Investigation of the internal electric field uniformity in (Cd,Mn)Te, (Cd,Mg)Te and (Cd,Mn)(Te,Se) crystals by using the Pockels effect

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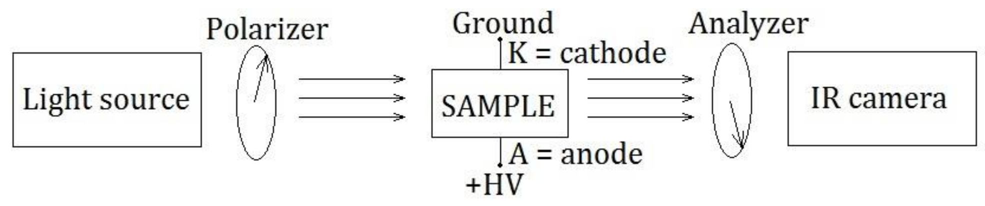
Introduction

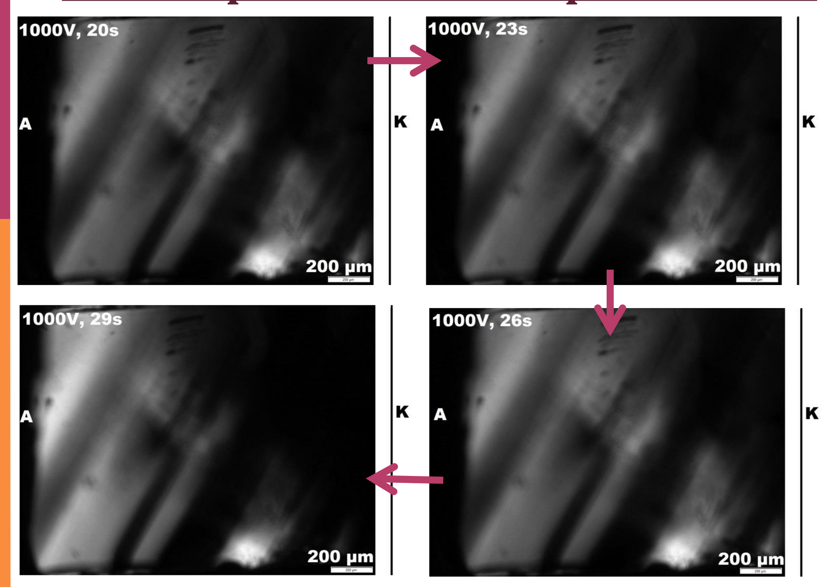
- Crystals based on CdTe with addition of manganese **Mn**, magnesium **Mg** or selenium **Se** are currently investigated as new materials in fabricating **room temperature X and γ radiation detectors**. Nowadays in this group of detectors the leading materials are: CdTe and (Cd,Zn)Te. They work in energy range from 30 to 800 keV. These detectors are needed for various **applications**, for example: in national security, in monitoring and assuring the non-proliferation of nuclear materials, in imaging devices for medicine or in research in space.
- Crystals for nuclear radiation detectors have to fulfill **special requirements**, for example:
  - High resistivity $\rho \sim 10^{10}$ Ω·cm;
  - Monocrystallinity – neither grains nor twin boundaries presence;
  - Low concentration of tellurium precipitations/inclusions ⩽ $5 \cdot 10^{3}$ cm^{-3};
  - Uniform distribution of internal electric field – high charge collection efficiency.
- Internal field measurement in nuclear radiation detectors has always been a difficult task. Hopefully, all discussed here materials crystallize in zinc blende structure (they do not have an inversion symmetry), so they have strong linear electro-optical coefficient, which allows to make use of **Pockels effect**. Pockels effect occurs in materials which are considered as optically isotropic under field free conditions. The velocities of light waves travelling inside the crystal are same in all directions respect to the crystal orientations. Under applied electric field such crystals become birefringent. The velocity of light wave polarized along the direction of applied electric field is different from light polarized perpendicularly to the applied field. Therefore, the two orthogonally polarized light waves travelling at different velocities through the crystal introduce a phase difference between the two waves. The phase difference varies linearly with the internal electric field intensity and the passing length of light inside investigated crystal. A sample with uniform distribution of internal electric field should be lightened up likewise in all sample's points. When bright and dark areas (areas with different refractive indexes) in one sample can be distinguished, that means there is a non-uniform distribution of internal electric field and relying on such sample, the nuclear radiation detector cannot be built.

