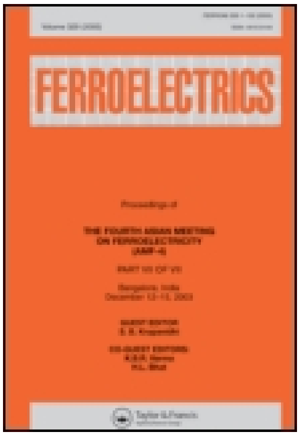


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# Advantages of obliquely cut TGS crystals in pyroelectric applications

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# ADVANTAGES OF OBLIQUELY CUT TGS CRYSTALS IN PYROELECTRIC APPLICATIONS

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Abstract-A considerable increase in the pyroelectric voltage responsivity of TGS can be obtained by slicing the crystal at an oblique angle to the pyroelectric axis. When approaching the transition temperature, both the maximum gain and the angle between the optimum orientation and the pyroelectric axis increase as the dielectric anisotropy increases. The maximum voltage responsivity attainable in oblique cuts is about twice that obtained in a regular cut lying perpendicular to the pyroelectric axis.



## INTRODUCTION

Pyroelectric crystals are generally studied along the pyroelectric axis since their characteristic properties are emphasized along this direction. Nevertheless, in practical applications properties along the pyroelectric axis are not always optimal.

The present study is concerned with the pyroelectric figure of merit given by the ratio, $p/\varepsilon$, of the pyroelectric coefficient, $p$, to the dielectric constant, $\varepsilon$.[1] This ratio determines the open circuit pyroelectric voltage response,[1] and influences the sensitivity of the pyroelectric vidicon in a certain mode of operation.[2,3] The optimum $p/\varepsilon$ ratio is not necessarily obtained along the pyroelectric axis since, in general, both $p$ and $\varepsilon$ are maximum along this direction. In fact we have shown[4] that in pyroelectric crystals with strong dielectric anisotropy, a significantly higher figure of merit can be obtained along specific directions which are not parallel to the pyroelectric axis. In this paper we survey the analysis for TGS crystals (point group 2) and present experimental data that show the possibility of obtaining an increase as great as a factor of 2 in the figure of merit of this material when optimum oblique cuts are used.

## ANALYSIS

We refer to an orthogonal system of coordinates x, y, z, where x and y lie along the crystallographic axes a and b respectively, and the z axis is at right angles to x and y (Fig. 1). The pyroelectric coefficient and dielectric permittivity along a general direction represented by an azimuth $\phi$ and a polar angle $\theta$ are:

$$p(\theta) = p\cos\theta \;,$$
$$\varepsilon(\theta,\phi) = (\varepsilon_{11}\cos^2\phi + \varepsilon_{33}\sin^2\phi + 2\varepsilon_{13}\sin\phi\cos\phi)\sin^2\theta + \varepsilon_{22}\cos^2\theta \;, \quad (1)$$

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where p is the magnitude of the pyroelectric coefficient vector and $\varepsilon_{ij}$ are the components of the dielectric permittivity tensor. The orientation that optimizes the ratio $p(\theta)/\varepsilon(\theta,\phi)$ is in the plane of the pyroelectric axis and the principal axis along which the smallest permittivity, $\varepsilon_m$, is obtained. This plane is defined by the azimuth:

$$\phi_o = 0.5\tan^{-1}[2\varepsilon_{13}/(\varepsilon_{11}-\varepsilon_{33})] \ . \quad (2)$$

If $\varepsilon_m$ is larger or equal to $\varepsilon_{22}/2$ than the figure of merit, $M = p/\varepsilon_{22}$, along the pyroelectric axis is optimum. However, if $\varepsilon_m$ is smaller than $\varepsilon_{22}/2$, higher figures of merit than M can be obtained along directions which are not parallel to the pyroelectric axis. In this case the maximum result is obtained along a direction $(\phi_o,\theta_o)$, where

$$\theta_o = \tan^{-1}[(\varepsilon_{22}/\varepsilon_m)-2]^{\frac{1}{2}} \ . \quad (3)$$

