Epitaxial growth of pulsed laser deposited Ge-Sb-Te thin films on (111) oriented substrates

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Introduction

Phase change materials based on the material system Ge-Sb-Te (GST) have been widely used for optical storage for decades and is gaining more interest as a candidate for storage class memory. Recently, it was shown that memory devices with a ordered structure possesses improved switching characteristics in terms of speed and stability[1]. Even more highly ordered Ge-Sb-Te-films in form of epitaxial layers have been achieved with MBE[2], however, with severe limitations regarding deposition rate.

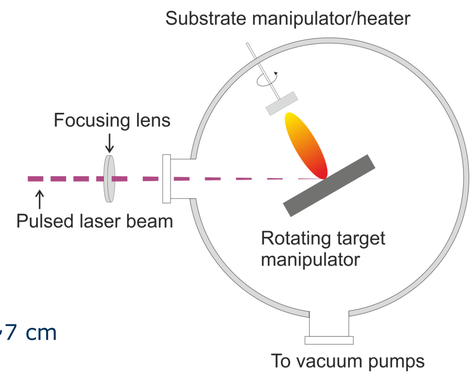
Here, Pulsed Laser Deposition (PLD) is used to deposit high quality epitaxial GST films from a compound target at high deposition rates (1-100 nm/min)[3,4] and the resulting films were investigated mainly by XRD and TEM.

[1] R. E. Simpson et al., Nat. Nano. **6,** 501 (2011).
[2] F. Katmis et al., Cryst. Growth Des. **11**, 4606, (2011)
[3] E.Thelander et al., J. Appl. Phys. **115**, 213504 (2014)
[4] E.Thelander et al., Appl. Phys. Lett. **105**, 221908 (2014)

Pulsed laser deposition

Experimental parameters

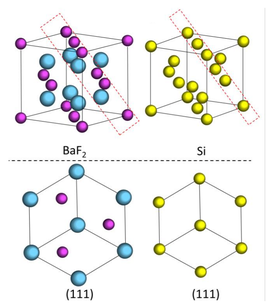
- KrF-excimer laser (248 nm)
- f_{laser}: 1-100 Hz
- ~20 ns pulse length
- Fluence: 0.9 J/cm^2
- Target: $Ge_{2.4}Sb_{2.4}Te_5$
- Ar-flow: 1 sccm (10^{-5} mbar)
- Target-substrate distance: ~7 cm



Materials

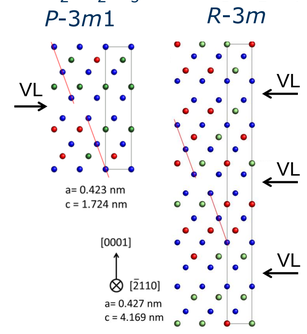
Substrates

BaF_2(111) Si(111)

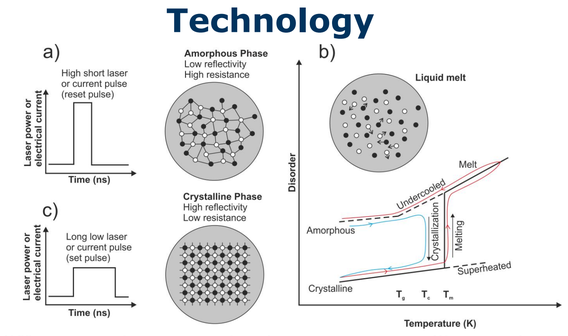


Thin films

$Ge_2Sb_2Te_5$ *P*-3*m*1 $Ge_1Sb_2Te_4$ *R*-3*m*



Technology



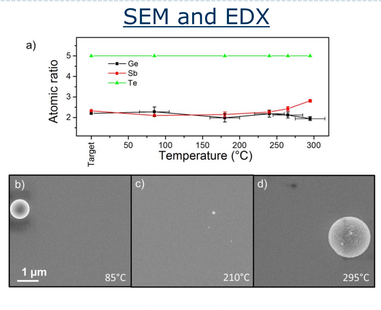
- Distinct differences in properties between crystalline and amorphous state (electrical and optical)
- The differences can be read out as digital data (0 and 1)
- Used in re-writable optical media/non-volatile electronic memories