Experimental setup



Pockels effect setup for internal electric field measurements in CdTe-based crystals. Polarizer is set at angle of 45° with the direction of electric field. IR transmission images of unbiased crystal are recorded with analyzer parallel to polarizer then with cross analyzer both biased and unbiased.

Time dependence of sample's answer



- The evolution with time of the electric field has also been observed when the same sample was biased at other voltages (100-1000 V).
- The higher voltage, the slower sample's answer.

$Cd_{0.9}Mg_{0.1}Te$ as-grown
Crossed polarizers, +1000 V
Intensity of IR light: „1"

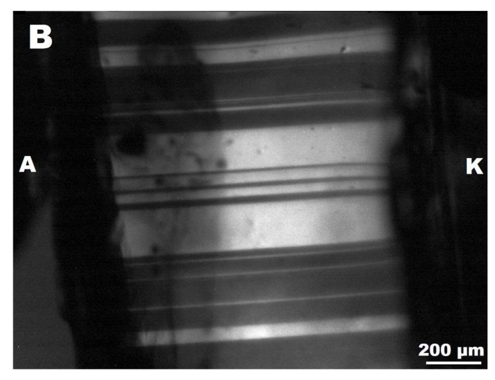
(Cd,Mg)Te

(Cd,Mg)Te crystal after etching revealing crystal polarity. There are visible numerous twins (dark parallel lines).
(Cd,Mg)Te crystals show strong tendency in twins forming, independent on Mg content.

Pockels images of $Cd_{0.92}Mg_{0.08}Te$:In (In $1 \cdot 10^{14}$ cm^{-3}) sample with different electrical contacts configuration (Intensity of IR light: „1")

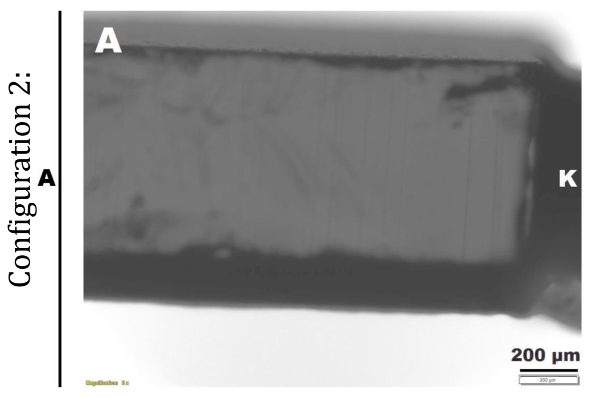
Configuration 1:

A) Parallel polarizers, 0 V;



B) Crossed polarizers, +800 V

Configuration 2:



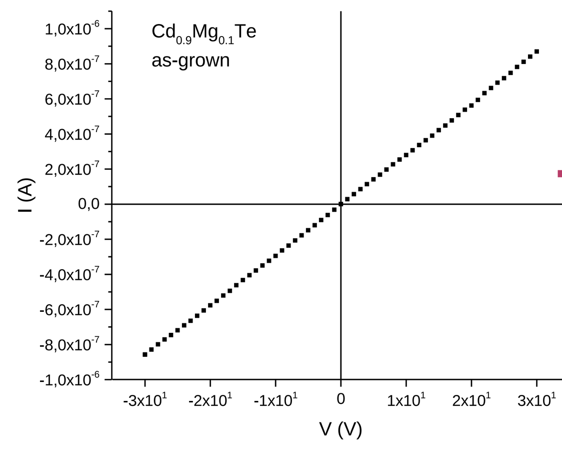
A) Parallel polarizers, 0 V;

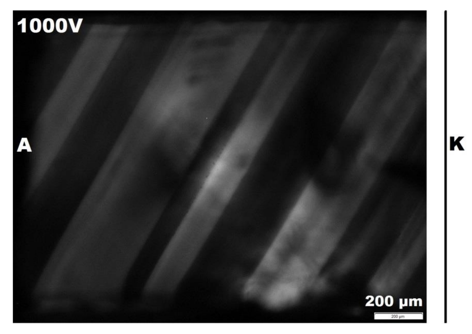
B) Crossed polarizers, +1000 V

In both A-pictures have been presented IR-images of unbiased samples, when the polarizers are parallel. There are visible thin dark lines related to twin boundaries which are decorated by tellurium inclusions.

