THE EFFECT OF IMPERFECTIONS ON THE USABILITY OF QUARTZ FOR OSCILLATOR-PLATES

JOSEPH S. LUKESH,
Long Branch Signal Laboratory, Signal Corps Ground Signal Agency, Bradley Beach, New Jersey.

ABSTRACT

Imperfect quartz used for the manufacture of communications crystals compared favorably with highest quality raw material in regard to yield of satisfactory oscillator-plates. Inclusions not visible except by their scattering effect on light do not prevent the use of quartz for crystals up to 8.5 megacycles. Inclusions visible to the unaided eye reduce ability of the quartz to oscillate. Some twinning may be tolerated in specialized locations.

INTRODUCTION

During the winter of 1942–1943, the United States was threatened with a serious shortage of imported quartz. Since domestic production was negligible, it was necessary for the Signal Corps to consider methods of expanding the usefulness of the existing stock-pile. One possibility lay in the use of raw material which had been classified as below grade and set aside. Some 500,000 pounds had been so classified, principally because of the presence of blue needles. Since no real evidence existed as to whether the presence of blue needles—or, indeed, any other of the recognized flaws—rendered the quartz unusable for oscillator-plates, an investigation was initiated to determine the usability of imperfect quartz for AT- and BT-cut plates of frequencies up to 8500 kc/sec. The study reported herein was the confirming evidence which brought about the revision of specifications and the release of the greater part of the so-called "below grade" quartz for use in the manufacture of quartz plates.

THE NATURE OF IMPERFECTIONS

In an accompanying paper, Gordon[1] has described the nature of the various imperfections found in quartz. They may be divided into two groups: inclusions and structural defects. Inclusions range in size from atomic impurities through needles visible under ordinary lighting. This category also includes bubbles, which may be considered to be negative inclusions. Very small inclusions are visible only through their scattering effect on an intense beam of light. The principal structural defect is twinning, although lineage structure is present.

The experimental work described in this report was concerned pri-

[1] Gordon, Samuel G.. The inspection and grading of quartz. *Am. Mineral.*, this issue.

marily with the inclusion imperfections. They were classified, not on the basis of their mineralogical character, but, rather, in the categories recognized by raw quartz inspectors. This resulted in duplication as, for instance, veils are merely microscopic bubbles localized in curved sheets. Phantoms are either color or bubbles, or combinations of both, parallel to natural crystal surfaces.

Inclusions

Selection of Specimens. The majority of the inclusions are difficult to locate in a finished oscillator-plate and, in order to be sure that the plates were representative, it was necessary to choose raw material with high concentrations of each imperfection. Since, as a rule, the imperfections are not uniformly distributed throughout a given piece of quartz, selected specimens were trimmed of all material not containing the imperfection being studied. Because of this no data can be given on yield per pound of raw material. Samples were selected which contained as high a concentration as could be found of the following imperfections: smokiness, blue needles, chuva, rutile needles, microscopic bubbles, veils and phantoms. Every effort was made to obtain material containing only the particular flaw being investigated.

Preparation of Oscillator-Plates. The specimens containing each imperfection were processed into oscillator-plates following the usual manufacturing techniques. That is, no attempt was made to make the plates to any predetermined dimensions. Each plate was hand lapped to final frequency and edge-ground to adequate activity. Frequencies ranged from 3500 kc/sec to 8500 kc/sec. The finished plates were then mounted in holders and tested for performance over a temperature range of −35°C to +55°C. Control crystals were also prepared from clear quartz of Grade A quality.

Performance tests consisted of measuring frequency and activity over the prescribed temperature range, using the standard tolerances applicable in certain Signal Corps radio sets. The allowable frequency drift was plus or minus two hundredths of a per cent. There were no failures because of excessive frequency drift, nor was there any evidence of influence of imperfections on the frequency characteristics, within limits of measurement.

In all cases, failure of a plate to meet specifications was due to low activity at some point in the temperature range. Such "activity dips" are common-place in plates made without regard to pre-determined lateral dimensions. The usual procedure is to disassemble the crystal unit and adjust the lateral dimensions by edge grinding until the "dip" has moved out of the specified temperature range. In this investigation such re-working of the plates was not carried out. Hence, failure of an oscillator-plate to meet activity requirements does not mean, necessarily, that it could not be made acceptable. The purpose of this study was to determine the comparative yields obtained from clear, Grade A quartz and from imperfect material. It was sufficient to compare only the initial yields.

Experimental Results. In Table 1 are listed the experimental results for oscillator-plates made from quartz containing the various inclusions. In addition to those listed in the table, a number of plates were made from smoky quartz of varying intensity of color. It was found to be no more difficult to process colored quartz than clear quartz except for optical orientation of very dark material. Finished plates exhibited the same physical properties—frequency-thickness constant (within limits of measurement), characteristic shape of frequency vs. temperature curve, activity dips, etc.—as clear quartz.

