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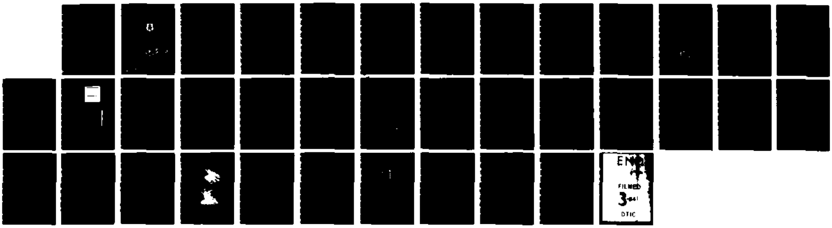

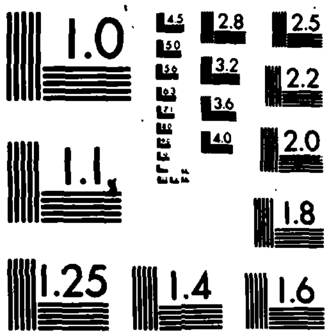

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FOREIGN TECHNOLOGY DIVISION

MICROWAVE SEMICONDUCTOR EQUIPMENT
PRODUCED IN POLAND

by

Jerzy Klamka

EDITED TRANSLATION

FTD-ID(RS)T-1884-83 20 January 1984

MICROFICHE NR: FTD-84-C-000083

MICROWAVE SEMICONDUCTOR EQUIPMENT PRODUCED IN POLAND

By: Jerzy Klamka

English pages: 32

Source: Elektronika, Vol. 21, Nr. 1-2, 1980, pp. 44-54

Country of origin: Poland
Translated by: LEO KANNER ASSOCIATES
F33657-81-D-0264
Requester: FTD/TQTR
Approved for public release; distribution unlimited.

PREPARED BY:

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MICROWAVE SEMICONDUCTOR EQUIPMENT PRODUCED IN POLAND

by Prof. Dr. Hab. Jerzy Klamka
The Electronic Technology Institute of the CEMI, The Discrete Semiconductor Equipment Section 44

In 1978 we celebrated the 25 year jubilee of continuous development of Polish radar. The development of this field of technology, so important for the national economy and national defense, is dependent upon designs and production possibilities of subsystems and microwave elements used in radar equipment. Playing a key role among these are microwave semiconductor devices (MPP) produced in Poland.

As in the leading countries of the world, work in the fields of the theory, design and technology of microwave semiconductor devices has been carried on for years in Poland. The designed equipment has been closely adapted to the newest devices produced by our radar industry. These devices are designed and produced in the Discrete Semiconductor Equipment Section of the Electronic Technology Institute of the CEMI.

The History of the Development of Microwave Semiconductor Devices

The work on microwave semiconductor equipment was begun 20 years ago. Research was started on varactors for parametric amplifiers, which took place in the Institute for Basic Problems of Technology of the PAN [1]. The research unit, which performed the research there, increased with time, leading subsequently to the Electronic Technology Institute of the PAN and finally to the Electronic

Technology Insitute of the CEMI. At the same time, together with an expansion of the themes connected with microwave equipment, there .E appeared larger organizational units, such the laboratory, then institution (1970) and the section in 1972, in which besides research-developmental work, small serial production of the microwave diodes was also undertaken.

In the history of the development of microwave semiconductor devices it is possible to discern several characteristic stages.

In the first of them, in the years from 1959 to 1967, work was carried out on the design and technology of varactors intended for parametric amplifiers and harmonic generators. As a result of this a series of types of germanium, silicon and gallium-arsenide varactors were produced [2-14]. These varactors were used for example in Avia A and Avia B radar. The working out of the production of varactors in short series in the IPPT-PAN started off application work both in industry (PIT, WZR Rawar) and in academic centers. This was, consequently, the beginning of the development of microwave semiconductor electronics in Poland.

The second stage of MPP production, between 1968 and 1974, encompassed a significantly broader theme than had been the case in the previous period. Besides work on the newest types of silicon varactors [15] research was performed parallely in the field of avalanche diodes [16-20], PIN diodes [21-25], Gunn diodes [26-27] and Schottky diodes [28]. Work was also performed in the field of the microwave surveying of the basic parameters of the mentioned types of diodes. As a result of this the following types of technology were produced:

--PIN diodes intended for work in the S and X bands, used successfully

for example in scaled microwave systems produced in the PIT;
--several types of avalanche diodes intended for work with constant power in the X band (with an initial power within the boundaries of 50 and 750 mW);
--two types of Gunn diodes with a constant power in the X band between 50 and 250 mW; also designed were;
--the first models of the Schottky diode in the S and X bands;
--a technique for measuring the microwave parameters of the above mentioned diodes. A series of measurement heads were also designed and produced, and a series of varactors for the needs of the PIT and WZR Rawar (some of them were produced for export) was introduced into laboratory production.

Deserving of special attention is the fact that technological work was performed at that time with the aid of atypical and rather crude apparatuses. Nevertheless, the varactor production was organized and begun in such a way as to completely meet the national need in the field of the produced types of these devices. Also produced in this field were models of all the necessary types of microwave diodes (avalanche, Gunn, PIN, Schottky) anticipated for radar equipment designed in the PIT. Some of these, such as avalanche and PIN diodes, were produced in short series and were used in various microwave systems.

This was, therefore, a very fruitful period in the development of microwave semiconductor devices, regardless of the shortages of apparatuses in national institutions [29]. An entire diode thematic was worked out. The diodes produced, subsequently, stimulated application work both in the radar industry and in other scientific centers in Poland, which were occupied with microwave technology.

The next two and a half year period (the end of 1974 to the middle of 1977) was not very fortunate for MPP development. Organizational and cadre changes were instituted in the national "Microwave Institute" and support for its activity (in the technological field) in cooperation with the "Microelectronic Institute had to correct the situation and create new possibilities for MPP production. This did not lead, however, to the expected results. As a result of this, production of varactors manufactured according to older methods fell, and the modernization of their production with the use of line technology (intended for the manufacture of scaled systems) did not ensue. In this period no new microwave devices were produced. Prepared prototypes of new diodes, although based on achievements of earlier periods, required basic design-technological modifications.

The Newest Achievements of the DM Section in the Field of MPP 45

In June 1977 on the basis of the Microwave Institute the Discrete Semiconductor Device Section was founded (DM section), in which research and production in the field of MPP was chiefly undertaken. Contrary to the earlier period, the DM section possessed to a greater extent its own modern technological equipment. This created the possibility of the more rapid production of new microwave devices. This also allowed the modernization and increased efficiency of the production of already existing microwave diodes.

The new conditions and possibilities, as well as the organizational and cadre modifications carried out in the the DM section, led to the rapid progress of research-developmental work in the field of microwave semiconductor equipment, as well as an increase in the size of its production. In the course of two years a series of new types of microwave diodes was designed and introduced into production (table 1), the production of these diodes was radically increased (illustration 1) and the technology of the older types of varactors, which functioned until 1974, was modernized.

All the new microwave devices correspond to foreign diodes and are characterized by the required reliability. They also hold up under harsh mechanical-climatic conditions. Modern production technology guarentees their greater reproducibility and decreases labor requirements. This has resulted in increased laboratory production capacity, as well as a decrease in personnel needs.

The production level achieved in 1979 meets the needs of the Polish radar industry in the field of the mentioned types of microwave diodes.

The development of Polish radar has led to the further expansion of the venue of the DM section. Besides traditional diode thematics and microwave survey, work is now commonly carried out on transistors and microwave subsystems.

