

**INTERROGATION OF GERMAN SCIENTISTS
REGARDING QUARTZ CRYSTALS
AND OTHER PIEZOELECTRIC MATERIALS**

**Report prepared by
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REPORT
ON THE
INTERROGATION OF GERMAN SCIENTISTS
REGARDING QUARTZ CRYSTALS AND OTHER
PIEZOELECTRIC MATERIALS,

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FOREWORD

It was evident at the close of the war that Germany had embarked upon an extensive program of ersatz materials for quartz crystals. The program consisted of (1) a search for a method of synthesis of quartz and (2) an exploration of a variety of substances which might be grown artificially and have favourable piezoelectric properties.

The following interrogations involved the principal characters, now available, who were associated with both aspects of the ersatz program.

A. INTERROGATION OF P.L. GÜNTHER - HEIDENHEIM

29 and 30 NOVEMBER 1945

1. At the request of the Luftwaffe in June or July 1944, Günther began experiments on the production of artificial quartz crystals by the reaction of Si Cl₄ with various oxides. This work was begun at Breslau, and in March 1945 he was moved to Leuchstaffel G.m.b.H. at Steinbach in Thuringia. The work on production of quartz by the reaction method was not successful enough to continue, and Günther was shifted to work on detector crystals. He worked on Silicon and pyrite. His assistant Chytrek was given charge of actual production of quartz by the Nacken method. This progressed only three or four weeks until the end of the War.

2. The oxides which were tried in the attempt to produce quartz by reaction with Si Cl₄ included Al₂O₃, H₂O, Mn O, Fe₂O₃, CaO, Li₂O. The reaction expected was of the type: $3 \text{ Si Cl}_4 + 2 \text{ Al}_2\text{O}_3 \rightarrow 3 \text{ SiO}_2 + 4 \text{ Al Cl}_3$.

3. The general technique can be described as a high temperature vapor reaction. Two specific methods were tried with the materials sealed in quartz glass tubes.

a. Both compounds in the tube were heated in an oven to within 5° C of the quartz inversion point.

b. Both compounds sealed in tube but the SiCl₄ was kept at room temperature (25°); the oxide was heated to temperatures, varied in different attempts up to 500° + C.

4. Crystals of microscopic size were formed. Günther has serious doubts if they were quartz. They could not be proved piezoelectric by Prof. Bergmann at the Tech. Hoch Sch. (Breslau) on a very sensitive "click-tester". The crystals were too small to be checked by other methods. Spectographs were not taken. The "click-tester" is apparently an improved Giebe-Scheibe instrument, and is described in Scheibe's book, "Piezoelectricitat".

5. The basis for experimenting with this method was the conventional statement in the literature that Si Cl₄ and Al₂O₃ gave a strong reaction. Günther

stated that a reaction was apparent, but the result was not SiO_2 , but might be a sodium silicate from reaction with the glass of the tube. Furthermore he suspects that H_2O in the oxide facilitated the reaction.

6. The production methods used at the Leuchstaffe GmbH plant by Chytrek for making quartz were reported incompletely by Günther as follows:

a. Autoclaves were 15 inches high by 10 inches in diameter, made of iron and lined throughout the interior with silver to prevent reaction with H_2O above the critical temperature. No provision for circulation of solution was made.

b. Seed was suspended in solution by platinum wire. Günther was emphatic on this point although he was checked on it, and when told it was contrary to the reported Nacken method he insisted positively that the seed was submerged in the solution.

c. So far as Günther knew, the solution was pure H_2O , and granular vitreous (fused) SiO_2 . He indicated that if the pH value was controlled he did not know it. Small, natural, untwinned quartz crystals were used as seeds. He did not know how many seeds were used at once.

d. The autoclaves were placed in "furnaces"; the temperature used was around 350°C . The slight temperature differential between bottom and top of solution was relied on to produce growth on seed.

e. Günther thinks possibly Chytrek had solubility data, but did not see it himself.

f. Actual operations progressed only 3 or 4 weeks at Steinbach before U.S. troops came. Enough success was apparent to be encouraging.

