1. Introduction

Lattice imperfections together with composition, purity and idealized structure control properties of single crystals. Changes in defect structure are produced by a variety of treatments involving thermal, pressure and chemical variations and their combinations. A variety of single crystal materials are used in electronic, optoelectronic and other solid state devices. Processing steps used for fabrication of devices such as ion implantation also produce strong changes in the real structure of crystals. Many of the devices have to perform under electric fields. The continuous decrease of size of devices is leading to devices functioning under higher electric fields. An understanding of the real structure of crystals subject to electric fields is, therefore, of considerable topical interest [1]. There are additional considerations which make the study of electric field induced defect structure in crystals an interesting problem. The electric current in semiconductors and dielectric loss factor in insulators is not stable with time when high electric fields are applied. These show instabilities which are typical for the magnitude of the applied electric load [2]-[6]. Further, inside the solid under load, the current is not expected to be uniformly distributed. Small channels or filaments are supposed to carry larger current as compared to the remaining bulk. The filaments had been postulated to be linked with material inhomogeneities [3], [7].

In view of the considerations mentioned above a detailed experimental study of the changes induced by electric fields in the real structure of semiconducting and insulating crystals was undertaken. High resolution X-ray diffractometric and topographic methods were employed for direct observation of the defect structure. Multicrystal X-ray diffractometers have been used. Electric fields of varying frequencies starting with DC fields and going up to microwave region [8] have been applied. Several interesting results have been obtained. The main results of these experiments are briefly reviewed in this paper.
2. Experimental Details

2.1 The Quadruple X-ray Diffractometer

A general purpose quadruple crystal X-ray diffractometer has been developed and used for these experiments [1], [5], [9]. Fig. 1 shows a schematic line diagram of this system. It can be used in three as well as four crystal configurations. X-ray beam from a fine focus X-ray source is collimated with the help of a 400 mm long lead clad aluminium tube having a fine vertical slit at one end. The source is generally a Philips 2 KW tube mounted horizontally to give a foreshortened focal spot of 0.4 x 0.4 mm². The beam emerging from the collimator slit has a divergence of a few minutes of arc in the horizontal plane, which is chosen to be the plane of diffraction. Two crystals of Bonse-Hart type were used as the monochromators [10]. Both of these are silicon single crystals, with diffracting surfaces along {111} planes. On orientation for diffraction, this combination can resolve the $K\alpha_1$ component of the $K\alpha$ doublet from the $K\alpha_2$ component, the accompanying BremsStrahlung waveband and the residual direct beam. This beam is isolated with the help of a vertical slit and used as the exploring beam. This arrangement is similar to that developed earlier in our laboratory [11], [12], [13]. The results reported here were obtained with Mo$K\alpha$ radiation. This beam has very narrow spectral width and its angular spread is limited to a few seconds of arc.

The specimen crystal is the third crystal of the diffractometer. It can be provided with rotations around a vertical and a horizontal axes. In addition, a traversing mechanism is incorporated for translating the specimen across the exploring X-ray beam in a smooth and uniform manner. Both the rotations cover the entire circle. The smallest angular motion around the vertical axis is of 0.4 arc seconds whereas that around the horizontal axis is of 10 arc seconds. The minimum linear motion that can be imparted is 0.01 mm. The specimen can be aligned for diffraction from any desired set of lattice planes by combining the two rotations. By using the traversing mechanism, diffraction from any region of the specimen crystal can be studied. Traverse topographs can be recorded by moving the specimen crystal across the exploring beam and coupling the photographic film rigidly to it. Since, the exploring beam is highly collimated and monochromated the resolution attained with this technique is much higher than that can be attained with the standard Lang topography method. The specimen can be oriented in the Bragg (reflection) as well as Laue (transmission) geometries. The setting of the diffractometer can be dispersive: (+, -, -) or non dispersive: (+, -, +). Most of the results reported here were obtained with the nondispersive setting.

The beam diffracted from the third crystal falls on the fourth crystal which is used as an analyzer. The mechanical devices used to impart rotational and linear movement to this crystal are similar to those used at the third crystal stage. In these experiments the analyzer was used in the Bragg setting.