B-pictures are Pockels images. The bias is applied and polarizers are crossed. There can be distinguished brighter and darker areas. These areas are separated by twin boundaries and are connected with different refractive indexes, and therefore with different value of electric field.
There can be observed a difference of obtained Pockels images, depend on contacts configuration.
In case of second configuration, when the direction of electric field is perpendicular to twin plane, contrast is worse. It follows the electric field is weaker.

Dependence on electrical contacts



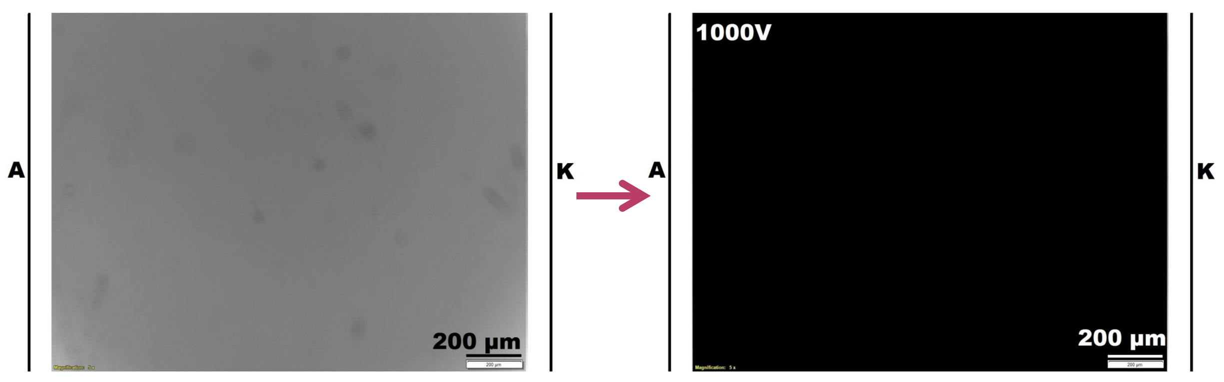


$Cd_{0.9}Mg_{0.1}Te$ as-grown
Crossed polarizers, +1000 V
Intensity of IR light: „1"

Electrical contacts cannot produce any defects, they cannot have an influence on internal electric field in crystal. Linear current-voltage dependence is desired.

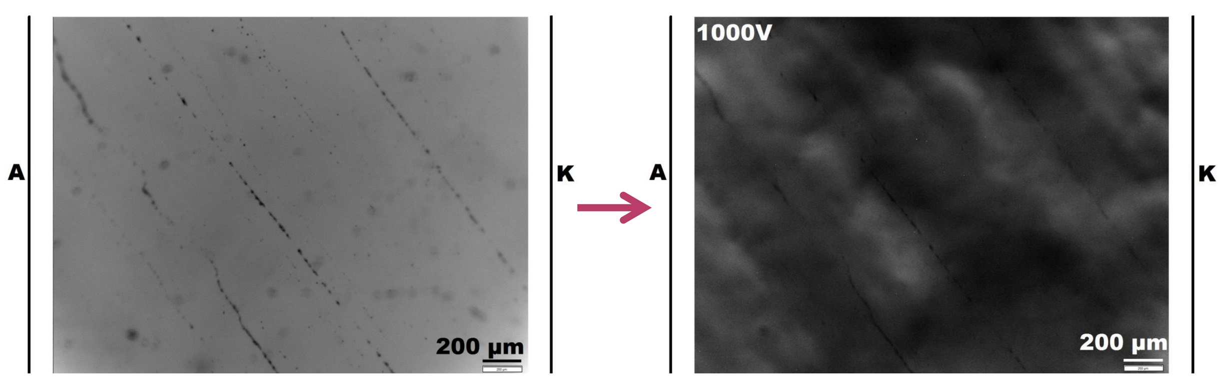
(Cd,Mn)Te

Sample without any defects – specimen shows a uniform field throughout the volume.