The results of the labors of the DM section connected with the new devices and microwave subsystems introduced into production are presented in another part of this article. The parameters of all the commonly manufactured microwave products are also given.

	7 Rok produkcji		
	1977	1978	1979
1 Waraktory	BXDP-14 BXDP-43 BXDP-44 BXDP-45 BXDP-51	BXDP-14 BXDP-43 BXDP-44 BXDP-45 BXDP-51 BXDP-52 BXDP-74 BXEP-74	BXDP-14 BXDP-43 BXDP-44 BXDP-45 BXDP-51 BXDP-52 BXDP-74 BXEP-74
2 Diody Gunna	–	CXDP-44	CXDP-43S CXDP-44
3 Diody PIN	–	–	BADP-23 BADP-26 BAEP-26
4 Diody Schottky'ego	–	–	BADP-14 BAEP-1[illegible]
5 Diody lawinowe	–	–	BXDP-82
6 Generatory Gunna	–	–	GFX-001 GFXE-002

8 Uwaga: 1) w ramach danego typu diody istnieją podtypy, których parametry podane w dalszych tabelach;

9 2) podtypy diod z literą Y w ich oznaczeniu są dostarczone odbiorcy bez specjalnego atestu

Table 1. Basic types diodes and microwave subsystems laboratory produced in the DM section between 1977 and 1979
1. varactors, 2. Gunn diodes, 3. PIN diodes, 4. Schottky diodes, 5. avalanche diodes, 6. Gunn generators, 7. production year, 8. Note, 1) within the framework of a given type of diode there exists subtypes, whose parameters are given in other tables, 9. 2) subtypes of diodes with the letter Y in their designation are supplied to the consignee without special attestation

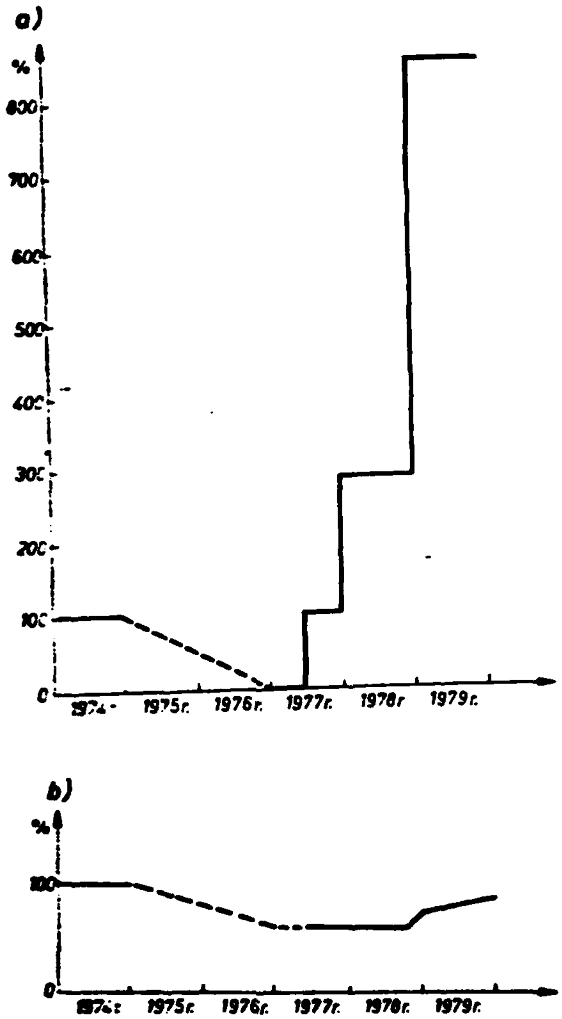


Illustration 1. The increase in the annual production of microwave diodes: a) in relation to the 1974 level; b) in comparison to the level of employment

Illustration 2. Microwave diodes and semiconductor transistors presently produced in the ITE (DM section)

The Construction and Assembling of MPP

Microwave semiconductor diodes developed in the Institute are for the most part produced in the OC4 housing according to international standards. The majority of the types of varactors have, however, other kinds housings. Their design was worked out in the ITE ten years ago [9, 13]. The diodes in such housings are used as before in many systems produced in Poland. In illustration 2 is 47
presented microwave diodes, which were manufactured in different housings. These are ceramic-metal structures with an alundum insulator. Their schema together with their dimensions are given in illustration 3.

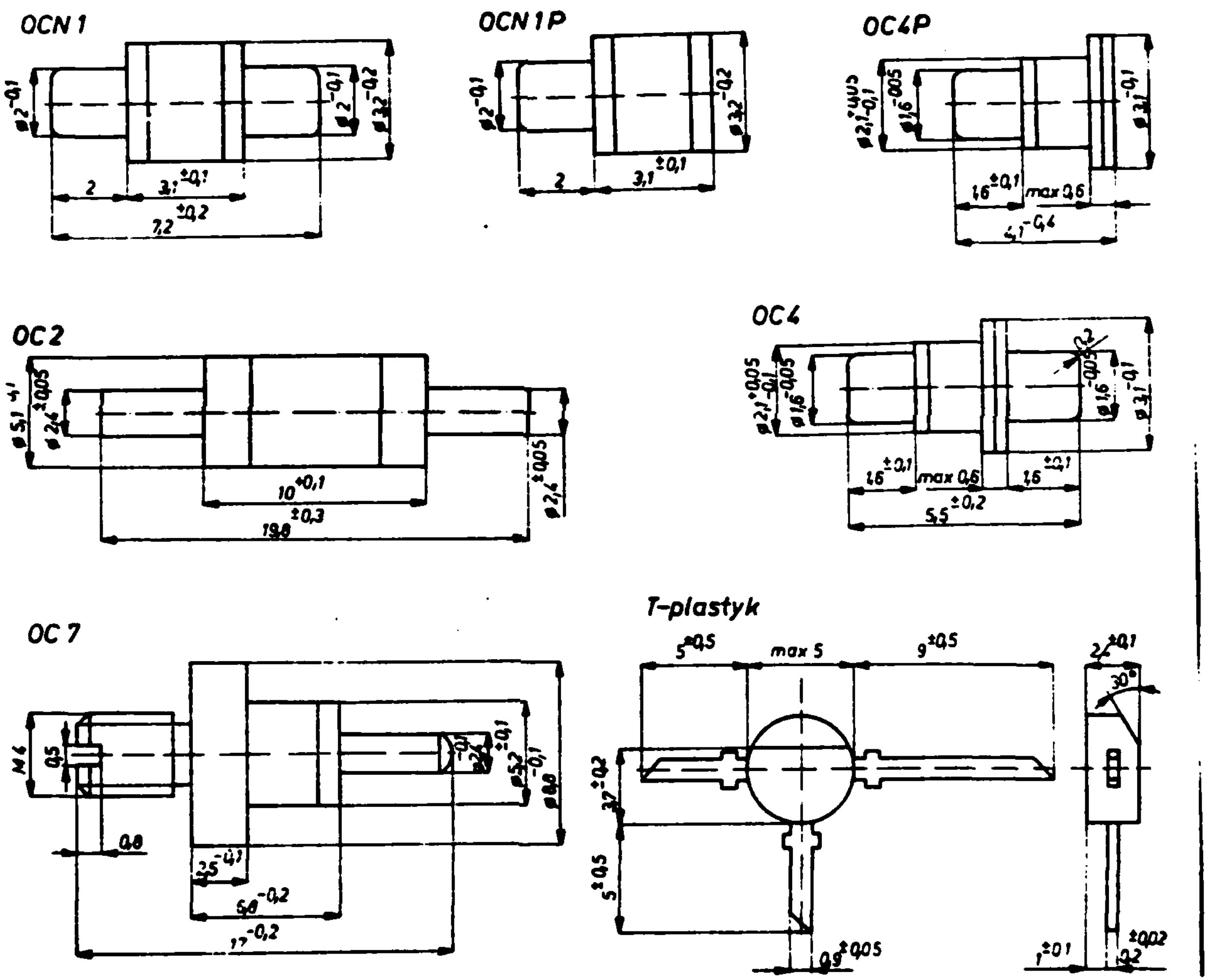


Illustration 3. Housings of microwave semiconductor devices produced in the ITE (DM section)