The diffractometer was aligned in the nondispersive setting (+, -, +, -) in all the experiments. When the specimen was oriented in Laue setting, (220)
diffracting planes were used. For Bragg geometry, its
diffracting planes were either of the following planes:
(111), (333) and (555). These planes are parallel to the
surfaces of the specimen.

The high resolution techniques are very sensitive
to the quality of the surface of the specimen and the
method of their mounting on the diffractometer. We
have found the following technique to be satisfactory
for fixing the specimen. The specimen is placed on a
seat machined in a teflon holder. Its inner opening has
a diameter of about 20mm. A teflon annular ring of the
same inner and outer diameters is placed on top of the
crystal and screwed to the holder sandwiching the
specimen in between. The ring is screwed to the hol-
der. Screws are tightened to the extent that the crystal
is just held there without appreciable mechanical
strain. The shape of the diffraction curves and the
radius of curvature act as good monitors. Diffraction
curves and traverse topographs are recorded before,
during and after the application of the electric field.
Also, curvature measurements are made under all the
three conditions. For this purpose, the orientation of
the diffraction vector is plotted as a function of the
linear position of the specimen across the X-ray beam.
The slope of this curve gives the radius of curvature.
The analyzer crystal is particularly effective in
measuring changes in interplanar spacing from one
region to other or those induced by the electric field.

2.2 Specimen Crystals

Silicon: Disc shaped dislocation free silicon single
crystals were used as specimen. These were n-type
with different resistivities: 50 $\Omega$cm and $10^4$ $\Omega$cm.
Their surfaces were along (111) planes and thickness
varied from 0.2 to 1 mm. All of these were products of
M/s Wacker GmbH, München, F.R. Germany. Speci-
men surfaces were prepared carefully to ensure that
these were free of any surface damage resulting from
grinding and lapping operations. Circular aluminium
electrodes were vacuum evaporated on to the two flat
surfaces of the specimen. These were 5 mm in diame-
ter and their thickness varied from 80nm to 2 $\mu$m
for DC field experiments. For microwave field experi-
ments one side of the 25 mm diameter silicon disc was
covered with 2 $\mu$m thick layer of aluminium. The
other side was covered with a 1.8 $mm$ wide strip-line
of the same thickness [8]. The length of the strip was
aligned along $<112>$ or $<110>$ directions. The struc-
ture is similar to a microwave integrated circuit [14].

LiF: These were 0.5 mm thick discs with larger
surfaces along (001). The surface damage was
removed by etching the specimen after the lapping.
Aluminium electrodes (80nm thick; 5mm diameter)
were vacuum evaporated on to the two surfaces.

For DC field experiments, two metal wires with
diameter of about 0.1 mm were joined to the alumi-
nium electrodes with a small amount of conducting
paint. After it dried up, a droplet of an epoxy resin was
applied above the paint to give mechanical strength to
the joints. Fig. 2(a) shows a line diagram of the
electrodes deposited on a specimen crystal. For re-
cording traverse topographs the specimen is moved
across the X-ray beam and the volume explored lies
under a rectangular area shown (chain-dotted) in the
figure. For microwave field applications a thin copper
strip of matching width was joined to the aluminium
strip line on one end and to a coaxial connector on the
other. The electrode geometry in this case is shown in
Fig. 2 (b).

2.3 Power Sources

Well regulated sources of DC field were em-
ployed. The current and the potential difference

Fig. 2(a) A ketch showing the electrode geometry on the
specimen for DC field experiments. The rectangle (in
chained line) defines the region of the specimen from
which high resolution traverse topographs were recorded.
LiF crystals were rectangular in shape but the electrodes
were circular as on silicon.

Fig. 2(b) A sketch showing electrodes on a silicon
single crystal disc in the form of a microwave strip line.
across the specimen were continuously monitored. For microwave field, a microwave generator with magnetron as a source operating at 2.45 GHz was used. The output of the generator is connected to a directional coupler which feeds power to the specimen. A Hewlett Packard power meter is also connected to the directional coupler which measures the input power, the reflected power and the transmitted power.