The figure of merit, $M_{opt}$, in a target cut perpendicular to the direction $(\phi_o,\theta_o)$ is given by:

$$M_{opt} = p/[4\varepsilon_m(\varepsilon_{22}-\varepsilon_m)]^{\frac{1}{2}} \ , \quad (4)$$

and the gain factor, $G = M_{opt}/M$ , is

$$G = \varepsilon_{22}/[4\varepsilon_m(\varepsilon_{22}-\varepsilon_m)]^{\frac{1}{2}} \ . \quad (5)$$

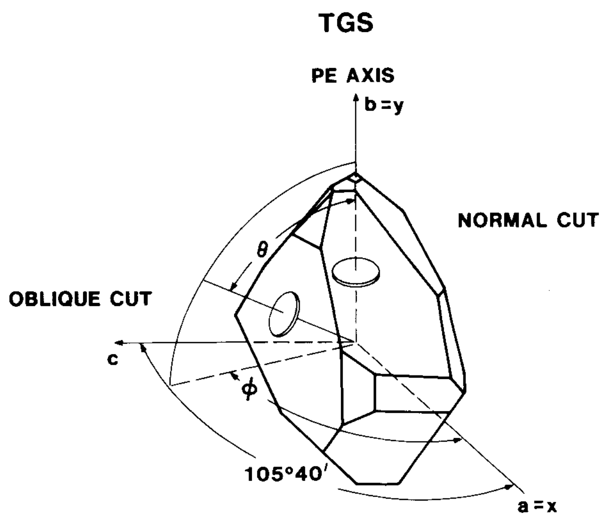


FIGURE 1 Choice of orthogonal axes for TGS. An obliquely cut target is specified by an azimuth $\phi$ and polar angle $\theta$ of the normal to its faces.

when $\varepsilon_{22}$ is much larger than $\varepsilon_m$, Eqs. (4) and (5) can be approximated by:

$$M_{opt} = 0.5p/(\varepsilon_m\varepsilon_{22})^{\frac{1}{2}} \quad (6)$$

and

$$G = 0.5(\varepsilon_{22}/\varepsilon_m)^{\frac{1}{2}} \ . \quad (7)$$

Eq. (6) indicates that in an optimum oblique cut the pertinent permittivity is the geometric average of the permittivity along the pyroelectric axis and the minimum permittivity in a direction perpendicular to this axis. This gives rise to a large gain when the anisotropy ratio $\varepsilon_{22}/\varepsilon_m$ is large.

## Experimental

In order to calculate the optimum performance of TGS targets, both the pyroelectric coefficient and the complete permittivity tensor were measured as a function of temperature. Measurements were performed on crystal plates (4x4x0.1 mm) coated with antimony electrodes. The components $\varepsilon_{11}$, $\varepsilon_{22}$ and $\varepsilon_{33}$ were determined from capacitance measurements on plates cut normal to the x, y, and z axes respectively. The component $\varepsilon_{13}$ was calculated from capacitance measurements on two plates cut parallel to the pyroelectric axis and normal to directions that formed angles of 45° and 135° with the positive direction of the x-axis. Capacitance and pyroelectric current were measured using a computer controlled system similar to that described in Ref. 5. Capacitance was measured with an HP 4274A LCR meter in a field of 8 V/cm at 10 kHz. Pyroelectric currents were measured with an HP 4140-PA meter while the sample was heated at 2°C/min. A programmable switch (HP 4083, 19657A) was incorporated to permit simultaneous measurement of capacitance and pyroelectric current for accurate determination of the figure of merit.

Figure 2 shows the temperature dependence of the components of the permittivity tensor measured in TGS. From these data the optimum angles $\phi_o, \theta_o$ and the gain G were calculated (Fig. 3) using Eqs. (2), (3) and (5). The principal axis along which the permittivity is minimum is close to the z axis and to a good approximation $\varepsilon_m$ is equal to $\varepsilon_{33}$. When the transition temperature is approached, the anisotropy ratio $\varepsilon_{22}/\varepsilon_m$ increases rapidly giving rise to a rapid increase of the gain. Fig. 4 shows the figure of merit $M = p/\varepsilon_{22}$ measured in a normal cut and the optimum figure of merit $M_{opt}$ obtained by multiplying M by the gain factor G. When the transition temperature is approached, the figure of merit in the normal cut decreases, however, increasing figures of merit can be obtained in optimum oblique cuts. The maximum figure of merit in oblique cuts is about twice that obtained in the normal cut.