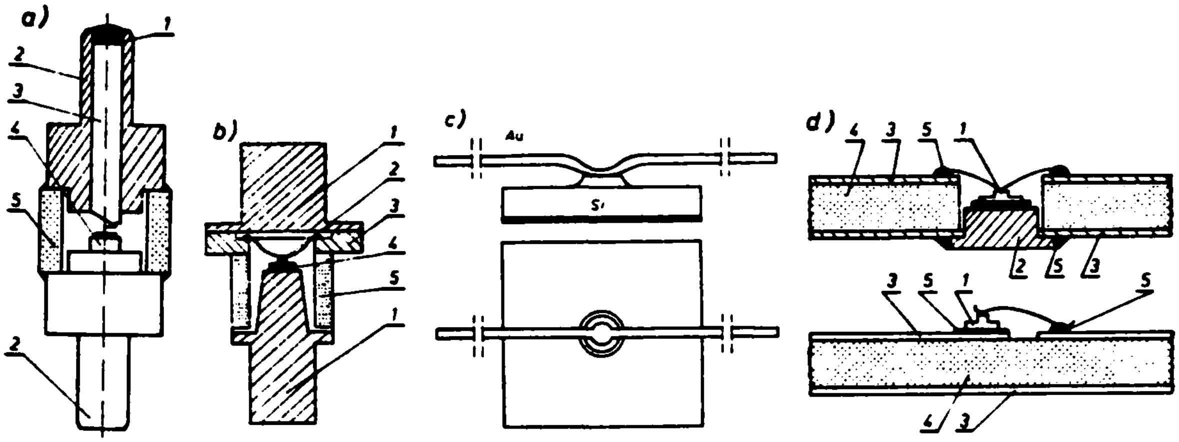


Illustration 4. Design examples of microwave diodes: a) a design of a diode with a linked contact (1--solder, 2--electrodes, 3--linking electrode, 4--structure, 5--ceramics); b) the structure of a diode with a welded contact (1--electrodes, 2--Au wire, 3--collar, 4--structure, 5--ceramics); c) the structure of a diode with intended for scaled microwave systems; d) examples of the structure's situating in a striped line (1--structure, 2--metal support, 3--metal track, 4--insulator, 5--connection through the weld by conducting paste)

Despite the many types of housings, the connected structures are 47
mounted in them in a twofold manner. All housings, with the exception of the OC4, have a design anticipated for the assembly of a structure in a mesa form, with the part contacting the top in the form of a metal bowl. The diode's assembly is very simple here. This leads to the fact that on one side the structure is soldered to the housing's support (depending on the type of housing with the different forms). However, from the other side it is inserted into the housing connecting the electrode. Situated on its end an elastic, phosphor-bronze coated chip, resistant to shock, ensures good contact with the structure's bowl. Then, the end of the housing's upper electrode is soldered, which immobilizes the inside electrode and encloses the diode. An example of this assembled diode is given in illustration 4a.

The assembly of the diode structures in the OC4 type housing requires special equipment. The structure after soldering to the housing's support is connected to the housing's collar by gold wire. Both of its ends are welded by thermocompression or by ultrasound. The diode's enclosing follows after the welding of the upper electrode (the cap) to the housing's collar (illustration 4b).

In the case of scaled microwave systems, welded structures without housings, which have passive layers of oxides on their surface, are often used. In this case such structures with connected gold conducting wires are delivered to the consignees. They are next mounted directly in the microwave striped line (illustration 4d). The connection of the base and the structure's conductor can be performed by aid of a special paste, which conducts current well.

Microwave diodes in the housings presented here are resistant to shock and acceleration. These devices are resistant to vibration at frequencies of 10-150 Hz at 25 g.

In illustration 5 the first structural design of microwave transistors worked out in the Institute is presented. It is intended for work in frequencies up to .9 GHz. At such frequencies it is possible to use plastic instead of ceramic insulators, necessary for all frequencies, taking into consideration the greater loss in the microwave band. The assembly of a series of transistor structures procedes in an open-work form (illustration 5). The next process in the stamping plant is the formation of plastic wafers, in which the structures are sunk (illustration 5b). The transistors from the open-work stripes, whose external appearance is presented in illustration 5c, are cut out on the end. The transistor housing's supplementary schema and the values of its parameters are given in illustration 6.

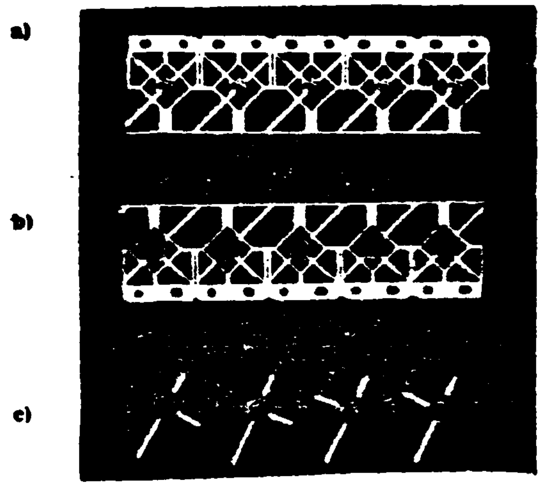


Illustration 5. BFP-479 transistors in the final production phase: a) after mounting in the open-work, b) after sinking into the plastic, c) after cutting

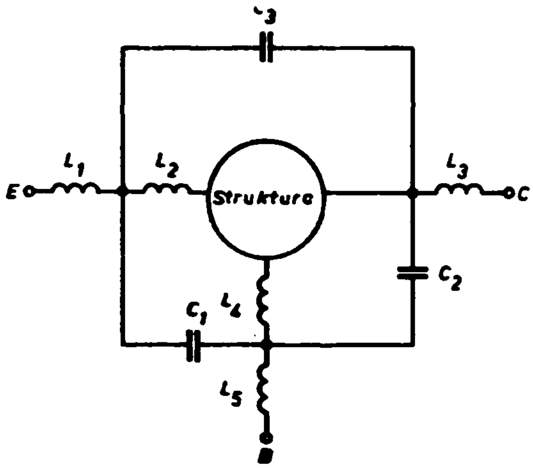


Illustration 6. A supplementary schema of the BFP479 transistor. The typical values: C_1=.28 pF, C_2=.34 pF, L_1=1.3 nH, L_2=2 nH, L_3=1.5 nH, L_4=1 nH, L_5=.3 nH

Varactors

Varactors have been designed and produced in the ITE for almost 20 years. The technology of these devices has been improved in the direction of increasing the reproducibility of parameters and decreasing labor consumption. New types of diodes with improved electrical parameters have also been designed.