3. Results and Discussion

All the specimen crystals were thoroughly characterized on the diffractometer before subjecting them to electric field. Diffraction curves and high resolution traverse topographs were recorded and curvature measurements were made. These experiments were also performed during the application of the field to the specimen as well as after the field was removed. The value of the electric field was gradually increased, starting with zero value. The electric load on the specimen is defined in terms of the power lost in it in a unit volume or in short, power density. It is denoted by P. We shall separately describe results obtained with DC and low frequency fields and fields at microwave frequencies. Most of the results are those obtained with silicon crystals, but some results obtained with LiF crystals will be described separately.

3.1 Results of Experiments Performed on Silicon Single Crystals Subject to DC Fields

Fig. 3 shows a typical diffraction curve of a dislocation free silicon single crystal before any field has been applied. MoK$_\alpha$$_1$ exploring beam was used. Specimen was about 1 mm thick with resistivity of about 50 $\Omega$ m (n type).
been applied to it. This curve has been recorded with (220) diffracting planes in symmetrical Laue (trans-
mission) geometry and the (+, -, +, -) setting of the
diffractionometer. As mentioned above, the specimen 
was at the third crystal position. This curve is very
sharp with a half width of only 3 arc seconds [1]. This 
shows that the resolution of the diffractionometer is high
and the crystal is nearly perfect. Fig. 4 shows a curva-
ture plot of the specimen of Fig. 3. Here, orientation of
the normal to the diffracting planes (diffraction vec-
tor) is plotted as a function of the linear position of the 
irradiated area across the X-ray beam. The slope of 
this curve gives the radius of curvature of the speci-
men. In this particular case the radius of curvature is 
240 m. All crystals are slightly curved. The curvature 
is a very good indication of the degree of stress in the 
wafer. Therefore, it is linked with the perfection of 
crystals. In some cases, we have observed a radius of 
curvature of about 900m. Crystals with usual degree
of perfection show a radius of curvature of only 10-
20m.

Fig. 5 shows a high resolution traverse topograph
of the same specimen whose diffraction curve and 
curvature plot are shown above. It may be stressed 
that this topograph was recorded while maintaining 
the specimen at the diffraction maximum of Fig. 3. 
The half width of this curve is about twenty times 
smaller than that obtained with the Lang method [15]. 
This special feature is the strong point of this unique 
new technique. An examination of Fig. 5 shows that 
no line defect is present in the volume explored during
traverse. The intensity is fairly uniformly distributed 
showing the high quality of the specimen crystal. 
Some images are seen just outside the electrode 
region near the electrical wire contact on the left hand
side. As mentioned above, the connecting wires make 
epoxy resin. A few small droplets of this 
resin have spread out on the crystal surface
outside the electrode region. Strain around these images is 
photographed.

The contours of the electrodes are clearly imaged
in Fig. 5. This is due to the strain produced by the thin 
electrode film. In fact the contours of the electrodes 
on the two surfaces appear to be displaced with re-
spect to each other. This is partly because the X-ray 
beam getting recorded on the topograph makes an an-
gle of 90°-2θb=69.4° to the surface of the specimen 
and not 90° as would have been ideal.

A weak fringe-like pattern is also observed in Fig.
5. The fringes are perpendicular to the diffraction
vector. There appears to be a small distortion of the 
fringe like pattern in the electrode region. These frin-
ges suggest that an interference effect is taking place. 
Pendellosung fringes are observed in traverse topo-
graphs of nearly perfect crystals with slowly varying 
thickness [16], [17]. The present specimen was of 
nearly uniform thickness. The exact origin of these 
fringes is not yet clear.