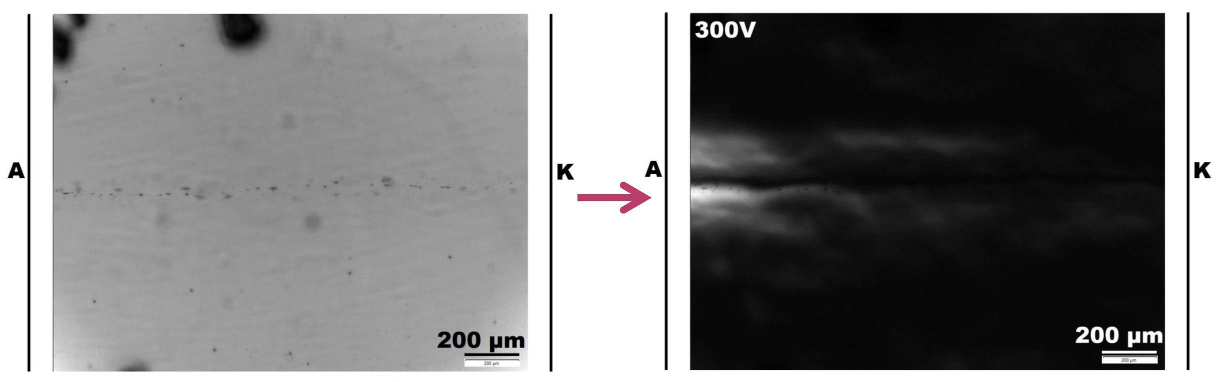
$Cd_{0.95}Mn_{0.05}Te$:V (V $3 \cdot 10^{16}$ cm^{-3}) as-grown; intensity of IR light: „1"
A) Parallel polarizers, 0 V; B) Crossed polarizers, +1000 V

Sample with several lines of tellurium inclusions – despite evident presence of defects, the internal electric field is more uniform in comparison to (Cd,Mg)Te crystals.



$Cd_{0.95}Mn_{0.05}Te$:V (V $5 \cdot 10^{13}$ cm^{-3}) as-grown; intensity of IR light: „1"
A) Parallel polarizers, 0 V; B) Crossed polarizers, +1000 V

Sample with one line of tellurium inclusions – within a distance of about 200 µm from the line of tellurium inclusions there is a non-uniform distribution of internal electric field.

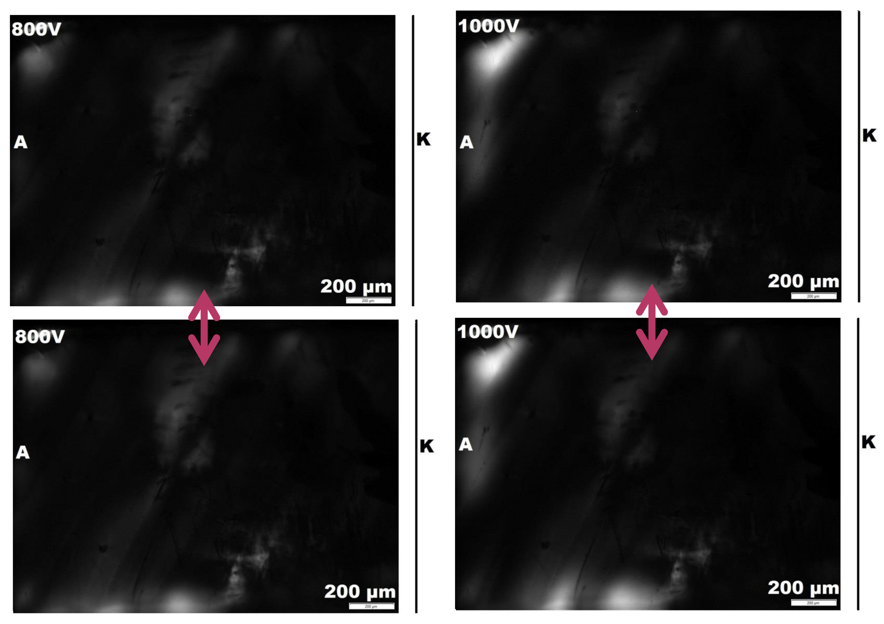


$Cd_{0.95}Mn_{0.05}Te$:V (V $5 \cdot 10^{13}$ cm^{-3}); intensity of IR light: „1"
A) Parallel polarizers, 0 V; B) Crossed polarizers, +1000 V