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B. INTERROGATION OF KURT SPANGENBERG-HEIDENHEIM,

29 NOVEMBER 1945

1. Spangenberg and his laboratory were moved from Breslau to Jena about 1 January 1945. This was a serious interruption to his investigations. For many years he had been growing crystals and prepared to work from melts, citing the example of NaCl in which large cylindrical crystals could be drawn out of a crucible after a seed had been inserted on a rod. However, it was obviously impossible to treat SiO_2 that way because of the inversion point. The same was true of the substances he was called on to investigate.

2. He checked the compounds in the list given me by Dr. Sawyer, and made the following comments:

a. KH_2PO_4 and $\text{NH}_4\text{H}_2\text{PO}_4$ and the analogous arsenates; See below.

b. $\text{Ba}(\text{NO}_3)_2$, KLiSO_4 , NaLiSO_4 : seeds only were grown preparatory to starting work on larger crystals.

c. $\text{Sr}(\text{NO}_3)_2$ and $\text{Pb}(\text{NO}_3)_2$: these proved to be piezoelectric but could not be grown without twinning in any of the usual ways. There was not time to find a successful technique. (Spangenberg repeated many times his dissatisfaction at having to work under pressure; he wanted 10 years to do what was ordered in 6 months.)

3. Seeds were secured in general by placing 4" x 10" evaporating dishes in CaCl_2 dessicators. Spangenberg believes spontaneous crystallization, or inoculation, of a super saturated solution would give better seeds. The seeds which were used were always unclear, and the resulting new crystals always had flaws.

4. Spangenberg outlined the techniques in use for (post-seed) growth:

a. Carefully controlled slow cooling.

b. Static evaporation.

c. Evaporation by regulated dry air flow with very close control of temperature.

d. Circulating system with temperature differential.

5. He used method 4c, claiming a control of temperature as close as $+ 0.001^{\circ} \text{C}$ by means of several thermostats in the thermal bath. The thermostats were U tubes of toluol (or CaCl_2 solution) with a mercury column closing or opening a capillary gas fuel tube. He prefers gas as a heating element because he believes it can be more closely controlled than electric elements. The thermal bath contains either glycerine (preferred) or water, and is vigorously stirred to distribute the heat. The thermal bath should have 50 to 60 liters of fluid to the 8 to 10 of the inner container of solution. Dry air is admitted across the top of the solution in the inner vessel from one or more inlets, measuring and regulating the rate of flow by an airflow meter. The moist air is given outlet by other tubes. The lid is sealed on. A stirrer moves the solution very slowly; its driving rod admitted through the cover by a mercury trap. The seeds are suspended from hairs attached to glass rods which pass through rubber stoppers in the cover.

a. Hairs are used to suspend the seeds. The seeds are drilled, and the hair passes through the hole. A wire instead of hair, would cause fracturing of the edges of the hole; cause cracks to start in the seed, and equally important, cause granules or splinters which would serve as secondary nuclei. Textile fibres also cause secondary nuclei.

6. Spangenberg had also worked with a circulating system which he discussed with some reluctance, since it was not described in the literature, and he had not patented it, hoping to retain it as a professional secret. In essence the system consisted of a very tall vessel containing the solution with an inverted elongated funnel suspended inside, so arranged that the warm solution would rise through the inner vessel and settle around the outside, between the container and the inner tube. Excess raw material might be left on the bottom throughout the process. Seeds could be suspended at the top of the inner tube or in the descending cool solution. He suggested a temperature differential of 20° and 40° between top and bottom. Another type of circulating system was discussed: Two vessels at the desired temperature differential with high and low level tubes

connecting them. This scheme was not favored, however.

7. The work on $K_2H_2PO_4$ and $NH_4H_2PO_4$ and analogous arsenates progressed to the point where samples of approximately 1" length were submitted to Bechmann for piezoelectric tests. All had some flaws in them, and Spangenberg claims not to know the specific results of the tests. He thinks Gerber made the investigations.