On application of low electric fields no signifi-
cant change is observed in the topographs. Only a
small shift in the diffraction peak position is observed 
[5]. On reaching a power density value of 0.01
Wmm⁻³, however, remarkable changes are observed 
in the topographs. Fig. 6 shows a high resolution topo-
graph of the crystal of Fig. 5 recorded during the 
application of a field of about 1400 V/cm which 
corresponds to a P-value of 0.01 Wmm⁻³. A large 
number of dot-like images are observed in the area 
under electrodes [1]. A strong black and white dy-
namical contrast is observed in each image. Each dot

Fig. 5 A high resolution traverse topograph of the speci-
men of Figs. 3 and 4 recorded before any application of 
electric field. (220) diffracting planes and MoKα₁ exploring 
beam were used.
is divided into a black and a white part. The black half in each case is on the tail side of the diffraction vector. The head of this vector points towards the white half. An application of the known contrast criterion shows that the region under the dots is pushing out the surrounding volume [15], [18]. If the electric current is not homogeneously distributed at microscopic scale, such a strain pattern is possible due to the accompanying temperature variation. The images seen here are most likely to be those of the filaments or channels which carry more electric current than the bulk of the crystal.

We have determined the size of the images of the filaments observed in Fig. 6. These were in the range 100-160 µm. However, it is to be kept in view that the high resolution traverse topographs are very sensitive to strain in the specimen. Therefore, the core of the filaments is expected to be much smaller than the observed dimensions.

The background fringe pattern observed in Fig. 5 has considerably weakened in Fig. 6. This shows that this is affected by the field, perhaps due to a slight decrease in the degree of perfection of the specimen. However, no measurable change in the shape of diffraction curves was observed on the application of electric field.

The images of the filaments have been observed in a number of crystals prepared from different boules [15], [4], [5]. Even those crystals which were prepared from the same boule showed somewhat different structure. Detailed investigations on crystals of widely different resistivities are being pursued now.

We shall describe a few results obtained on specimens prepared from the same boule from which the specimen of Figs. 3-6 was prepared. Fig. 7 shows a typical high resolution traverse topograph of a silicon single crystal recorded with electric power density above the threshold value of power density. Dot like images are clearly seen in the electrode region. However, these are not as uniformly distributed as in Fig. 6. Before the application of electric field no such images were observed in the topograph.

Fig. 8 shows a high resolution traverse topograph of another silicon single crystal recorded while the
crystal were subject to an electric load above the threshold of the P-value. In this case also the electric field induced images are seen clearly under the electrode region. The shapes of these images are different from those observed in Figs. 6 and 7 [19]. Line like images have also been observed in some crystals [1], [19].

A comparison of the defect structure observed in Figs. 6-8 strengthens the view that electric field induced images are those of filaments or channels. Small microscopic inhomogeneities in the specimen, for example, due to point defect aggregates in even dislocation free crystals can lead to non-homogeneous current flow during electrical conduction. This might be responsible for the observed structure. As we shall see later even microwave fields produce similar defect structure.

It may be stressed here that no major change is observed in the shapes of the diffraction curves when the P-value is close to the threshold value for appearance of the filaments. Changes observed at higher P-values will be discussed later.

The value of the lattice parameter of the specimen crystal was very carefully monitored as the field strength was gradually brought to the threshold value. This was done by recording the angular position of the analyzer crystal for diffraction maximum. No measurable change in the d-value could be detected, showing that it was below $\Delta d/d \sim 10^{-5}$.

We had considered the possibility of the field induced images being associated with the dipolar dislocation loops of vacancy type [1]. The loops are expected to lie very close to the surface of the specimen. As a check, traverse topographs were recorded in the Bragg geometry with (111), (333) and (555) diffracting planes [1]. Both surfaces of the specimen were examined. In these topographs the dot like images were not observed. Therefore, there is no significant strain in planes which are parallel to the specimen surface. This result shows that it is unlikely that the observed defect structure is due to dipolar dislocation loops lying near the surface.

A remarkable feature observed in Fig. 6 is the general increase in blackening in the area under electrodes and also close to these. This shows an enhancement in the intensity of diffraction. The enhancement considerably increases at higher values of the power density [20]. Enhancement is particularly high when microwave field is applied to the crystals as we shall see later.