Until recently, all the types of varactors produced were based on the p-n microjunction, whose design was worked out in 1965 [11]. This is dependent on the formation of a bowl of smelted Au-Ge eutectic alloy on a Si chip coated with nickel, which contains the p-n junction made by a diffusion technique. During the etching of the chip's surface, the bowl protects the part of the junction placed beneath it, and during assembly the varactor makes ohmic contact with the spring located inside the diode's housing. This method allows that in case of the lack of typical or costly equipment the p-n junction can be made for microwave diodes, as well as simplifying assembly. Such junctions (illustration 7a, b) are made individually. The bowl is made individually and every junction is etched individually. Depending on the initial material, structures for varactors used in parametric amplifiers, as well as for power varactors, intended for harmonic generators (multipliers), are made in this way. Structures connected to the first of the mentioned group of varactors are made from p type silicon ($\rho \approx 3.10^{-3}\ \Omega$cm), although the remaining structures are made based on type n epitaxial layers (the choice of resistance is conditioned by U_{BR}) [9].

In connection with the considerable expansion of the production of varactors, the most labor intensive aspect of their production has been modernized. The technology used in some types of varactors allows the simultaneous production of the microjunction. This is made on a larger silicon chip, containing the p-n junction before its cutting into the structure. This has become possible thanks to the introduction of thermal oxidation, photolithography and "inset" etching in SiO_2 layers, where the microjunction has to be made. As before, the nickel layers, which make ohmic contact, are placed in these places of the silicon's surface. Next, layers of gold and stannum of corresponding thickness are placed on this layer. After heating, the Au-Sn layers form the bowl with a eutectic composition. In order to ensure good contact with the spring of the diode's housing, the bowl's surface is coated with gold. After the etching of the chip's surface around the bowl several microjunctions with equal electric parameters are obtained simultaneously. After the chip's cutting individual structures with similar geometry are obtained, as previously had taken place (illustration 7b). 48

BXDP-14 and BXDP-51 varactors have already been produced in the given manner. The electrical parameters of these diodes are given in tables 2 and 3. Further steps have been taken within the framework of the modernization of varactor technology and the correction of their exploitation parameters. Planar technology has been used in the production of these devices. The new BXDP 52 varactor, which has a miniaturized OC4 housing, has been designed on the basis of this. This varactor with regard to electrical parameters corresponds to the BXDP 51 varactor, but is mounted into a smaller OC4 housing according to international standards. This new varactor has better electrical parameters (table 3) and is easier to produce.

The planar junction structure is made with the use of modern technological processes applied in these cases. This ensures a greater reproducibility of parameters, decreases labor consumption and considerably increases output. During the technolgocial process, the junction structures are thermally made passive by oxides, which ensure greater resistance to the diodes' external exposure, as well as increasing their stability and reliability.

Table 2. Silicon varactors for parametric amplifiers in the L band
1. diode type, 2. junction capacitance C_{jo} at $U_R=0$, 3. capacitance ratio, 4. penetration voltage U_{BR} at $I_R=10\,\mu A$, 5. cut-off frequency f_c at $U_R=-6V$, 6. total power P_{tot} at $t_{umb}=25^{o}C$, 7. heat resistance R_{thj-c}, 8. housing type, 9. or

1 Typ diody	2 Pojemność złącza C_{jo} przy $U_R=0$ [pF]	3 Stosunek pojemności C_{jo}/C_{j-6} [pF/pF]	4 Napięcie przebicia U_{BR} przy $I_R=10\,\mu A$ [V]	5 Częstotliwość graniczna f_c przy $U_R=-6$ V $f=3$ GHz [GHz]	6 Moc całkowita P_{tot} przy $t_{amb}=25°$ C [mW]	7 Rezystancja cieplna R_{thj-c} [°C/W]	8 Typ obudowy
BXDP14 I	1–1,2	2	6	90	300	200	OCN1 lub 9
BXDP14 II	1,2–1,4	2	6	90	300	200	OCN2
BXYP14	1–1,4	2	6	90	300	300	OCN1

Table 3. Silicon varactors for frequency multipliers in the UKF, L, S and X bands
1. diode type, 2. junction capacitance C_{j-6} at $U_R=-6V$, 3. capacitance ratio C_{jo}/C_{j-6} at $U_R=0$ and $U_R=-6$ V, 4. penetration voltage U_{BR} at $I_R=10\,\mu A$, 5. cut-off frequency f_c at $U_R=-6V$ f=3 GHz, 6. total power P_{tot} $t_{umb}=25^{o}C$, 7. heat resistance R_{thj-c}, 8. band, 9. housing type, 10. Note: the BXYP43, BXYP44, BXYP51, BXPY52 diodes and their subtypes also have the same electrical parameters, as well as those which correspond to them, but are delivered without special attestation, 11. or

1 Typ diody	2 Pojemność złącza C_{j-6} przy $U_R=-6$ V [pF]	3 Stosunek pojemności C_{jo}/C_{j-6} przy $U_R=0$ i $U_R=-6$ V [pF/pF]	4 Napięcie przebicia U_{BR} przy $I_R=10\,\mu A$ [V]	5 Częstotliwość graniczna f_c przy $U_R=-6$ V $f=3$ GHz [GHz]	6 Moc całkowita P_{tot} przy $t_{amb}=25°$ C [W]	7 Rezystancja cieplna R_{thj-c} [°C/W]	8 Pasmo	9 Typ obudowy
BXDP43	8–10	2	90	15	4	18	UHF.L	OC7
BXDP44	2,5–3,5	2	60	60	2	35	L	OC3
BXDP45A	2,5–3,5	2,3	60	40	2	40	S	OC4
BXDP45B	2,5–3,5	2,3	60	50	2	40	S	lub 11
BXDP45C	2,5–3,5	2,3	60	60	2	40	S	OC41
BXDP51	0,5–0,9	2	12	120	0,5	200	X	OC4 lub 11 OC41
BXDP52A	0,5–0,9	2	30	120	0,3	150	X	OC4 lub 11
BXDP52B	0,5–0,9	2	30	150	0,3	150	X	OC41

10 Uwaga: diody BXYP43, BXYP44, BXYP45, BXYP51, BXYP52, i lub podtypy mają takie same parametry elektryczne jak ich w/w odpowiedniki, lecz są dostarczane bez specjalnego atestu.

1 Typ diody	2 Pojemność złącza C_{j-4} przy $U_R = -4$ V [pF]	3 Stosunek pojemności C_{j0}/C_{j-20} przy $U_R=0$ i $U_R=-20$ [pF/pF]	4 Napięcie przebicia U_{BR} przy $I_R = 10$ µA [V]	5 Częstotliwość graniczna f_c przy $U_R = -4$ V i $f=3$ GHz [GHz]	6 Moc całkowita P_{tot} $t_{amb} = 25°$ C [mW]	7 Rezystancja cieplna R_{thj-c} [°C/W]	8 Typ obudowy
BXDP74A	0,8 – 1,2	3,9	40	90	300	80	OC4
BXDP74B	0,8 – 1,2	3,9	40	100	300	80	OC4
BXEP74	0,8 – 1,2	3,9	40	100			Struktura złączowa (bez obudowy) 9
BXYP74A	0,6 – 1,0	3,7	40	90	300	100	OC4
BXYP74B	0,6 – 1,0	3,7	40	100	300	100	OC4

Table 4. Silicon varactors for generator change-overs and microwave filters
1. diode type, 2. junction capacitance C_{j-4} at $U_R=-3$, capacitance ratio C_{jo}/C_{j-20} at $U_R=0$ and $U_R=-20$, 4. penetration voltage U_{BR} at $I_R=10$ µA, 5. cut-off frequency f_c at $U_R=-4$ V and f=3 GHz, 6. total power P_{tot} t_{umb}-25°C, 7. heat resistance R_{thj-c}, 8. housing type, 9. junction structure (without housing)

