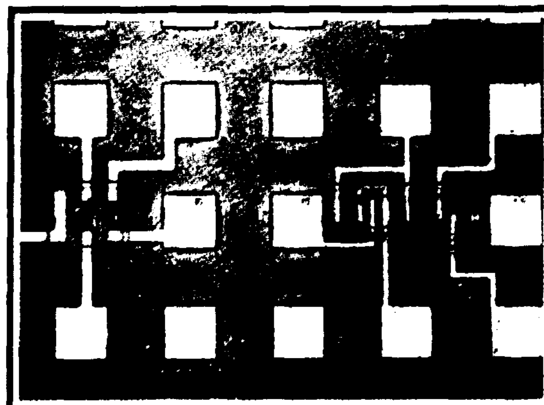
Test Chip - Small Transistor structures



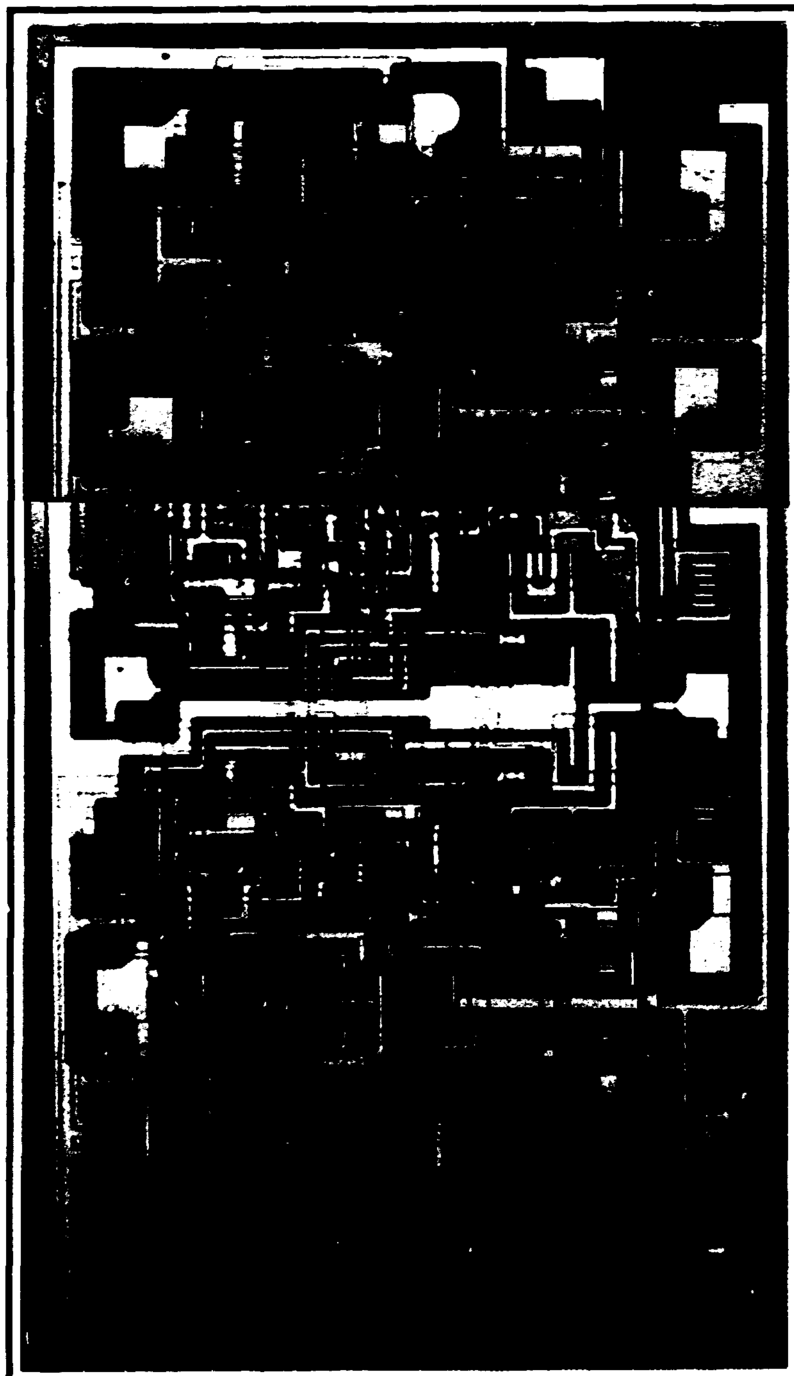
Test Chip section view showing Epi thickness BN + diffusion, Isolation and emitter base width.



IC 7400 Chip after Goldwire Bonding.



Epi Resistor Large/Medium Trnsistor



Photograph of IC 7476 Chip Size 2.83 x 1.65

ET&T ACTION POINTS

	ACTION	*PRESENT STATUS*
1)	To fit Moisture sensors in Hydrogen Plant.	Action Complete.
2)	To repair Compressor motors	Action Complete.
3)	Spares for Liquid Nitrogen Plant	Action Complete.
4)	To replace tanks in DI Water Plant.	Action Complete.
5)	Balance air conditioning system	Action Complete.
6)	To provide "Expandable sticky tape" for expander	Action Complete.
7)	To provide spares for Diffusion Furnaces.	Action Complete.
8)	To provide container for Liquid Nitrogen.	Action complete
9)	Commissioning of Gold Evaporator	Action Complete
10)	KW Power Meter repair	Action Complete
11)	To provide 20 Lts. of Photoresist	Action complete
12)	To supply proper workholder for Gold Evaporator	Action complete

PROJECT COST

The total plant cost including cost of machinery raw material, project services, training etc. has been worked out in detail.

An abstract of the cost is given in the table below. All prices are in United States Dollars :

Sr. No.	Area of Operation	Cost in US$
1.	Diffusion/Epitaxy/Evaporation	724250
2.	Photolithography	154000
3.	Assembly/Test/Quality control	475455
4.	Facilities	2017500
5.	Raw Materials	202530
6.	Extra materials supplied	113105 · 113105
7.	Project management procurement, Technical documentation and other services	1201770
	TOTAL =	~~4887510~~ 4888610.
		4888610.

PROJECT AT GLANCE

This is a first largest project of this kind in UNDP system. The mile stones of the project are as follows:

1979 Negotiations between UNDP & DPRK Government and Project document was prepared.

1981 After two years of delay the project was awarded to ET&T. The project has four main Components.

1982 ET&T started ordering the equipment and submitted the plan for buildings.

1983 First TAC meeting was held in January. Also in the same year in August equipment started to arrive and ET&T opened a Site Office.

1984 Training of the Institute's engineers in India completed. Institute completed civil construction of the building and started implementing TAC's recommendations.

1985 UNIDO contacted BMM - a firm in Ireland for Installation of firealarm, exhaust system and affluent treatment plant.

1986
- January- Assembly system was commissioned and Performance test was successfully carried out.
- March- Assembly system was handed over to the institute.
- October- Wafer fabrication facility was made ready by ET&T and extensive training programme for institutes was under - taken.
- November- All fabircation process steps were executed by ET&T and Plant as a whole was commissioned.
- December- The plant was handed over to the Institute.

  ET&T fabricated successfully two types of TTL Circuits.