3.2 Study of Fade-out Characteristics of the Electric Field Induced Defects in Silicon Single Crystals

The images observed in high resolution traverse topographs on application of high electric field to the crystal did not disappear just after switching off the field. These were also not permanent. Their fading out characteristics have been studied by X-ray diffraction topographic evaluation at different time intervals after the field was switched off [1]. We shall describe results obtained with the specimen of Figs. 3-6. Typical time intervals used for evaluations were: few hours; 1 day; 4 days; 5 days; 7 days; 11 days; 38 days; 40 days and 57 days. Most of the images are observed to persist even after one day of the application of the field. Fig. 9 shows a topograph recorded one day after switching off the field during which Fig. 6 was recorded. Except for the decrease in the general blackening, the defect structure is similar to that observed in Fig. 6. The enhanced blackening disappears on
switching off the field. An appreciable decrease is observed in the number of images after 4 days. This process of fading out continues as the time passes. At the end of 57 days, all the images of the filaments faded out completely. Fig. 10 shows a topograph recorded 57 days after switching off the electric field. No dot-like image is observed in this topograph.

The specimen crystal was again subjected to a high electric field after the complete fading out of images produced by the first application of the electric field (Fig. 6). Fig. 11 shows a traverse topograph of this crystal recorded when it was subjected to an electric field corresponding to a P-value of about 0.01 Wmm$^{-3}$. Images of filaments are again observed in this topograph. Their shapes and locations are the same as observed on the first application of the electric field. Small differences in their sizes are, however, observed. This result confirms that the images observed on application of the field are linked with materials inhomogeneities in the material.

3.3 Study of Effect of Electric Field of Microwave Frequencies on Silicon Single Crystals

For experiments at microwave frequencies, the specimen was prepared as a microwave integrated circuit as shown in Fig. 2(b). The diffractometer was used without the analyzer in the three crystal mode: (+, −, +). The diffraction curves were, therefore, somewhat broader. In this case also diffraction curves, traverse topographs and curvature measurements were made before, during and after the field was switched off. Remarkably strong changes in the intensity of diffracted X-ray beam were observed. Fig. 12 shows a plot similar to the curvature plot shown in Fig. 4. However, in this case the intensity at the diffraction maximum is plotted as a function of the linear position of the specimen across the X-ray beam. Three plots are seen which correspond to before field, during field and after field situations. In this experiment the diffracting planes are parallel to the strip line, i.e. the diffraction vector is perpendicular to the strip line. It is observed that before the field is applied, the intensity of diffraction is nearly the same from all regions of the specimen, as it should be for a good quality crystal. Only in the middle region there is a small dip. This is the region of the strip line and this decrease is due to the strain in the crystal produced by the deposition of the strip line. The application of the field drastically changes the intensity distribution [8]. On the right hand side of the strip line (linear positions 12 mm), there is a large increase in the intensity of diffraction. The maximum enhancement is at linear position of 13 mm. It is by a
factor of about 2.7. The magnitude of increase in intensity is observed to diminish with the distance from the strip line. However, even in regions very far away from the strip line (~6 mm), it is quite significant. On the left hand side of the strip line the intensity of diffraction shows a significant reduction. The maximum decrease is by a factor of about 1.7. The reduction in intensity is also not limited to regions close to the strip line, as seen in Fig. 12.

On switching off the microwave field, the changes in diffracted X-ray intensity disappear instantaneously. The plot is very nearly the same as that observed before the application of the field (Fig. 12). A small irreversible change in the intensity distribution is observed. This is showed by the shaded region.

The diffraction curves of these specimen were quite sharp with a half width of about 6-7 arc seconds for 220 reflection F8]. Fig. 13 shows a set of two diffraction curves of the specimen of Fig. 12. The full line curve had been recorded during the application of the microwave field (power ~ 9W). The broken line curve was recorded just after switching off the field. The curve recorded before the application of the field is very nearly identical to the dotted line curve shown here [8]. It has not been shown in this figure for the sake of clarity. The shapes of both the curves of Fig. 13 are very nearly the same. This is very anomalous. The peak intensity shows an enhancement of almost 2.5 times and the shape is nearly the same. The integrated intensity showed an increase of ~2.8 times. An increase in integrated intensity signifies a decrease in the degree of perfection of the crystal, or an increase in 'mosaicity' [21]. However, this should be accompanied by a broadening of the diffraction curves [21]. Even larger changes, of more than a factor of ten, have been observed from some parts of the specimen when (TT3) diffracting planes were selected for experiments at somewhat higher microwave powers.