8. The work on the mixed crystals, i.e., NH_4 replacing K in both phosphates and arsenates, was in the early experimental stages at the close of the war. Spangenberg's approach was to try three mixtures, $1/4 HLi_4$, $1/2 NH_4$, $3/4 NH_4$ - as a starting point. He also tried three temperature ranges: $25^\circ C$, $50^\circ - 60^\circ$, and $80^\circ - 85^\circ$. He professed not to recall which appeared to be the optimum range for the three mixtures.

9. In response to the question whether or not solubility curves were used to select the best working temperatures. Spangenberg said that the data were not used, but the temperatures for producing the best crystals were always determined experimentally. Solubility data (curves) existed, but he had no knowledge where they might be now.

10. On other types of crystals, Spangenberg had the following remarks to make:

a. One of three types of SiC crystals is piezoelectric, but it could not be grown separate from the other forms. It was impractical to have the masses of silicon carbide crystals selected by hand.

b. In regard to boracite, the tetragonal form is piezoelectric, but could not be made without twinning. The rhombic form is not piezoelectric. Spangenberg and Winchell's book for reference, and supported his contention from it. Mg would not be helpful; it occurs in boracite in nature, but complicates the crystal properties, and makes growth too difficult a problem. He believes Dr. Sawyer misunderstood him if he thought he said Mg would be helpful.

11. The program of mixed crystals was undertaken when the simple crystals proved to have had temperature coefficients. Since the curve point of $NH_4H_2PO_4$ is $-118^\circ C$, and the coefficient is very small near that

point, it was hoped that a mixed crystal with a higher inversion point could be found which would have a low temperature coefficient.

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C. INTERROGATION OF MAX HAASE - RESIDENCE

30 NOVEMBER 1945.

1. Haase's work was done at Zeiss, Jena, and he worked with Joos and Gerber on Na Br O_4 , phosphates, and arsenates. Work was begun intensively only in July 1944.

2. Considerable success was achieved with Na Br O_4 and $\text{NH}_4 \text{H}_2 \text{PO}_4$ and $\text{KH}_2 \text{PO}_4$. Haase displayed a beautifully clear crystal each, of the Bromate, 1'' square on the base extending to 2 1/2'' on the edge, $\text{NH}_4 \text{H}_2 \text{PO}_4$, 1 1/2'' square at prism base and 1 1/2'' high to the apex of the pyramid.

3. Seeds were drilled with 2 holes and wired on to the underside of a special steel plate (steel V2 A) which in turn was rotated in the vessel containing the solution. This vessel was mounted in a thermal bath of water with electric heating elements, thermometer with mercury column and contacts and stirrers. Temperature was controlled to $\pm 0.05^\circ \text{C}$, started at 35°C and lowered to 29°C in 8 to 10 days. Great stress was placed on keeping the upper surface warm. To achieve this the level of the thermal bath was kept higher than the solution in the inner vessel. Also a light bulb was sometimes kept just above the surface. The constant temperature bath had an inclosure over it (with doors to work through) in order to keep the temperature of the solution warm at the top. The need for such precautions is to prevent nuclei forming and depleting the solution. So concerned was Haase about the superfluous nuclei that he devised a funnel bottom with a stop-cock to drain off the bottom of the vessel; not used ordinarily.

4. Crystals were not grown to larger sizes because they were still being tested. It was anticipated that the oscillator plates would be small and that crystals giving 3/4'' cross-sections would be easy to handle and quickly grown.

5. Haase expressed almost disgust in answering emphatically "No" to the question whether or not anything was added to the solution to control the shape of the crystals. However, he did admit that in the case of Na Br O_4 there was an excess of HBrO_4 in the solution, and that for $\text{NH}_4 \text{H}_2 \text{PO}_4$, the solution should be slightly alkaline. No definite pH values could be recalled. in

reference to the addition of substances, I mentioned that Nacken was reported to use an oleate. He replied that that was "dirty", meaning not clean. I explained that other not-dirty (clean) substances could be used, but he would not admit using anything other than experimenting with the acidity and alkalinity of the solutions.