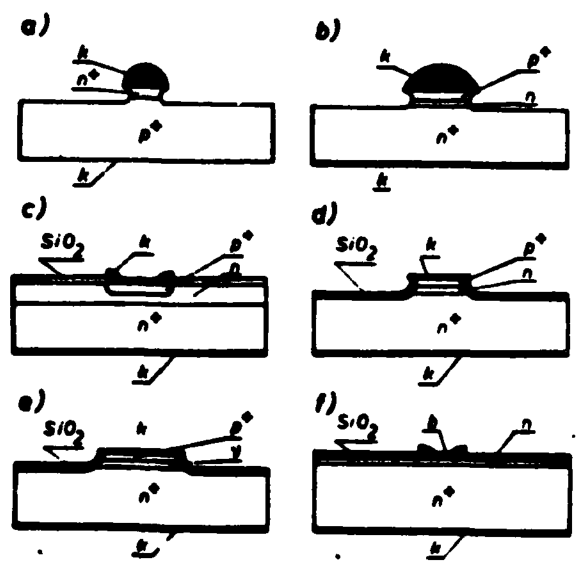
The structure of the BXDP 52 diode ensures better heat offtake into the housing, through which a considerable reduction of thermal resistance in comparison to the value of this parameter in the BXDP 51 diode is obtained. The values of the parasitic parameters are also reduced. The inductance and capacitance of the OCN4 housing are contained within the limits of 1.2 nH and .30 pF, when in the OC4 this does not exceed .8 nH and .25 pF [30,31]. 48 49

A sketch of the technology of the varactor's planary structure follows. A SiO_2 layer is formed on the n type epitaxial layer (ρ =.35 Ωcm, h_e=4.5 µm), installed on a strongly doped base (ρ <10^{-2} Ωcm). Next, after the use of the photolithographic process and etching, an inset (Ø=70 µm) is formed in the insulating layer, by which the boron's diffusion is accomplished at a depth of 3 µm. The p-n microjunction is created in this manner. In subsequent processes a contact suitable for the p type layer is created in the inset by inserting the Pt, and then adding Cr and Au layers. After part of the base is ground down, a nickel contact is formed. In this way several hundred structures can appear simultaneously on one silicon chip. After the chip's cutting individual structures are obtained (illustration 7c), which are mounted in the OC4 housing.

The technology of junction structures used in varactors intended for the change-over of microwave circuits (BXDP 74, BXEP 74) was designed individually [32,33]. The p-n junction was made here at a depth of around 3 m as a result of the diffusion of boron in the layer's epitaxial part (ρ =.4 Ω cm and a thickness of around 4 m) inserted on a strongly doped base with a resistance on the order of 10^{-3} Ω cm. The junction structure obtained in many of the technological processes has the form of a covered mesa, which makes the SiO_2 layer passive (illustration 7d). The varactors from this type of structure obtain a greater cut-off frequency and more useful capacitance-voltage characteristics than planary varactors. The effective protection of the p-n junction's flange used against external influences guarentees the varactor's good electrical stability. With BXDP 74 varactors, the structures are also mounted in the OC4 type housing.

The passive junction structures, with a junction in the form of gold wire, are intended for use in scaled microwave units, such as the BXEP 74 discrete changing-over varactor.

The electrical parameters of the 74 series of varactors are given in table 4.



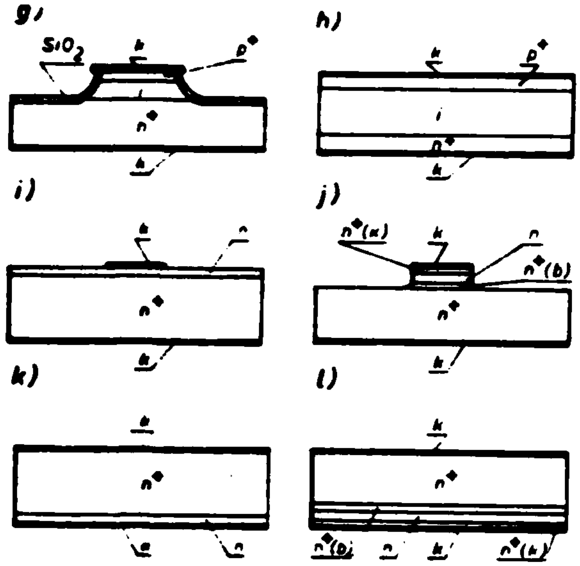


Illustration 7. Junction structures used in microwave diodes produced in the ITE: a) the p-n microjunction of a varactor with a mesa form with a spherical contact; b) the p-n microjunction of a power varactor with a spherical contact; c) the planary structure of a varactor; d) the junction structure of a varactor with a mesa form; e) the junction structure of a p^+-v avalanche diode; f) a structure with a Schottky barrier; g) the junction structure of a low power PIN diode; h) the junction structure of a high power PIN diode; i) the structure of a Gunn diode with one epitaxial layer; j) the structure of a low power Gunn diode with a triple epitaxial layer; k) the structure of a Gunn dode with one epitaxial layer; l) the structure of a Gunn dide with a triple epitaxial layer: n^+(k)--the n+ type epitaxial contact layer; n^+(b)--the epitaxial buffer layer, k--the ohmic contact, b--the buffer layer, --the area of the type n autonomous semiconductor, i--the area of the autonomous semiconductor

Avalanche Diodes

Avalanche diodes, besides varactors, are intended for multiplying a signal's frequency.

The function of these diodes rests on the storage effect of the smaller axis carriers near the p-n junction, introduced during the diode's conduction, and then on their rapid regeneration when the diode is polarized in the reverse direction. As a result of this a greater impulse of current is obtained in the reverse direction, as well as its rapid decline (less than 1 ns). This allows the greater product of the frequency multiplication in one level of the multiplier. Contrary to multiplication by aid of varactors, where the multiplication's efficiency declines with the increase of the harmonic order (n) to the tune of $1/n^2$, multiplication by using avalanche diodes is more advantageous. The efficiency of the harmonic generators here decreases proportionally to 1/n (with n>5 [12]).

Research on avalanche diodes, performed in the Institute, has led to the designing of these diodes' optimal technology.

Avalanche diodes (BXDP 82), which have been introduced into laboratory production, have a p^+-v-n^+ mesa type junction structure, covered by a SiO_2 insulating layer (illustration 7e). The technology of this type of structure is similar to that of structures from illustration 7e. The difference depends on the technological preparation of the silicon chip before the mesa is formed. The initial material is a strongly doped base (10^{19} at. cm^{-3}) with an installed epitaxial layer with a resistance of around 100 Ωcm. The chip is made for this layer by boron diffusion. The proper choice of the geometry of the material's structure and the technological processes allow the creation of a junction structure with a suitable doping distribution, which forms an inhibitory electric field in the junction's region. This field gathers around the charges of carriers introduced during the diode's conduction, which after the polarization's change is rapidly removed, creating a right angle impulse of current.

The electrical parameters of the BXDP 82 avalanche diode are given in table 5. Special attention should be given to the value of the the cut-off frequency and very small transition time τ_t [34].

