Positron lifetime spectroscopy of vacancy-related defects in ZnO

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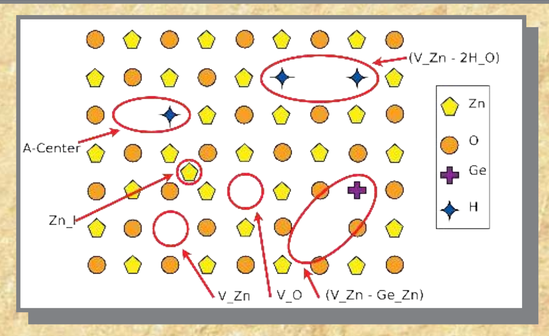
Poster number: MoP-45

1. Motivation

- *Single crystalline Zinc Oxide represents promising material to manufacture blue and UV light emitters and high-temperature and high-power transistors.*
- *An engineering of point defects existing in ZnO crystals represents principal task for routine productions of high quality crystals for such application.*

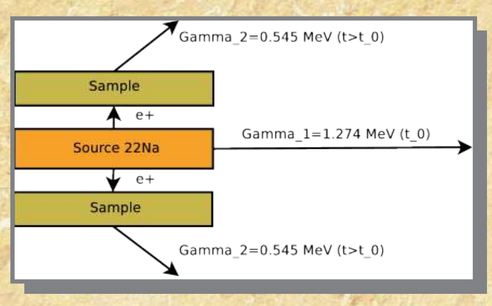
2. Point defects

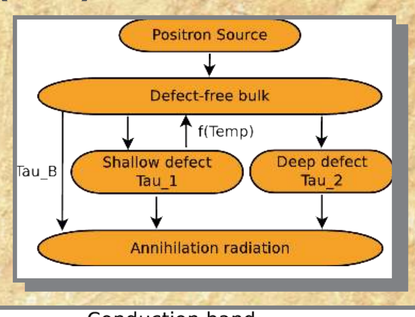
- *Vacancies*
- *Intersticials*
- *A-centers ($V\text{-}X_D$)*
- *Neutral ($V\text{-}2X_D$)*



3. Experiment and Theory

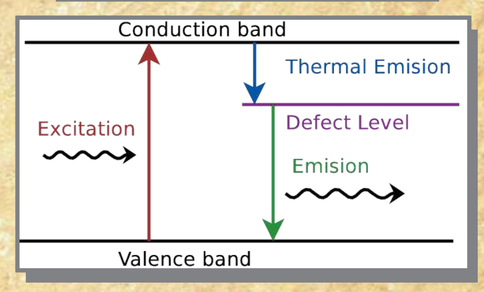
Positron annihilation spectroscopy (PAS)





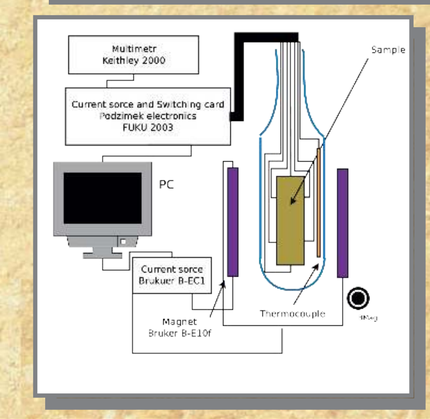
Photoluminiscence (PL)

1. *Room Temperature*
2. *Low Temperature*



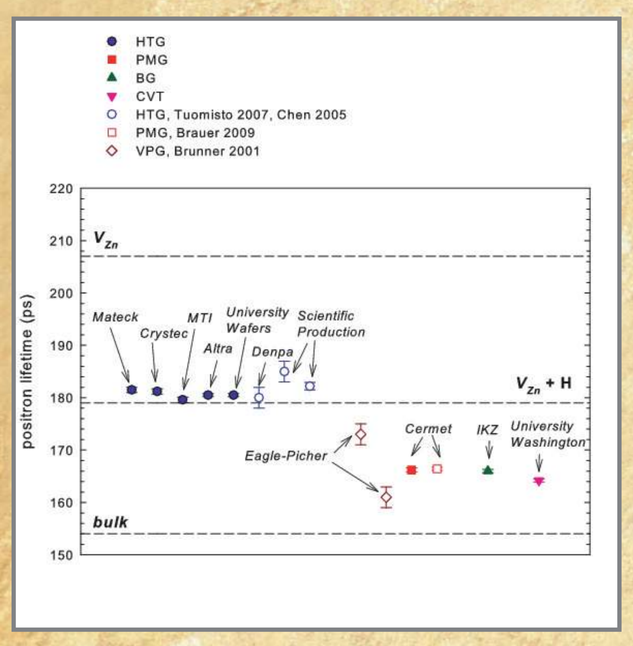
Galvanomagnetic measurement (LT Hall effect)

- *Lower limit: 77 K*
- *Upper limit: 330 K*



Chemical Analysis (ICP-MS)