6. Specimens of Na Br O_4 were given to Gerber to test. Cut angles mattered little for temperature-coefficient, since the substance was isometric. The cut used was perpendicular to the base and the edge opposite. This gave triangular sections from which circular plates were ground.

7. Likewise specimens of the phosphates and arsenates were given to Gerber. He pronounced the ammonium phosphate the best of the group, including the Na Br O_4 . (See interview with Gerber). However, the temperature coefficients were so high as to require thermostating, and therefore it was agreed to try mixed crystals, (See Spangenberg interview) in the hope of improving the temperature coefficient.

8. Haase, like Spangenberg, did not use solubility covers to determine optimum temperatures for crystallization. He insisted such controls must be determined experimentally, since fast crystallization was not necessarily best.

9. Most crystals need to be "annealed" after removal from solution.

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D. INTERROGATION OF E. GERBER - REIDENHEIM,

30 NOVEMBER 1945.

1. Gerber was associated with Joos and Haase in the crystal work at Zeiss, Jena. His job was the technical physicist's function of determining properties, - piezoelectric and elastic moduli, etc., and to select angles for cutting and the like,

2. In general the discussion in which Günther and Haase participated, was limited to the most promising materials ($\text{NH}_4 \text{H}_2 \text{PO}_4$ and Na Br O_4) of those submitted to him, and their comparison to quartz. Gerber preferred the phosphate to the bromate because it was more stable mechanically, and was easier to handle. Because of this factor, ammonium dihydrogen phosphate is, in Gerber's opinion, capable of use for frequencies as high as 10 M/s, whereas the bromate can not be ground thin enough (mechanically weak) to go above 4 M/s.

3. Gerber gave the following figures with some degree of assurance: At 776 Kc the R of quartz = 300 ohms, R (Bromate) = 300 - 400, R ($\text{NH}_4 \text{H}_2 \text{PO}_4$) = 50. (Reference to equivalent circuit nomenclature). The Q (or Dämpfung), expressed by $\frac{R}{2\pi f L}$, for all three is of the order of 5 to 10.10-6. The limiting voltage which can be applied to the synthetic was determined as 1.7 volts/m of wave length. Applies up to 30 m, possibly 400 M/s.

4. In response to questions regarding the Zeiss technique of thin-quartz-plate grinding, Gerber stated that quite a large number of plates of 49° cut had been produced at 60 M/s by very careful handwork by very skillful workmen. The laboratory made a very few at 100 M/s, but the reported 200 M/s was projected research only.

5. Tourmaline crystals were made as high as 400 M/s by skillful handwork. These were 7 mu thick. No synthetic tourmaline was attempted.

6. The angles cut found to be best for both the phosphate and the bromate were at 45° to two axes.

7. Gerber tested the synthetic 52° plate of synthetic

quartz prepared by Nucken and confirmed that its properties were identical with natural quartz. He described the plate as 20 x 10 x 5 mm.

8. He indicated that the ceramic oscillators developed by Hescho were not as satisfactory as anticipated. They were too bulky and heavy for practical field use, and were not as stable as hoped.

9. According to Gerber most of the German crystals were used in parallel resonance with Pierce type circuits. Series resonance applications were not used, and there was only limited use of Miller circuits. (He was speaking here of oscillator units, not filters.)

10. For qualitative tests of piezoelectricity (which did not interest him particularly), he knew of nothing better than the one described by Schiebe in "Piezoelectricitat", and mentioned by Guntner. (See interview).

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E. INTERROGATION OF RICHARD NACKEN - SCHRAMBERG,

5 and 6 DECEMBER 1945.