1 Typ diody	2 Pojemność złącza C_{j-6} przy $U_R=-6$ V	3 Napięcie przebicia U_{BR} przy $I_R=10$ µA	4 Częstotliwość graniczna f_c przy $U_R=-6$ V	5 Czas przejścia τ_t przy $I_F=10$ mA $U_R=10$ V	6 Moc całkowita P_{tot} przy prądzie stałym przewodzenia $t_{amb}=25°$ C	7 Sprawność podwajania przy $f_{wy}=4$ GHz	8 Efektywny czas życia nośników mniejszościowych przy $I_F=10$ mA $I_R=6$ mA	9 Typ obudowy	10 Rezystancja cieplna R_{thj-c}
	[pF]	[V]	[GHz]	[ns]	[W]	[%]	[ns]		[°C/W]
BXDP82	1–2	50	100	0.25	3	55	25	OC4	40
BXYP82	1–2	50	100	0.25	-	–	25	OC4	50

Table 5. Silicon avalanche diodes for multiplying frequencies in the S and L band 50

1. diode type, 2. junction capacitance C_{j-6} at $U_R=-6$ V, 3. penetration voltage U_{BR} at $I_R=10$ µA, 4. cut-off frequency f_c at $U_R=-6$ V, 5. transistion time t at $I_f=10$ mA $U_R=10$ V, 6. total power P_{tot} at a constant conduction current $t_{amb}=25^oC$, 7. doubling efficiency at $f_{wy}=4$ GHz, 8. effective life of the small axis carriers at $I_F=10$ mA $I_R=6$ mA, 9. housing type, 10. heat resistance R_{thj-c}

1 Typ diody	2 Pojemność złącza C_{jo} przy $U_R=0$	3 Częstotliwość graniczna f_c przy $U_R=0$ r_s przy $I_F=20$ mA	4 Całkowity współczynnik szumów $f_{pcz}=30$ MHz $f=3$ GHz	5 Impedancja Z_{IJ} dla: $f_{pcz}=30$ MHz $P=1$ mW $f=3$ GHz	6 Współczynnik fali stojącej S_v przy $Z_o=50$ $P=1$ mW, $f=3$ GHz	7 Moc fali ciągłej P_{cw}	8 Energia ostrego impulsu W_i przy $\tau=2.5$ ns	9 Typ obudowy
	[pF]	[GHz]	[dB]	[Ω]	[V/V]	[mW]	[erg]	
BADP14	0,6	55	6	300–400	2	50	5	OC4, OC4P
BAEP14	0,6	55	6	300–400	2	50	5	10 Struktura złączowa bez obudowy
BAYP14	0,6	55	6	300–400	2	50	5	OC4

Table 6. Schottky silicon diodes for mixers, which operate in the S band

1. diode type, 2. junction capacitance C_{jo} at $U_R=0$, 3. cut-off frequency f_c at $U_R=0$ r_s at $I_f=20$ mA, 4. total noise coefficient $f_{pcz}=30$ MHz $f=3$ GHz, 5. jimpedance tZ_{tj} for: $f_{pcz}=30$ MHz $P=1$ mW $f=3$ GHz, 6. coefficient of the standing wave S_v at $Z_o=50$ $P=1$ mW, $f=3$ GHz, 7. continuous wave power P_{cw}, 8. sharp impulse energy W_i at $t=2.5$ ns, 9. housing type, 10. junction structure without housing

1 Typ diody	2 Napięcie przebicia U_{BR} przy $I_R=10\ \mu A$ [V]	3 Pojemność całkowita C_{TO} przy $U_R=0$ f=1 MHz [pF]	4 Pojemność całkowita C_{T50} przy $U_R=50V$ f=1 MHz [pF]	5 Rezystancja R_s przy $I_F=100$ mA [Ω]	6 Czas przełączania t_{rr} przy $I_F=100$ mA $I_R=500$ mA $R_L=100$ [ns]	7 Współczynnik fali stojącej S_o przy $U_R=0$ f 1 GHz [V/V]	8 Moc całkowita P_{tot} przy prądzie stałym przewodzenia $t_{amb}=25°C$ [W]	9 Moc mikrofalowa P_{Maiss} przy pracy impulsowej [kW]	10 Rezystancja termiczna R_{thj-c} [°C/W]	11 Typ obudowy
BADP 28	700	1,5	0,8	0,6	300	60	5	5	25	OC4
BADP 26	150	0,75	0,5	1	80	60	2	0,6	60	OC4

Table 7. PIN silicon diodes for commutators and limiters
1. diode type, 2. penetration voltage U_{BR} at $I_R=10\ \mu A$, 3. total capacitance C_{TO} at $U_R=0$ f=1 MHz, 4. total capacitance C_{T50} at $U_R=50$ V f=1 MH, 5. resistance R_s at $I_F=100$ mA, 6. commutation time t_{rr} at $I_F=100$ mA $I_R=500$ mA, $R_L=100$, 7. coefficient of the standing wave S_o at $U_R=0$ f=1 GHz, 8. total power P_{tot} at the constant conduction current $t_{amb}=25°C$, 9. microwave power P_{Maiss} at impulse operation, 10. thermal resistance R_{thj-oc}, 11. housing type, 50

1 Typ diody	2 Nominalne napięcie zasilania U_o [V]	3 Zakres częstotliwości f [GHz]	4 Minimalna moc wyjściowa P_{wy} [mW]	5 Zakres przestrajania Δf [MHz]	6 Maksymalna czułość przestrajania napięciowego Δf/ΔU$_o$ [MHz/V]	7 Maksymalne napięcie zasilania $U_{o\,max}$ [V]	8 Maksymalny prąd zasilania $I_{o\,max}$ [mA]	9 Zakres temperatury otoczenia w czasie pracy t_{amb} [°C]	10 Typ obudowy
CXDP43A	9±0,8 V	10,3–10,5	15		15	12		-40 – 70	OC4
CXDP43B	10,5±0,8 V	9,2–9,6	10		15	12		-40 – 70	OC4
CXDP44	8–12	8,2–12,4	100	1000		12	500	-35 – 100	OC4
CXYP43–1	6–12	8–12	5			12	125	-40 – 55	OC4
CXYP43–2	6–12	8–12	10			12	150	40 – 55	OC4
CXYP43–3	6–12	8–12	15			12	200	40 – 55	OC4
CXYP43–4	6–12	8–12	28			12	225	-40 – 55	OC4
CXYP44–1	6–12	8–12	50			12	700	-35 – 100	OC4
CXYP44–2	6–12	8–12	100			12	850	35 – 100	OC4

11 Uwaga: parametry określa się podczas pracy diody w specjalnych generatorach kontrolnych dla każdego typu diody.

Table 8. Gunn diodes intended for microwave generation in the X band
1. diode type, 2. nominal amplification voltage U_o, 3. frequency range f, 4. minimal initial power P_{wy}, 5. changing-over range f, 6. maximum sensitivity of votalge changing-over f/ U_o, 7. maximum amplification voltage Uo_{max}, 8. maximum amplification current $I_{o\,max}$, 9. temperature range of the surroundings during operation t_{amb}, 10. housing type, 11. note: parameters are determined during the diodes' operation in special generators controlled for each type of diode

Schottky Diodes 51

Work on Schottky diodes has been carried out in the DM institute for six years. In this period a series of technological versions and models of these types of diodes intended for operation in the S and X bands has been developed. A Schottky contact based on a silicon-silicide platinum circuit was formed in these diodes. It is characterized by a considerable heightening of the potential barrier, which is not advantageous from the point of view of the diode's noise. With regard to this, recently there was designed new technology, thanks to which a relatively low potential barrier can be obtained. This has become the basis for the structure and technology of a prototype of the BADP 14 silicon diode (and its modification, the BAEP 14 for scaled microwave circuits). The mentioned diodes are intended for operation in a mixer system in the 1-4 GHz range.