The changes in the diffracted intensity are anisotropically distributed. These are dependent upon the relative directions of the strip line and the diffraction vector. For example, when (TT3) diffracting planes were selected for experiments, the increase in diffracted intensity was observed from all the explored volume of the specimen. Decrease in intensity was not observed from any region of the specimen.

All the changes in diffracted X-ray intensity discussed above are also observed in high resolution traverse topographs in a pictorial manner. In addition, the dot-like structure which appeared on application of DC electric fields (Fig. 6), is also observed. Fig. 14 shows a high resolution traverse topograph of the specimen of Figs. 12 and 13. It was recorded just after the field was switched off. The dot-like structure is clearly visible. Contrast around the strip line position is also seen in this photograph. The dots are not
confined to the region under the stripline. These are observed all over the specimen. Their sizes are approximately the same as observed in Fig. 6. The black and white contrast is also quite similar.

An increase in the diffracted X-ray intensity can be understood by assuming the lattice planes to be slightly curved [18], [22]. If the radius of curvature of planes and the diffraction vector point in the same direction, an increase in intensity is expected. A decrease will be observed if the two vectors point towards opposite directions. Such a curvature is also observed around dislocation loops [23] and at the boundary of epitaxially grown films on single crystals [18]. This type of situation does not exist in the present case. Experiments performed with (113) and (113) diffracting planes showed an increase in diffracted intensity from the entire volume when a microwave field is applied. These observations suggest that the microwave field has a strong interaction with the electromagnetic wave field of the X-rays inside the crystals.

3.4 Study of Effect of Very High DC Electric Field on the Real Structure of Silicon Single Crystals

So far we have discussed results obtained with electric fields of, moderate values. The P-values were a few times $10^{-2}$ W mm$^{-3}$. In a few cases the electric field strength was increased gradually until the specimen ceased to be a single crystal [5], [6]. It had been observed that when the electric field strength is increased a shift in the peak position is observed [4]. This can be due to a change in the lattice parameter of the specimen or due to a change in the orientation of the specimen or due to both. In this series of experiments an attempt was made to isolate the two by using an analyzer crystal after the specimen. Fig. 15 shows a set of diffraction curves of a silicon crystal recorded at different P-values. Curve DC-2 is the zero field curve recorded in the three crystal configuration of the diffractometer. In all the other curves, the diffractometer had the analyzer and was set in the (+,-,+,-) configuration. As the P-value increases, the angular position of the diffraction peak changes and its shape also starts showing changes. Also, the peak executes slow oscillations around the shifted position. At P=0.015 W mm$^{-3}$, the shift in peak position $\Delta \theta$ is 32 arc seconds. This is the rotation necessary to be given to the specimen to bring it back at the diffraction maximum. The analyzer crystal orientation needs to be readjusted if the d-value also changes. At P=0.175 W mm$^{-3}$, $\Delta \theta$ was about 200 arc seconds. The height of the peak decreases and the half width increases

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**Fig. 13** A set of two diffraction curves of the specimen of Fig. 12. The full line curve was recorded during the application of a microwave field (2.45 Ghz; 9W). The dotted line curve was recorded after removal of the field.

**Fig. 14** A high resolution traverse topograph of a silicon single crystal. It was recorded after switching off the microwave field that was applied to the specimen for some time.
significantly. The fluctuations in the peak position become rather fast.

At a P-value of 0.6 Wmm\(^{-3}\), a drastic change in the shape of the diffraction curve is observed. This curve loses its sharpness and its peak intensity becomes very small (DC-5). The shape of the curve is such that it can no longer be considered as a single crystal. This change is irreversible. Even the region surrounding the electrodes gives similar diffraction curves. The peak position shift is very large but the fluctuation of peak position cease to exist. In fact, it was observed that the fluctuations disappear at P \approx 0.4 \text{ Wmm}^{-3}. Curve DC-6 was recorded one hour after the field was switched off. Its shape is similar to that of DC-5.

