# Sammendrag av tre Benson-artikler (2014-2016)

# Benson et al. (2014)

Benson et al., “Impact of tellurium precipitates in CdZnTe substrates on MBE HgCdTe deposition”, *Journal of Electronic Materials*, vol. 43, no. 11, pp. 3993–3998, 2014.

## Objective

Analyze near-surface tellurium precipitate related defects, particularly small pits and raised protrusions.

## Experimental details

* AFM and scanning profilometry
  + *Aim:* Characterize the surface topography of the Te precipitates and morphological defects in the substrates.
* Nomarski phase contrast microscopy
  + *Aim:* Locate morphological defects on the substrate surface.
* Near-infrared transmission microscopy
  + 52 images focusing through the complete depth at the center of a 775um thick 2x3 cm2 substrate.
  + *Aim:* Observe Te precipitate size and density and correlate with surface defects.
* Dark field microscopy

## Results before etch

* Near-IR reveal that the Te precipitate density is fairly uniform throughout the bulk of the wafer, and that the Te precipitate density is laterally fairly uniform in the near-surface region (equivalent to the density in the bulk). 15 Te precipitates in focus per near-IR image (512.1 x 382.7 um2).
* Average surface roughness as determined by AFM is ~0.3nm.
* Nomarski phase contrast microscopy detects very few defects.
* Dark field microscopy is able to detect a few more and displays Te precipitates and Te precipitate strings in the near-surface region.

## Results after etch

* MBE preparation etch remove ~2-10 um. Average density of pits/bumps ~3x103 cm-2. RMS roughness of surface as determined by AFM is ~0.4nm.
* From near-IR and dark field microscopy, the bumps and small pits on CZT surface are associated with strings of Te precipitates in the near-surface region of the substrate.

1. Raised bumps are Te precipitates near the surface where the Br:methanol etch has not yet exposed the Te precipitate . The etch does not remove material surrounding a Te precipitate as rapidly as the planar surface. Larger raised bumps are a result of shallow Te precipitate string where multiple Te precipitates are in the near-surface region.
2. Once the Te precipitate has been exposed by the Br:methanol etch, the Te precipitate is rapidly undercut. This leaves the exposed surface of the Te precipitate sticking above the surface.
3. Shallow surface pits are formed when Te precipitates are undercut from the surrounding surface plane and dispersed in the etch liquid.

# Benson et al. (2015)

Benson et al., “As-received CdZnTe substrate contamination”, *Journal of Elec-tronic Materials*, vol. 44, no. 9, pp. 3082–3091, 2015.

## Objective

Analyze the initial ‘out of the box’ wafers for surface impurity contamination, polishing damage, and tellurium precipitates/inclusions size/density in the near-surface region.

## Experimental details

* AFM and scanning profilometry
  + *Aim*: Characterize the surface topography and morphological defects in the substrates.
* Nomarski phase contrast microscopy
  + *Aim*: Locate morphological defects on the substrate surface.
* SEM with EDS
  + *Aim*: Determine the composition on residual polishing grit.
* Near-infrared transmission microscopy
  + *Aim*: Observe Te precipitate/inclusion size and density and correlate with surface defects.
* Automated near-IR microscopy system with an automated routine for detecting, counting, and sizing the Te precipitates/inclusions.
  + *Aim*: Perform large wafer (6x6 cm) analysis.
* Total reflection x-ray flourecence (TXRF)
  + TREX 630T TXRF instrument (Mo or W anode configuration)
  + Detection limit: ~1x1010 atoms cm-2.
  + Spot size: ~10 mm diameter circle
  + Analysis depth: ~2-3 nm
  + *Aim*: Analyze impurities on the surface.
* 5800 MultiTechnique System high-vacuum analysis chamber conaining XPS/Auger capabilities.
  + *Aim*: Characterize impurities on the wafer surface.

## Results

**Impurity analysis**

Table 1: TXRF. Maximum surface impurity concentration on 6x6 cm as-received wafer.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Element | Al | Si | Cl | S | P | Fe | Br | Cu | Zn |
| 1012 atoms cm-2 | 750 | 37 | 3120 | 170 | 71.0 | 10.2 | 1.90 | 4.00 | 80.0 |

Table 2: XPS. Maximum surface impurity concentration on 2x3 cm as-received wafer.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Element | Si | Cl | S | F | O | C | Te oxide thickness |
| 1012 atoms cm-2 | 82.0 | 20.0 | 42.0 | 5.90 | 350 | 460 | 0.34 |

* TXRF concentrations <= 1x1012 atoms cm-2. Cr, Mn, Ni, Ga, Ge, As, Sr, Y, Ta, W, Pt, Au, Hg, Pb, and Bi.
* Wide lateral variation (coefficient of variation > 1 and skew > 2) in surface contamination of Cl, Fe, Cu, and F makes uniform HgCdTe processing problematic.
* Pearson correlation coefficient was determined for each impurity element to all other elements.
  + TXRF – Strong correlation of the lateral impurity concentrations of Cu and Fe, strong correlation of Cl and S, and a moderate correlation of Br and Zn were found.
  + XPS – None of the impurity elements were found to be correlated.