The structure with a Schottky barrier (illustration 7f) is realized by an epiplanar technique. The intial material is a silicon base chip with a <111> orientation doped with arsenic (ρ =.01 cm), on which is formed an epitaxial layer doped with phosphor (ρ =.3 cm) with a thickness of around 1 μm. The metal forming the Schottky barrier on the silicon is infused in a 10^{-7} Tr vacuum through the inset in the SiO_2 layer. Then, the gold layer is placed in this same way, which faciliates the barrier's connection with the housing. The mentioned insulating layer with a thickness of .6 μm is formed in the process of the silicon's thermal oxidation. The inset with a diameter of 20 μm is made by a photolithographic technique and etching. The appropriate base contact is made by the infusion of several layers of metal. The first of these forms the lower metal-semiconductor junction, the other layers of gold permit the easy connection of the wire structures with the housing. Good results are obtained by using chrome as a contact layer.

A series of junctions with the Schottky barrier is found on the silicon chip mounted in the housing, although only one is used. These are reserve junctions, which can be used if the first of them has poor characteristics, which statically arise with an inaccurate connection [35]. The electrical parameters of the BADP 14 and BAEP 14 Schottky type diodes, which have already been produced, are given in table 6.

PIN Diodes

Presently, two basic types of low and high power PIN diodes are serially produced (the BADP 26 and the BADP 23). They are chiefly intended for commutators and microwave limiters.

Silicon with a resistance of 1000 Ω cm is the initial material used for the production of low power diodes. It serves as a base, on which a layer of strongly doped n^+ with a thickness of 150 μm is formed in the epitaxial process. Behind the base's opposite side is formed the p^+ region as a result of the boron's diffusion (5 μm). Before the base's diffusion the chip is thinned to a thickness of 15 μm.

The junction structure of a low power diode has a mesa form, and its flange is covered by a SiO_2 layer (illustration 7g). The technique of forming this type of structure is similar to the technology of the structures of BXDP 74 varactors.

High power diodes with a great penetration voltage and low thermal resistance have junctions whose surface is several times larger than that of low power diodes. This facilitates the formation of the junction structure. In this case, it is not necessary, as it was before, to decrease the surface of the active region in the chip and to form a microjunction on it. The active region here is under the entire structure's surface in the form of square chips, as in illustration 7h. Monocrystaline silicon chips with a resistance of 10 kΩ cm are the initial material, which is independent. Both the

p^+-i and i-n^+ junctions have a thickness of 7 and 30 μm, respectively, and the chip's total thickness is 130 μm. The ohmic contact for both sides of the chip is made by a currentless method by the inclusion of a nickel layer. Both sides, moreover, are gilded electrolytically in order to facilitate the diode's assembly. After the chip's cutting into structures with sides of 500 μm, they are lightly etched on the flange. Both types of structures are mounted in the OC4 type housing. In BADP 26 diodes, the structures are soldered to the housing's support, although in the BADP 23 diode they are welded on. Behind the other side the chips are connected to the housing with gold wire [36]. The electrical parameters of both types of diodes are given in table 7.

Gunn Diodes

The technology of Gunn diodes with a power between 50 mW and 250 mW, which operate with continuous waves in the X band, was designed in 1973 and 1974. A complete system was prepared then for laboratory production of these devices, and basic circuits for the measurement of the microwave parameters of these diodes was set up [26, 27, 37].

In 1978 prototype tests were finished and two basic types of Gunn diodes, the CXDP 43S and CXDP 44, were introduced into laboratory production. The first type of diode, produced in two variations (the CXDP 43A and the CXDP 43B) were intended mainly for Gunn generators. These generators were used in navigational and surface radar, which operated at various frequencies in the X band. They can also be used in other generators. The electrical parameters of the Gunn diodes presently produced are given in table 8.

The technology of both types of Gunn diodes, with a power between 20 mW and 100 mW, rests on earlier technological designs mentioned in the beginning of the article.

In the "43" series diodes the active region in the GaAs chip is found between the ohmic contact's island (Ø 80 μm) and the strongly doped base illustration 7i). The epitaxial layer has a thickness of around 10 μm and a doping level of around 3×10^{15} at.cm^{-3}. A Ge-Au eutectic layer infused with a 10 percent Ni doping, with a thickness of a few microns, makes up the contact. A thin layer of gold (.5 μm) is placed on this layer, which facilitates the diode's assembly (a wire connection between it and the housing). The ohmic contact is made behind the chip's opposite side in a similar way. A GaAs chip prepared in this way has the following dimensions after cutting: 400x400x100 μm. It is mounted in an OC4 housing. The chip is welded to the housing base from the mount's side by aid of a eutectic alloy of Ge and Au.

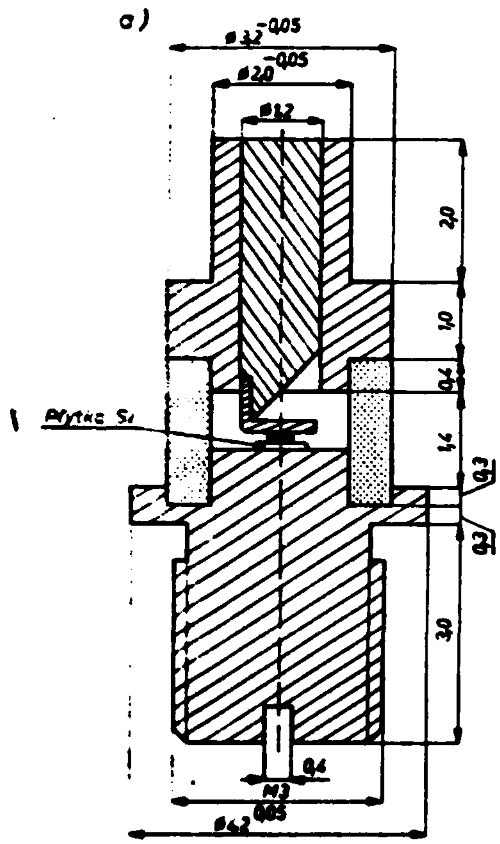
In the newer series of diodes gallium arsenide with a triple epitaxial layer is used. The layer of the active region has parameters similar to those of the "43" series of diodes. Behind both sides of this layer are found contact and buffer layers, which increase the homogeneity of the active region and the diode's contact. In this case, after the island's infusion, the GaAs region is etched around it and a lower mesa form is obtained (illustration 7j).

The structures used in higher powered Gunn diodes have similar material parameters and type of ohmic contact. The existance of differences depends on the size of the active region and manner of the chip's mounting in the housing. The ohmic contact on the entire surface of the GaAs chip is infused here behind both sides. Then, the larger chips prepared in this way are cut into structures, which have sides of 200 μm (illustration 7k). The structure is welded to the housing's base from the cathode's side (opposite to the previous case). Around a ten times smaller thermal resistance is obtained in this manner in relation to that, which diodes with chips welded to the housing from the mount's side have and five times greater intial power than that of a Gunn diode.

Recently, chips with a triple epitaxial layer have been used (illustration 71).

Avalanche Diodes

Avalanche diodes have never been produced serially, although their technology was designed a long time ago [20]. This results from the insufficient need for them.



Ill. 8.

b)

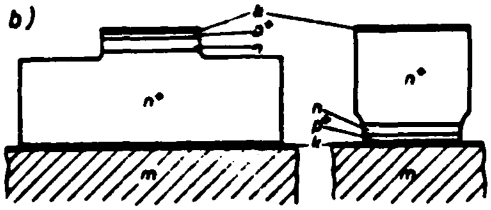


Illustration 8. a) the structure of an avalanche diode; b) the junction structures used in low power diodes; and the junction structures used in high power dodes with the structure's reverse mounting
1. Si chip

Until 1974 a series of avalanche diodes, which operate in 52
generators with a continuous power between 100 and 750 mW in the X band, were exclusively produced in an understandably short series. In illustration 8 is presented the design and junction structure of these diodes. The structures are mounted in OC4 type housings, where with regard to worse cooling conditions an initial power near 300 mW is obtained.