We have calculated the rise in the temperature of the specimen at different values of P. The observed shift in the orientation of the analyzer crystal at different levels of power density has been used for this purpose. Table 1 lists the values of \(\Delta \theta_B\), \(\Delta d/d\) and \(\Delta T\) at different P-values. For calculating JT, the value of thermal expansion for silicon has been taken as \(4 \times 10^6 \text{ K}^{-1}\).

The rise of temperature listed in this Table is only an average value. The topographic examination suggests that the temperature is not uniformly distributed. However, it is noteworthy that there is no significant rise in the temperature of the specimen close to the threshold value of P for appearance of images of filaments.

When the electrical current in the specimen reaches a value of about 10 mA or so, instabilities are observed. It rises by a few mAs for a few minutes and then regains its original value. Such instabilities indicate metastable equilibrium between the power supplied to the specimen and that dissipated by it [5]. We have monitored the diffracted X-ray intensity during such fluctuations. Fig. 16 shows simultaneous records of the electric current and diffracted beam intensity during a current instability. An exact correlation had been observed between the two.

3.5 A Study of Effect of High Electric Field on the Real Structure of Lithium Fluoride Single Crystals

Fig. 17 shows four diffraction curves of a LiF single crystal [4]. The curve recorded before the application of electric field (curve 1) is considerably
broader than the curves observed with Si single crystals. Its half width is about 100 arc seconds. Also, it has a small shoulder. This shows that the degree of perfection of these crystals is considerably lower than that of silicon single crystals, which is understandable.

On application of electric field a shift in the peak position is observed as in the case of silicon crystals. At P-value of 2 x 10^{-7} Wmm^{-3} (E=3 kVmm^{-1}; /=7 x 10^{-11} A), there is a remarkable change in the shape of the curve. A new peak is observed on the right hand side of the main peak (curve 2). In Fig. 17, the curves have been drawn in two ways. In the main plot, the position of the main peak of all the curves has been made to coincide. In the inset, the curves are shown displaced with respect to each other. The angular separation is as observed in the experiment. It appears that the field produces a low angle boundary which manifests itself in the form of the new peak. This new peak disappears as soon as the field is switched off.

On switching off the field, the diffraction curve changes back to its pre-field shape (curve 3, Fig. 17).

However, its angular position is not identical to that observed before the field was applied. If the crystal is left for some time, it tends to regain its pre-field angular position. For example, the fourth curve in Fig. 17 was recorded 12 hours after the field was switched off.

4. Conclusions

(i) Images of filaments are directly observed in high resolution traverse topographs of silicon single crystals when electric field strength reaches a threshold value of P(~ 10^{-2} Wmm^{-3}). The shapes and distribution of the images varies from sample to sample. These images are linked with structural and compositional inhomogeneities which are present as unavoidable residual point defects and their clusters. These are normally not observed in X-ray diffraction topographs. The application of electric field enhances the contrast and these are clearly seen. Observed sizes of filaments are typically 100-160 µm, but the core is expected to be much smaller. The shapes of images produced by DC fields and microwave fields are nearly the same. The lattice parameter of the specimen did not show any change (limit of detection: Δd/d ~ 10^{-5}). The images of filaments are quite stable and it takes about 60 days for the images to fade out.

(ii) At power densities higher than 10^{-2} Wmm^{-3} the position of diffraction maximum is not stable and it executes slow oscillations. At higher power densities the curves broaden and their peak intensity decreases. Finally, at a P-value of about 0.6 Wmm^{-3} the single crystal transforms into a polycrystalline mass.

(iii) At higher values of the electric field, the current through the crystals shows instabilities. These instabilities are accompanied by simultaneous variations in the diffracted beam intensity. This one to one correlation suggests a strong coupling between the electronic charge carriers and the crystal lattice.

(iv) An anomalous enhancement in the intensity of diffracted X-ray beam is observed on application of microwave field and high DC fields to the silicon single crystals.

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