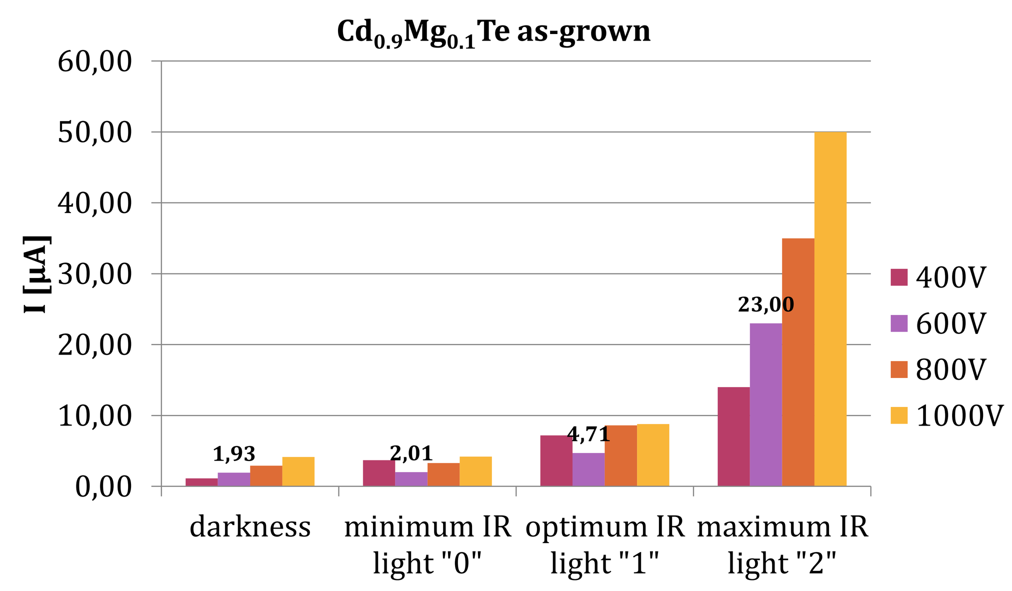
Choosing an optimum intensity of IR illumination

Intensity of IR light: „1"

Intensity of IR light: „2"



$Cd_{0.9}Mg_{0.1}Te$ as-grown; crossed polarizers



It is necessary to set an optimum intensity of IR light during the experiment – the lowest possible in order to minimize photogeneration of additional charge carriers. And at the same time, properly high so that Pockels effect could be observed.