1. As a professor at the University of Frankfurt am Main, and as director of the Mineralische and Petrographische Institut of the University, he had for many years carried on researches on rocks and minerals and their artificial production. He was supported in his research work by state funds. He planned to organize a Hydro-Thermal Institute for the study of mica, asbestos, quartz and other hydro-thermal minerals.

2. In 1936 he advised Dr. Lukop of Telefunken that quartz could be made artificially and suggested that the natural quartz supply would not meet large demands. After war began in 1939, he informed the government agents at Idar-Oberstein - the export-import center of gem materials including quartz - that the supply of natural quartz would not be sufficient. However no attention was paid to his suggestions.

3. At the end of 1943 and the beginning of 1944 the government became panicky and wanted him to produce quartz in quantity overnight. His laboratory was moved from Frankfurt am Main to Schramberg, and he was given ample space in the Nungers Watch Factory. By late 1944 he had established the conditions under which quartz would deposit rapidly yet clearly from solution on a seedplate of natural quartz. The method was reported to the government and that was the last he knew of the matter, except that Telefunken made patent applications on his method and ordered equipment, but never actually started manufacture. He denied all knowledge of the plant at Steinbach in Thuringia.

4. Nacken made it clear that he considered himself a research scientist and not an engineer. His method worked in the laboratory and it was the duty of others to convert the method to the techniques of production.

5. The method is based on the differences in solubility of crystalline quartz and vitreous silica. Vitreous silica is more soluble at all temperatures but at, and above 350°C the ratio is 10:1. Quantitatively Nacken cited 3 grams per kilogram of crystal to 30 grams per kilogram of vitreous. (These figures seem to me to be too large by perhaps a factor of 10, but can be checked. ACS.) The solubility curve of vitreous silica

is close to zero but rises very slowly; then as it approaches the critical temperature of water (375°C circa) rises very rapidly.

6. Above the critical point the solution is in the "fluid" state as opposed to "liquid" and "vapor". In this state its viscosity is very low; very slight temperature changes cause sufficient variations in specific gravity to promote rapid circulation. The solubility of SiO_2 is still the same as given in paragraph 5, since it is on a gram per kilogram basis.

7. Nacken has worked in the region of the critical temperature, both above and below it, and with steam phase alone and liquid phase alone, and made the following comments:

a. With steam alone trouble was encountered in the crystallization (devitrification) of the silica glass which was supposed to feed the solution. The formation of unwanted nuclei was also very common and sometimes tiny crystals coated the interior of the autoclave. Growth occurred on the seed-plate rapidly and often was not clear.

b. With water alone the crystallization is excellent but the transfer of material is too slow for practical use.

c. As a result he works above the critical point and uses an additional agent as an inhibitor of nuclei.

8. The method will be discussed under the following subjects: the autoclaves, the seed and its suspension, the solute, the nuclear inhibitors, and the furnace.

a. Several types of autoclave were used. The commonest and most successful type was a bomb composed of an outer jacket of two parts, an inner vessel and lining, and a two-part cover. The outer jacket was made of two cylindrical shells threaded so as to screw together over their entire length except for the top and base both of which were planed on their sides so that they would fit a vice and wrench. The center of both top and bottom had a small hole. The existence of the hole was not discovered until after the interrogation; hence its purpose was not learned. The inner vessel holding the solution is tapered slightly from top to bottom, has a slight rim

and fits snugly into the jacket. It has a bottom several times thicker than its walls. In preparation for use it is completely lined with silver foil and when placed in the jacket, a circular plate of silver foil is used to close the top. Above this are placed two iron plates with concave-convex contact surfaces. These surfaces, lubricated with graphite, transmit the closing pressure from the jacket as its two threaded parts are screwed together. Under the pressure and heat the silver foil top on the inner vessel makes a tight seal with the silver foil lining, so tight that it has to be cut open with a knife. Gold linings were tried, also a gold strip between the silver foil top and lining, but neither is necessary.