SiO2 and Al2O3 polishing grit. P, Fe, and Cu are potential contaminates in polishing grit slurry. Fe could also be coming from dicing the CdZnTe wafer. P and Fe may additionally be cross-contamination from other semiconductor polishing. Cl could be due to NaClO which is used as a standard polishing slurry cleaner.

**Polishing analysis**

Root mean squared roughness ~0.4 nm (determined for all the wafers at both the center and edge).

*Polishing scratches*: 0.3 nm in depth and 0.1 um wide.

*Polishing grit*: density vary from wafer to wafer from ~5x106 to 2x108 cm-2. Length varied from 100 nm to 1 um. Height was mearued to be 10 nm and 300 nm above the surface. SiO2 agglomeration electrostatically bound to the surface. Dislodging residual polishing grit pieces was attempted using the AFM tip as a manipulator. This proved unsuccessful.

**Te precipitate/inclusions in the near-surface region**

Te precipitate/inclusion size and density are obtained by near-IR automated microscopy.

A diameter histogram is obtained for the near surface (top ~140 um). The mean diameter is 1.5-2.5 um (typical size is ~2-3 um).

Fairly uniform density of average areal Te precipitates/inclusions is observed, but the Te precipitate/inclusion >10 um diameter are laterally non-uniformly distributed across the wafer with a density of 2.8x103 cm-3 (typical Te density ~2x106 cm-3).

# Benson et al. (2016)

Benson et al., “Analysis of etched CdZnTe substrates”, *Journal of Electronic Materials*, pp. 1–9, 2016.

## Objective

Analyze near-surface tellurium precipitate related defects, particularly small pits and raised protrusions and compare with wafers that have gone through a standard MBE Br:Methanol preparation etch.

## Experimental details

* Nomarski phase contrast microscopy
  + *Aim:* Locate morphological defects on the substrate surface.
* AFM and scanning profilometry
  + *Aim:* Characterize the surface topography of the Te precipitates and morphological defects in the substrates.
* SEM with EDS
  + *Aim:* Determine the composition on residual polishing grit.
* Total reflection x-ray flourecence (TXRF)
  + *Aim*: Analyze impurities on the surface.

## Results

CdZnTe particulates and residual SiO2 polishing grit were observed. Density varies from ~4x107 cm-2 to 2.5x108 cm-2. After the etch, no residual polishing grit was observed.

**Impurity analysis of As-Received CdZnTe Substrates**

Table 2: TXRF. Maximum surface impurity concentration on as-received wafer.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Element | Al | Si | Cl | S | P | Fe | Br | Cu | Zn |
| 1012 atoms cm-2 | 1700 | 37 | 3120 | 170 | 110 | 10.2 | 120 | 4.00 | 200 |

There is a correlation of lateral impurity concentrations of Si, Cl, P, and S for the as-received substrates. P and S are common components in surfactants used for slurry cleaning solutions.

The high Al concentration can be explained by the use of Al as a stabilizer in colloidal silica polishing slurry. Or from Al2O3 polishing grit used to bevel the substrate edge.

Use SEM and EDS at the edge of the substrates to demonstrate that residual SiO2 and Al2O3 polishing grit as well as residual mounting wax remain on the as-received wafer edge.

**Impurity analysis of MBE Preparation-Etched CdZnTe Substrates**

Table 2: TXRF. Maximum surface impurity concentration on MBE preparation-etched substrates.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Element | Al | Si | Cl | S | P | Fe | Br | Cu | Zn |
| 1012 atoms cm-2 | 2360 | 40 | 75 | 44 | 98 | 10.0 | 290 | 5.20 | 170 |

For the MBE preparation etched substrates, there is a lateral impurity correlation of Cl, P, and S.

*AFM*: Root mean squared roughness varied from ~0.5 nm to 1.0 nm across the wafer surface. Particulate length varied from 250 nm to 1 um. The height of the particulates was measured to be between 10 nm and 50 nm. The range of particulate density was 4x106 cm-2 to 8x107 cm-2.

*SEM+EDS:*Most particulates observed are CdZnTe particles/flakes. Some residual C-based flakes were also observed, but these could be due to MBE preparation handling. Residual SiO2 and Al2O3 as well as the residual mouting wax is removed from the wafer edge by the MBE etch.

The reduction of Cl can be accounted for since Cl is highly soluble in the organic solvents used.

Suspect that the Br:Methanol MBE preparation etch partially solubilizes the SiO2 polishing grit and disperses trace amounts of residual grit on the wafer surface. Suspect that this also is done to CdZnTe particles.