The junction structure is formed on type n epitaxial silicon layers with a thickness of 8 μm ($\rho \approx 1\ \Omega$ cm), installed on a strongly doped base with a resistance on the order of $10^{-3}\ \Omega$ cm. The p-n junction is formed in the process of the chip's boron diffusion (3 μm). The ohmic contact is formed during the chemical sedimentation of the nickel layer. The chip is then gilded on both sides. The thickness of chips prepared in this manner amounts to 60 μm. After cutting the individual square structures (with sides of around 200 μm) are mounted in different housings. So-called reverse mounting is used, which allows the active region's efficient cooling (the structure is welded to the base from the side of the type p).

The diodes produced have a penetration voltage of 70-80 V (at $T_j = 20^{\circ}C$), and the junction capacitance with a lack of polarization amounts to 3-5 pF. The generation efficiency with an intial continuous power is contained with 5 percent.

Avalanche diodes were used in generators designed in the Institute [38] and other scientific institutions (for example in the PIT and the WAT).

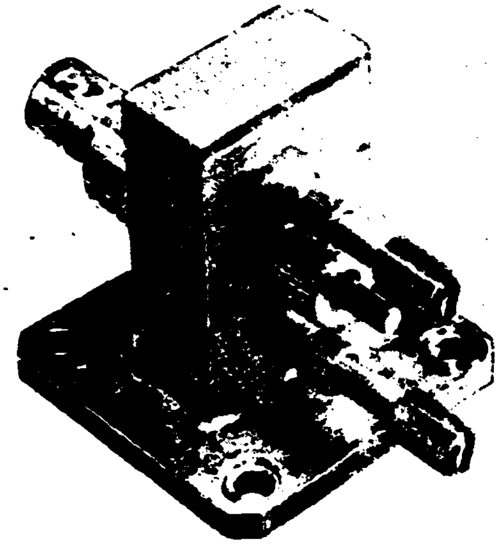


Illustration 9. A Gunn generator intended mainly for surface radar

Illustration 10. A Gunn generator intended chiefly for navigational radar

Gunn Generators

Recently in the DM section work has been undertaken on microwave subsystems, in which domestic semiconductor devices are used. Presently, two prototypes of Gunn generators are being designed [39, 40].

The first of them is intended for surface radar, where it plays the role of the microwave signal source in the velocity measurer. It can also be used in warning, safety and other devices. The generator operates in the 10 GHz ± 200 MHz band and is mechanically changed over. The CXDP 43A diode is used in it. The generator has a half-wave wave guide resonator, created from a R100 type standard wave guide, directly connected to the generator's outlet (illustration 9). The generator's initial power is greater than 15 mW.

The second generator (illustration 10) has the same type of resonator and connection. It is electronically changed over. The CXDP 43B Gunn diode and the BXDP 74 changing over varactor are located on the wave guide resonator's axis. The initial power (greater than 10 mW) is regulated mechanically from a level of .5 mW to the maximum poweer for the given Gunn diode. Mechanical change over is possible in the (.4 GHz ± 200 MHz band, and electronic change over in the 9.4 GHz ± 30 MHz band (at alternating changing over currents of 3 to 35 V).

The generator is used as a heterodyne in microwave receivers in sea navigation radars and as a lacal signal source in other devices.

Microwave Transistors

As a result of work in the field of microwave transistors, the technology for pnp transistors (type BFP 479), which also operate in the beginning range of the microwave band, was worked out. It is intended chiefly for operation in color television receivers. The junction structure of this transistor is opposite that used in npn type microwave transistors. It is, therefore, adapted to the amplification conditions in a television receiver. The worked out type of transistor can also be used in other instruments in the UKF band and in the beginning range of microwaves.

Illustration 11 presents the epiplanar structure of the BFP479 transistor. It is formed on silicon chips with a (pp^+) epitaxial layer. Both the base and the emitter are subsequently maded by implanting arsenic and boron ions, respectively. P-n and n-p junctions are obtained with a thickness of .4 and .6 μm. The base's grating is created by the diffusion of arsenic or phosphor (its thickness is 1.2 m). The ohmic contacts of the emitter and base are made by the infusion of the AlSi alloy. The emitter's contact, however, is composed of deposited layers of gold. The transistor is mounted in a T-plastic housing [41].

The electrical parameters of the BFP 479 bipolar transistor are as follows:

Specification Values

collector-base voltage (I_E=0)	U_{CBO}=30 V
collector-emitter voltage (I_B=0)	U_{CEO}=25 V
emitter-base voltage (I_C=0)	U_{EBO}=-3 V
collector's current	I_C=50 mW
total power at T_{amb}=25^oC	P_{tot}=170 mW
storage temperature	T_{stg}=-55 — 150^oC
junction temperature	T_j=150^oC
electrical parameters in the temp.	T_{amb}=25^oC
collector's current (I_E=0) at U_{CB}=20 V	I_{CBO}<100 nA
collector-base penetration voltage (I_E=0) at I_C=100 μA	$U_{BR/CBO}$>30 V
collector-emitter penetration voltage (I_B=0) at I_C=5 mA	$U_{BR/CEO}$>25 V
emitter-base penetration voltage (I_C=0) at I_E=10 μA	$U_{BR/EBO}$>3 V
current intensification coefficient at I_C=10 mA; U_{CE}=10 V	h_{FE}>20
cut-off frequency at: I_C=8 mA, U_{CE}=10 V, f=1 MHz	f_T>1.2 GHz
collector-base junction capacitance at I_E=0; U_{CB}=10 V; f=1 MHz	C_{CBO}<1 pF
power intensification coefficient at: I_C=8 mA, U_{CB}=10 V R_L=500 Ω, f=800 MHz	G_p>12 dB
noise coefficient at U_{CB}=10 V, R_g=50 Ω	

a) I_C=8 mA, f=800 MHz NF$\leq$4.5 dB
b) I_C=8 mA, f=800 MHz NF$\leq$6 dB

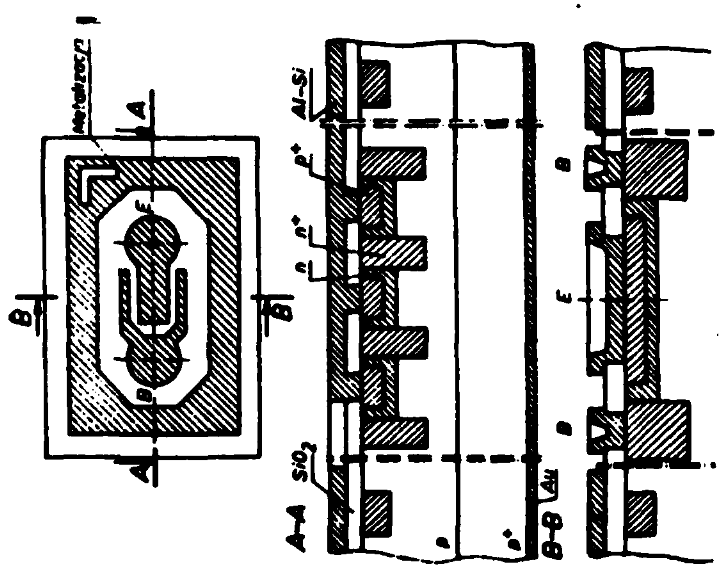


Illustration 11. the BFP 479 transistor's junction structure
1. metallization

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