- (1) Autoclaves of the type described were used in two sizes: one approximately $2 \frac{3}{4}$ inches in outer diameter and 4 inches high, with a capacity of 25 to 30 cubic centimetres in the inner vessel. The larger unit was about $3 \frac{3}{4}$ inches in diameter and $5 \frac{1}{4}$ inches high with a capacity of approximately 75 cubic centimetres.
- (2) Another autoclave was examined, having a diameter similar to the smaller autoclave but a length of approximately 10 inches. The inner silvered vessel was perhaps 8 inches long. The outer jacket was composed of several threaded parts. The purpose of this long bomb was to provide a more pronounced temperature gradient. However it did not prove particularly successful.

b. Nacken was quite emphatic that any piece of crystalline quartz would serve as a seed. He pointed out that new growth followed the same orientation as the seed and, hence, if the seed were twinned the new quartz would be likewise twinned. He used natural crystals, spheres, and plates of various orientations. He indicated that his best results came from small rectangles saved from a slice cut parallel to a major rhomb face. No particular orientation in the face is required although he has usually kept one side parallel to the intersection of the rhomb with the prism. Nacken insisted that the plate having a natural face resulted in better ("smoother") growth than in the case of a plate in which all surfaces

had suffered disturbance by abrasion. He did not try etching. The seed plates appeared to be $1/16 \times 1/2 \times 5/8$ in the samples of growth examined. The seed is suspended in the autoclave by means of a fine silver wire. Gold and platinum were tried but not found to be superior. Usually the wire is merely wrapped around the plate and twisted tight. The method of supporting the wire within the autoclave was not discussed, however it is emphasized that in those experiments which utilised a steam phase or part steam and part liquid, the seed must be above the level of the liquid.

c. Granular, broken silica glass was the most satisfactory source of silica. For the solution no significance was attached to the amount, - enough to have an excess present. Tubes of SiO_2 (vitreous) were tried, solution of the tube occurred but not as rapidly as from the finely broken glass; frequently the tube devitrified.

d. In searching for a means of inhibiting the spontaneous development of small crystals from the solution Nacken thought of weak alkaline waters in natural ground water. Hence he just tried NaHCO_3 and had some success. Lithium and potassium carbonates were not good, but sodium oleate and sodium stearate were better than sodium bicarbonate. The oleate was his first choice, the stearate second, and NaHCO_3 third. The organic solutions were used at N/10 concentration or less, while with the carbonate N/1000 to N/100 was a satisfactory range. Strong solutions favored to rapid (and imperfect) growth on the seed; weaker concentrations did not inhibit much.

e. The furnace used was the ordinary type of electric muffle with firebrick lining. Its oven was approximately $9 \times 9 \times 12$. The temperature controls had been removed and a new set provided which maintained the pre-set temperature at plus-or-minus 1°C . No special provision was made for a temperature differential other than that accidentally occurring between the base of the autoclave which rested on the bottom of the oven and the top of the bomb. This fact emphasises the basic principle of the method, namely, the dependence on the difference in solubility of vitreous and crystalline silica.

9. An alternative method was tried unsuccessfully. Superheated steam, lead through a vitreous silica tube, impinged on a small quartz crystal. Some rough growth

occurred on the seed, but the main result was the devitrification of the tube.

10. Nacken's laboratory, located on the fifth floor of a back wing of the Nunglans Watch Company, consisted of at least six rooms and was well equipped as a mineralogical and petrographic laboratory. In addition to an office there was a machine shop, chemistry laboratory with furnace, cutting room with diamond saw and a multiple petrographic lap, a general "student" laboratory with two x-ray cameras and several petrographic microscopes, and a photographic room with darkroom.

11. Nacken is living at 8 Hausse Schilteck, c/o Moser, Schramberg, Baden. The house is located on the left of the road leading from Schramberg toward Freudenstadt, just beyond a furniture factory, also on the left. Across from both are railway yards and station.

12. Vital statistics: Professor Doctor Richard Nacken, born 4 May 1884, at Rheydt (between Aachen and Düsseldorf).

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F. INTERROGATION OF RUDOLF BECHMANN, BERLIN

9 DECEMBER 1945.

(Joint with Mr. J.L. CREIGHTON, G.P.O.)