4. PAS Results

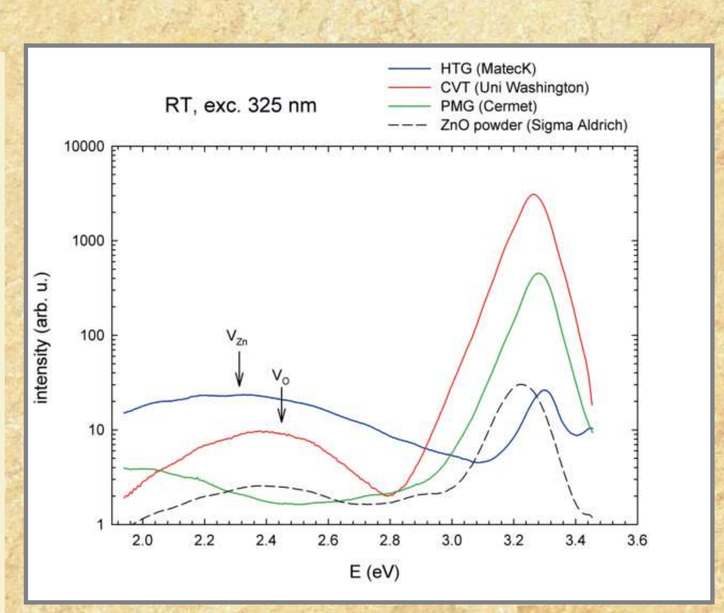


Positron lifetime for crystals grown by several methods and from several vendors. The grow methods are marked by shape of symbols, the producers are marked by arrow. The open symbols represents data from literature.

- *Samples from different vendors and grown by different technology (HTG - hydrothermal growth, PMG - pressurized melt growth, BG - Bridgman growth, CVT - chemical vapour transport, VPG - vapour phase growth).*
- *HTG yields the positron lifetime (≈180 ps), in contrast to other growth methods (≈165 ps).*
- *This finding was independent of the concentration of impurities determined by ICP-MSP.*
- *Possibility of trapping at (V_{Zn} - H).*

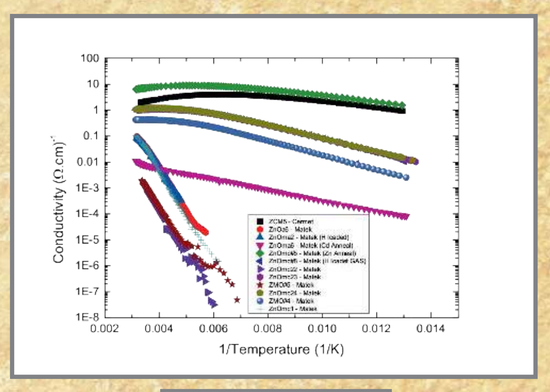
5. Photoluminiscence Results

- *Photoluminiscence confirm green luminiscence iduced by V_{Zn} at HTG samples.*
- *Combination of V_{Zn} and V_O probably induced the green luminiscence at CVT samples.*
- *The green luminiscence at PMG samples was not observed.*



6. LT Hall effect - Results

- *The HGT samples show basically two type of shape of temperature dependence of conductivity (σ(T)).*
- *The shape of σ(T) depends on detail compensation and for the deep analysis should be based on ICP-MS for each sample.*
- *The annealing changed the shape of σ(T).*



	N_D-N_A (cm^{-3})	E_D (meV)
ZCM5	$6.7 \cdot 10^{16}$	38
ZnOa6	10^{23}/$1.5 \cdot 10^{19}$	650/312
ZnOma6	$6 \cdot 10^{15}$	14.5
ZnOmc5	$3.5 \cdot 10^{17}$	22
ZnOmc8	$4.3 \cdot 10^{16}$	35

7. Discussion

- *The ZnO grown by HTG contains defect, with lifetime ≈ 180 ps, whereas crystals grown by other methods contains defects with lifetime ≈ 165 ps.*
- *Theoretical calculation imply that the lifetime 180 ps corresponds with positron trapping and annihilation in hydrogen-stabilized Zn vacancy (V_{Zn} – H).*
- *The presence of V_{Zn} was proved by photoluminescence for HTG samples.*
- *The LT Hall effect analysis was done and the activation energy for defects were set. The shape of conductivity lines depends on original concentration of impurity in various sample.*

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References

1. *KRAUSE-REHBERG, R., et al.: Review of defect investigations by means of positron annihilation in II-VI compound semiconductors. Applied Physics A: Materials Science. 1998-6-1, vol. 66, issue 6, p. 599-614.*

Summary

- ***The influence of growing methods of ZnO was shown. The HTG method generate different type of point defects (lifetime ≈180 ps) than other methods (lifetime ≈165 ps) independently on crystal vendors and on chemical composition.***
- ***This difference was explained by the positron trapping and annihilation in hydrogen-stabilized Zn vacancy (V_{Zn} – H) in the former case and by the bulk positron annihilation in the latter case.***
- ***The presence of V_{Zn} was proved by photoluminiscence.***
- ***The galvanomagnetic measurements were done, the concentration N_D-N_A and activation energy of defect was set.***