Image idea adapted from : Wuttig et al. Nat. Mater. **6,** 824 (2007)

Results

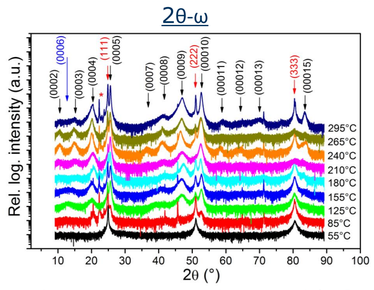
BaF_2(111)

SEM and EDX



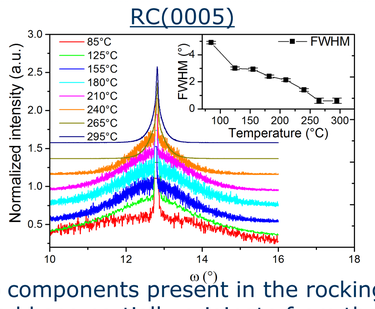
- Smooth topography, no large crystallites
- Composition close to target material
- No significant composition change below 250°C

2θ-ω



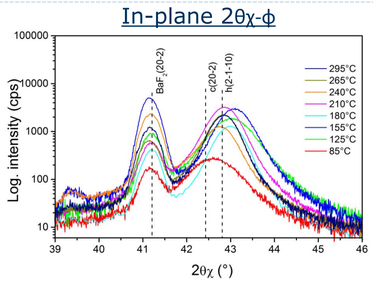
- Diffraction pattern consistent with $Ge_2Sb_2Te_5$
- Only (000*l*) reflections present

RC(0005)



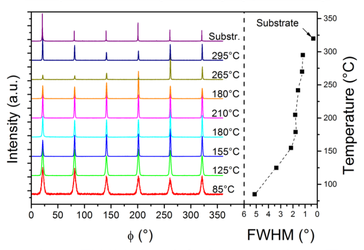
- Two components present in the rocking curve
- Broad base partially originate from the substrate
- At high T: FWHM < 0.06°

In-plane 2θχ-ϕ



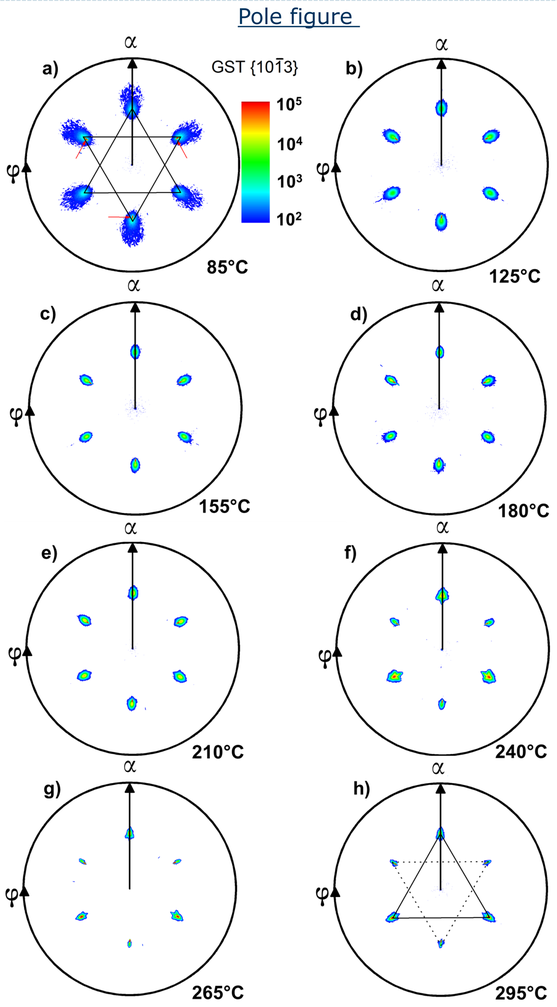
- Diffraction pattern mostly consistent with $Ge_2Sb_2Te_5$