## CONCLUSIONS

When the dielectric anisotropy is large, an appropriate deviation from the pyroelectric axis reduces the permittivity, ε, more than the pyroelectric coefficient, p, thus yielding an increase in the figure of merit p/ε.

The figure of merit of TGS targets can be doubled by slicing the crystal at optimum angles oblique to the pyroelectric axis. A comparison between TGS and DTGFB[4] shows that TGS in an optimum oblique cut can perform better than DTGFB in a normal cut. However, much better results can be obtained with obliquely cut DTGFB targets.

Large permittivity along the pyroelectric axis limits the performance of many other crystals in a normal cut. These crystals should be re-examined to evaluate their performance in optimum oblique cuts.

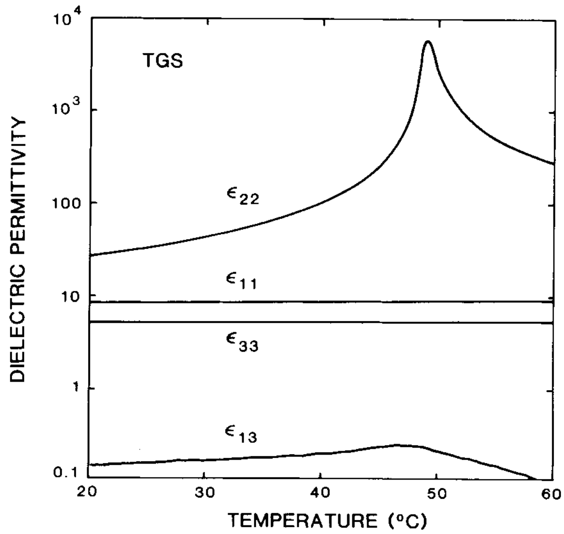


FIGURE 2 Temperature dependence of the components of the permittivity tensor in TGS.

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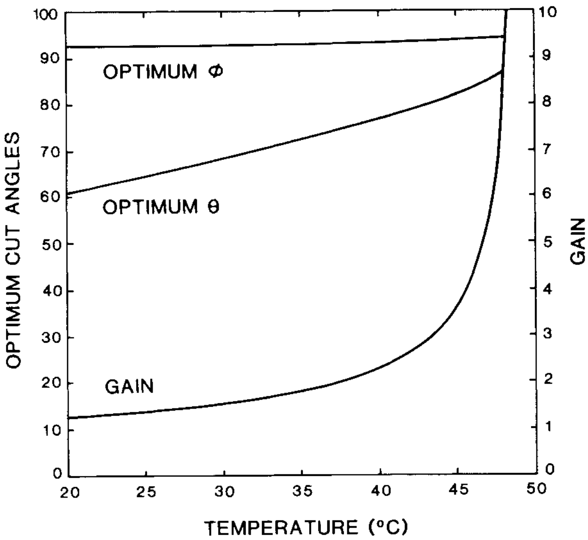


FIGURE 3 Calculated optimum angles and gain for TGS.

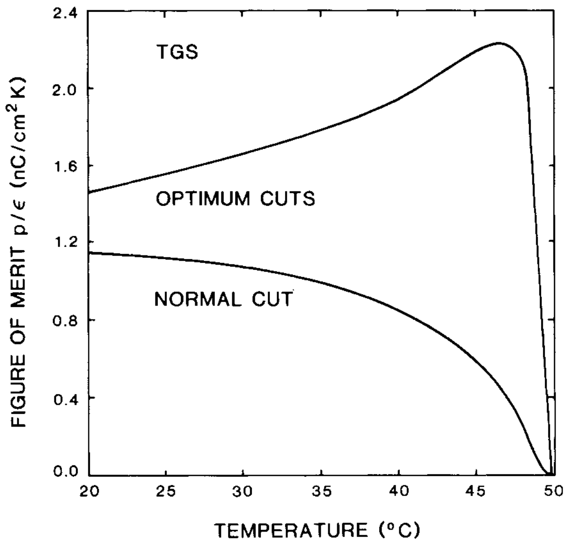


FIGURE 4 Temperature dependence of the figure of merit in TGS at a normal cut (measured) and in optimum oblique cuts (calculated).

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