1. Bechmann was in charge of development and production of quartz crystal units for Telefunken. In 1942 he was made Ringleiter für Quartz in the Speer Ministry and as such was responsible for the whole quartz industry.

2. No new firms were added during the war. Existing firms expanded under their own direction. Those in production were ten in number. Their December 1944 production and personnel were as follows:

<u>Firm</u>	<u>Production all types</u>	<u>Total personnel all all grades</u>
Telefunken	8600	141
Lorenz	1600	50
Siemens-Halske	250	13
Steeg und Reuter	5200	86
Zeiss	7200	49
Halle	700	7
Opta	2300	41
Quartz-Keramik	200	37
Ostmark	2100	119
Niendorf	1100 (not assembled)	7
Totals	<u>29250</u>	<u>550</u>

3. Before the war the annual production was of the order of 10,000. In 1942 it had reached 230,000; in 1943 350,000; and in 1944 approximately 400,000.

4. Production was estimated as falling into the following frequency divisions:

Over 10000 k/s	10%	Thickness sheet
5000 to 10000 k/s	5%	" "
1000 to 5000 k/s	15%	" "
500 to 1000 k/s	20%	" "
100 to 500 k/s	45%	Contour Mode
Less than 100 k/s	5%	" "

5. In general, methods of fabrication differed from those commonly used in the United States in the following respects:

a. Use of circular crystals involved the rounding operation between "dicing" and lapping.

b. Orientation by optical and mechanical means rather than by X-ray. (Only one plant used X-rays goniometers). Accuracy of z-axis orientation to better than plus-or-minus 6' was claimed for skillful use of conoscope. Mechanical measurement of angles in the case of faced quartz and pyroelectric patterns of red lead and sulphur powder in the case of unfaced quartz gave x- and y-axes. Extreme accuracy not highly important on x and y for circular crystals.

c. Etching was not used for final finishing. Crystals above 6 m/s were polished to transparency with rouge; under 6 m/s, the finish need not be a polish. It was claimed that no aging problems were encountered but it was admitted that the African campaign showed the need for hermetically sealed crystalholders. By the time such holders were provided the campaign was lost.

d. More extensive use of plating, sprayed and baked on with leads soldered to plating without reinforcing spot.

6 Major improvements during the war were said by Bechman to consist of:

a. Change in size of plates, consisting of a reduction in thickness shear plates for high frequencies and a change from AT to CT cuts resulting in eliminating the very large thick shear plates for the 200 k/s - 500 k/s range in favor of very small contour mode plates.

b. Introduction of the wide-spread use of silver plating for practically all crystals.

c. Standardization on four types of crystal holders. It is doubtful if this step was ever successfully put into operation for it did not include the hermetically sealed holders developed as a result of the African campaign, nor the tiny half-inch button type proposed as a late and extensive development. In any case, the specifications for the crystals themselves were drawn up for each type of equipment; a few spares were provided, but there was no attempt to attain interchangeability.

d. The development of very high frequency (60 m/s) crystals might well have been cited by Bechmann, but was treated separately. (See paragraph 8).

7. The organization and control of the industry was quite loose, particularly before 1943. No national stock-pile of raw-quartz was provided and each manufacturer bought individually. Telefunken maintained a buying agent in Brazil until at least 1941. Some quartz was brought in from the Ukraine, but Bechmann insisted that the quantity was very small and that "it would't work". No explanation of this cryptic statement seemed satisfactory. In 1942 Bechmann was made Ringleiter für Quarz and beginning then, he began to visit plants, attempted to bring about interplant cooperation (firms were still retaining trade secrets) and began to diversify manufacture within each plant to minimize effect of bombing. At this time he began to receive monthly and bi-monthly reports on stocks, orders and production and to compare efficiencies of the various firms.