In-plane RC(2110) (ϕ-scan)



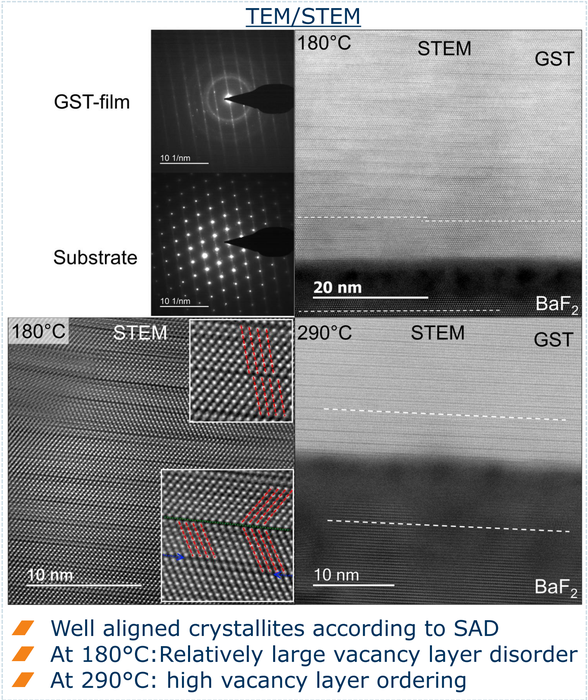
- Decreasing FWHM with increasing T
- Twist distribution of around 1.5° at high T

Pole figure



- Epitaxial growth already at 85°C
- Two equal rotational domains until 210°C
- Thereafter one domain dominates
- Epitaxial relationship: $Ge_2Sb_2Te_5$[-12-10]||BaF_2[1-10]

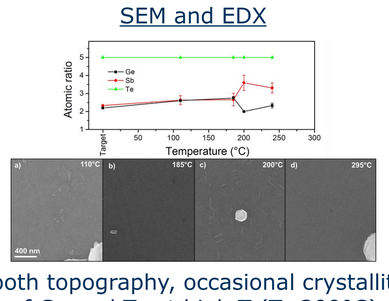
TEM/STEM



- Well aligned crystallites according to SAD
- At 180°C:Relatively large vacancy layer disorder
- At 290°C: high vacancy layer ordering

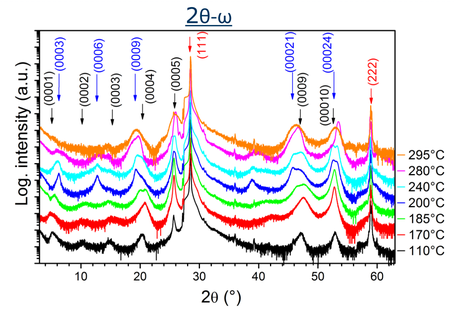
Si(111)

SEM and EDX



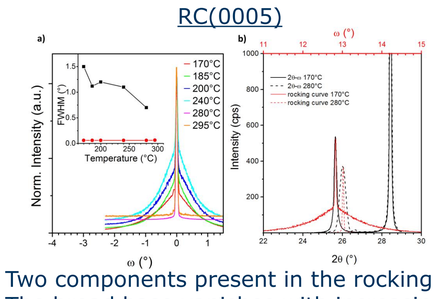
- Smooth topography, occasional crystallites
- Loss of Ge and Te at high T (T>200°C)