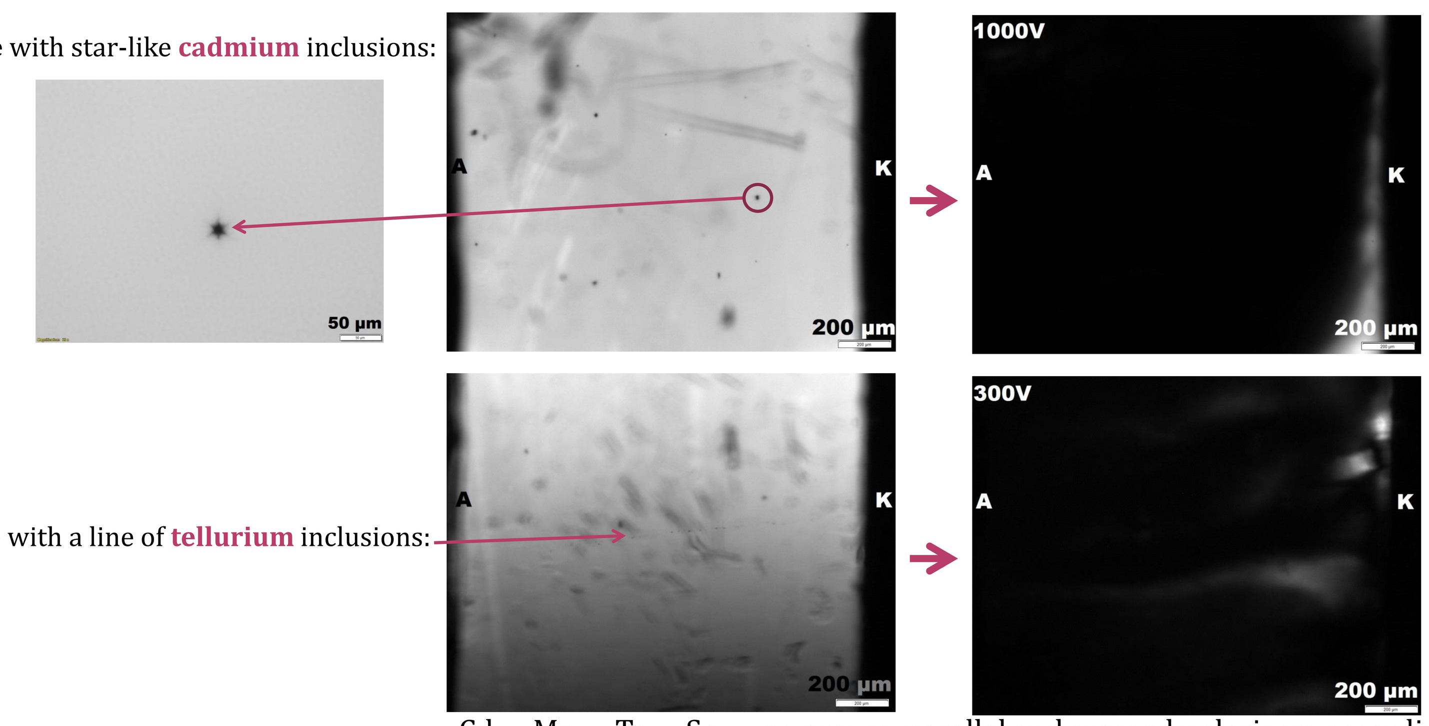
Neither in darkness, nor for minimum available intensity of IR illumination „0" used during the measurements, Pockels images cannot be visible. There is no difference in achieved pictures between those taken for average „1" (now called: optimum) or for maximum „2" intensity of IR light.

In the graph has been presented, that total flow current in sample strongly depends on the intensity of used IR light. That is why this intensity should be limited.

(Cd,Mn)(Te,Se)

Sample with star-like **cadmium** inclusions:

Sample with a line of **tellurium** inclusions:



$Cd_{0.95}Mn_{0.05}Te_{0.99}Se_{0.01}$ as-grown; parallel and crossed polarizers accordingly
Intensity of IR light: „1"

- In (Cd,Mn)(Te,Se) crystals it is difficult to achieve a high resistivity sample. In most cases the value of resistivity parameter does not exceed 10^{5} Ω·cm. That is why such specimens cannot be measured by using the Pockels effect.
- In all samples which have higher resistances, there are numerous cadmium and tellurium inclusions. In Pockels effect measurements the only signal comes from tellurium inclusions which are formed in a line. There is no signal in Pockels images from separated star-like cadmium inclusions.
- In the boundary region Pockels image is affected by edge roughness.

Summary

- Until now, in all investigated **(Cd,Mg)Te** crystals a non-uniform distribution of internal electric field has been observed. Crystals show a strong tendency in twin forming, independent of Mg content.
- It is very difficult to study the Pockels effect in **(Cd,Mn)(Te,Se)** crystals due to too low samples' resistivities which are in most cases ~10^{3}-10^{5} Ω·cm. In those which have higher resistivities there is a high concentration of tellurium and cadmium inclusions. That is why the distribution of internal electric field is non-uniform.
- In **(Cd,Mn)Te** crystals it is possible to obtain more uniform, in comparison to crystals with Mg, distribution of internal electric field. It is related to fact that in (Cd,Mn)Te crystals it is easier to achieve large monocrystalline blocks than in (Cd,Mg)Te.
- **Intensity of IR illumination** has an important influence on photogeneration of additional current in sample. That current could be related to additional charge carriers, ionization of dopants or other processes.
- In order to make use of Pockels effect it is necessary to take care of correct preparation of **electrical contacts** – they should be **linear** (linear I-V characteristic) and **time-stable** (surface current cannot change during detector's life).

References
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