8. One of the most successful developments of the crystal program was the method used at Zeiss for the production of 60 m/s crystals. Zeiss was the only place these were made, but between 10,000 and 15,000 were produced in 2 1/2 years. The special technique consists in ringing the blanks on to small (10 cm diameter) optical flats. Thirty or more 8-13 millimeter blanks were thus attached to the flats and hand-lapped with rouge with frequent micrometer measurements to assure parallelism of faces and eventually, interferometer measurements. These crystals were not used in communications. Bechmann did not know what they were used for unless it was V-2.

9. Communications seldom used crystals much in excess of 10 m/s. In response to the enquiry regarding the use of overtone frequencies, Bechmann said these frequencies were not used outside of the laboratories. In retrospect he does not understand why someone did not use crystals in that type of application.

10. Bechmann's knowledge of the ersatz program was apparently very deficient and disappointing. On the other hand he pointed out that Abraham Esau (earlier at Zeiss, later at P.T.R.) was in charge of that program. Dr. Kamm was in charge of the Leuchstoffe, G.m.b.H., quartz work. Neither of these men is currently available. Regarding the artificial quartz work, Bechmann stated, on second-hand information, that in four weeks a 1 millimetre thick, circular plate had grown to 100 millimetre length. He further claimed that the growth

occurs at right angles to the major seed-plate surfaces regardless of orientation. In other words an AT-seed-plate would produce a bar from which AT plates could be sliced. To the interrogator this appears to be either wishful thinking or misinformation.

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G. INTERROGATION AT MINERALOGISCHES UND PETROGRAPHISCHES
INSTITUT, UNIVERSITY OF GÖTTINGEN,
12 and 13 DECEMBER 1945.

1. Dr. Carl F. Correns worked on the problem of producing quartz crystals from a melt. In order to secure a temperature sufficiently below 575°C to avoid α -quartz, he selected a eutectic of KCl and LiCl in which to melt SiO_2 . Although the mixture has a low point of approximately 400°C he still could not avoid high quartz and hence got twinned crystals. He regarded the program as unsuccessful in practical terms.

2. Dr. Helmut G.F. Winkler was returned from the army at Corren's request to investigate the possibilities of producing nepheline crystals of sufficient size and clarity to be used for piezoelectric purposes. The method used was to melt the components of $\text{NaAlSi}_3\text{O}_8$ in the form of Na_2CO_3 , Al_2O_3 and SiO_2 in the proportions of 1:1:2. Mineralizers were added in the form of LiF and sodium silico-fluoride. The melting point was lowered considerably below 1248°C and moderately clear crystals in the form of hexagonal plates were formed approximately $1/4''$ by $1/16''$. These were sent to Rudolf Bechmann, Kingleiter für Quarz, in Berlin to be tested, but no report was received.

3. Dr. Walcher of the Physikalisches Institut was contacted to learn the location of Dr. Spitzer who, it was ascertained, is still at Kiel. Through Walcher one copy each of dissertations by Meyer, Gockel and Spitzer were obtained from the university library as follows:

- a. Manuscript "Zur Synthese des Nephelins" -
Dr. H.G.F. Winkler
- b. Dissertation "Die Dämpfung von Piezokristallen"
Gockel
- c. Dissertation "Messung der piezo-elektrischen
Moduln" - Meyer.
- d. Dissertation "Die Bestimmung der piezo-
elektrischen Moduln" - Spitzer.

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CONCLUSIONS

1. The quartz synthesis by Nacken appears to have considerable promise. The other scientists' attempts to grow quartz were not successful.

2. The growth of substances other than quartz progressed to a degree but could not be considered highly successful. The growth of $Mn_4H_2PO_4$, for example fell far short of the success obtained in the U.S. Of the substances not produced in U.S., sodium bromate, alone reached a point of trial application. Its temperature coefficient was not favorable and this fact spurred the investigations into other fields.

3. The German quartz industry during the war was not highly organized. The principal improvement, was the conservation of raw quartz by drastic reduction in the size of oscillator plates.