2θ-ω



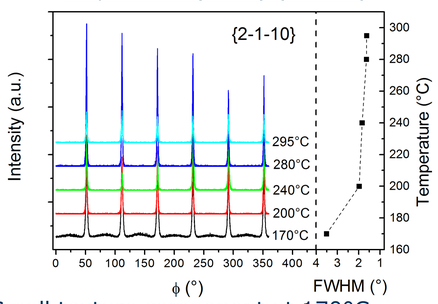
- $Ge_2Sb_2Te_5$ at low T (black annotation)
- $Ge_1Sb_2Te_4$ at high T (blue annotation)
- Only (000*l*) reflections present

RC(0005)



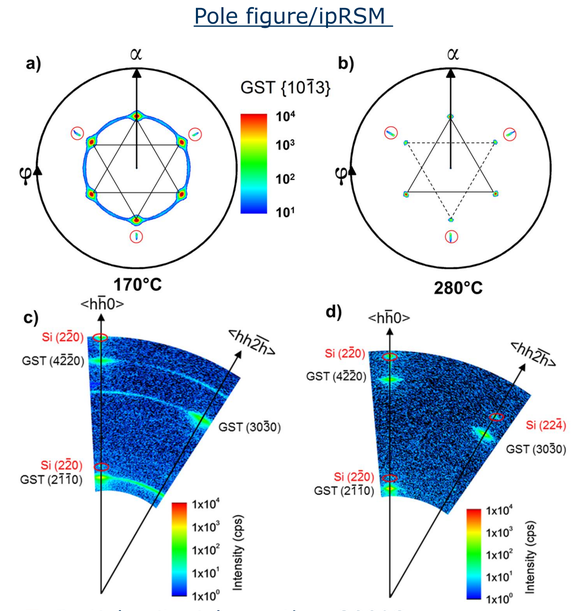
- Two components present in the rocking curve
- The broad base vanishes with increasing T
- At high T: FWHM < 0.06°

In-plane RC(2110) (ϕ-scan)



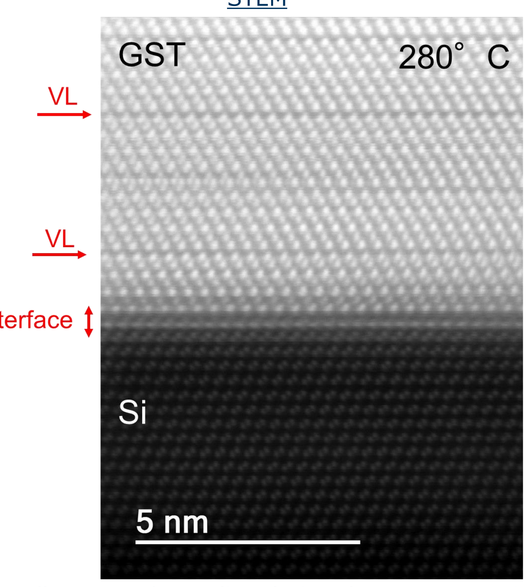
- Small texture component at 170°C
- Decreasing FWHM with increasing T
- Twist distribution of around 1.5° at high T

Pole figure/ipRSM



- Partial epitaxial growth < 200°C
- Two equal rotational domains until 240°C
- Thereafter one domain dominates
- Epitaxial relationship: $Ge_2Sb_2Te_5$[-12-10]||BaF_2[1-10]

STEM



- Small vacancy layer disordering due to evaporation of Ge and Te
- Sharp spatial interface → no large diffusion
- Possible interface structure: GST / VL / 1 ML Te / Si

Conclusions

PLD has been demonstrated as an effective deposition method for high quality epitaxial Ge-Sb-Te thin films. The films were mainly analyzed with XRD and TEM and they are characterized by a hexagonal structure with a pronounced vacancy layer ordering. A clear improvement of the crystal quality is achieved by increasing the substrate temperature, but at high temperatures also simultaneous desorption of Ge and Te occurs.

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