TABLE 1

Inclusion	Number of Plates Processed	Per Cent Meeting Specifications
Blue needles	149	72.5
Chuva	83	73.5
Visible rutile needles	52	0.0
Microscopic bubbles	143	66.5
Veils	104	64.5
Phantoms (color and bubbles)	83	83.0
Total (less visible rutile needles)	562	71.2
Control (Grade A quartz)	133	70.6

Discussion. The data listed in Table 1 indicate that those inclusions which are visible only by their scattering effect on a strong beam of light do not seriously affect the use of quartz for communications crystals. The same is true of color, which may be considered as being due to inclusions of atomic size. Rutile needles which are visible under ordinary lighting conditions prevent or decrease oscillation. It would appear from these results that size is the determining factor, rather than the nature of the inclusion. Blue needles, for instance, are generally supposed to consist of rutile needles of the proper size to scatter light with a Tyndall effect. Chuva is believed to be, in part, somewhat larger rutile needles. A thorough investigation, which was beyond the scope of this work, would probably reveal a relation between the fundamental frequency of the oscillator-plate and the permissible size of inclusions. Thus, in very high frequency plates, up to 25 megacycles per second, small inclusions seem to have a definite deleterious effect.[2] Similarly, low frequency crystals, particularly filter crystals, can tolerate substantial amounts of relatively large inclusions.

Structural Defects

Twinning. The commonest imperfection in quartz is twinning. Two twin laws predominate and these occur to such an extent that it is an extremely rare crystal that does not exhibit both. One of the types, electrical, has the effect of reversing the polarity of the two-fold axis, the handedness of the individuals remaining the same. The other, optical, is characterized by right- and left-handed individuals, as well as reversed polarity of the axis. Obviously, a satisfactory oscillator-plate could not be made if there were any great percentage of the quartz twinned as the

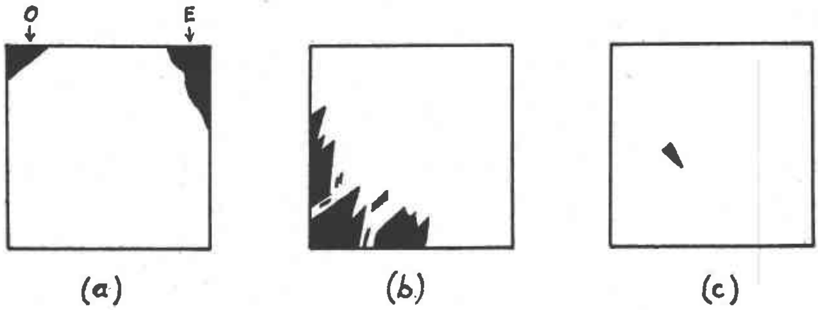

Fig. 1. Oscillator-plates with areas optically and electrically twinned.
1(a) Optical (O) and electrical (E) twinning.
1(b) and (c) Optical twinning.

individuals would have opposite electrical charges. Optically twinned quartz would be more unsatisfactory since the individuals of the twin would have different frequencies. However, it is not uncommon to find small areas of either electrical or optical twinning in oscillator-plates which have passed all performance tests. The areas must be small and should be confined to the corners and possibly the edges. In Fig. 1 are sketched three oscillator-plates which have adequate activity even though they contain twinning. Both optical (O) and electrical (E) twinning are present in (a) with only optical in (b) and (c). It is to be noted that the twinned areas can be quite large when they are located at the corners. However, that in the center (c), is only a small fraction of the area. Doubtless it would be possible to determine the amount and areal distribution permissible for each type of twinning. However, it would be impractical from a production point of view to produce plates in this

[2] Frondel, C., personal communication.

manner. The same should be true of rutile needles and large bubbles. These latter two are probably permissible in specialized locations.

Lineage Structure. The manufacture of oscillator-plates for communications purposes does not require extreme delicacy in physical measurements. For this reason, lineage structure has presented no problem. The effect of lineages—or discrete blocks, if such are present—would be to lower the Q of the plate. That is, there would be a damping effect due to the structural imperfection. The amount of damping could probably be measured under laboratory conditions, but its effect on the so-called "activity" of the oscillator-plate would not be noticeable in communications equipment. Reported occurrences of inactive or weakly active quartz may be the result of extreme lineage structure or of microscopic twinning.

Precision Crystals

The experimental results discussed above can be considered applicable only to plates produced by the usual technique whereby adequate activity over the temperature range is achieved by edge-grinding each oscillator-plate individually, so that no interfering modes of oscillation are coupled to the main mode throughout the applicable temperature range. Ideally, the proper dimensions should be determined for each frequency in advance and all oscillator-plates made to those dimensions. Although no thorough investigation was made of the possible effect of the various imperfections on the validity of pre-determined dimensions, encouraging indications that the dimensions will still be valid were obtained from studies of a precision crystal. Several oscillator-plates to be used in a 1000 kc/sec calibrating crystal unit having very close frequency drift tolerances were made from quartz containing blue needles. Dimensions which had been derived for clear, Grade A, quartz were used. All of the oscillator-plates met the specifications. Another indication that imperfections do not seriously affect the validity of pre-determined dimensions can be gathered from the fact that most dimensions being used at the present time are determined without regard to imperfection content. The usual yield of good plates is in the neighborhood of ninety-five or more per cent. Some of the failures may be attributable to imperfections, but the percentage is extremely small.

It is probable that any twinned areas in an oscillator-plate would have a noticeable effect on the validity of pre-determined dimensions. Such areas would effectively change the dimensions, so that the operating dimensions would not be the actual physical ones of the plate. In this connection, twinning on a microscopic or smaller scale would have the same effect and might account for some failures of otherwise correctly dimensioned plates.