IR-Based Temperature Measurement in Rotational Grinding of Sapphire Wafers

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Outline

1. Introduction
2. Temperature Measurement
3. Sensor Requirements
4. Experimental Setup
5. System Calibration
6. Grinding Tests
7. Conclusions and Outlook
Introduction

Sapphire and its Different Applications

Crystal properties

- Single crystalline with hexagonal-rhomboedal crystal lattice structure
- c-Plane Orientation (0001)
- defect and contamination free
- Diameter 50 - 200 mm (2-8”)
- Thickness approx. 250 \( \mu \)m - 1 mm

Mechanical – Chemical – Optical

Sapphire Wafer

- LED
- P-contact
- n-GaN
- p-GaN
- AlGaN
- InGaN MQW
- GaN-Buffer
- Substrate top side
- Sapphire substrate
# Introduction

## Process steps in Sapphire Wafer Manufacturing

### Front-End-Field

- **Multi-Wire-Slicing**
- **Lapping**
- **Polishing**

### Back-End-Field

- **Thinning**
- **Dicing**

### Primary Requirements

**Front-End-Field**

- high form accuracy
- low surface roughness
- low sub-surface damage

**Back-End-Field**

- minimum wafer thickness
- low internal stress
- (low surface roughness and SSD)
**Introduction**

Rotational Grinding - Grinding Wheel and Process Kinematics

- Grinding Wheel Alignment
- Segmented Grinding Wheel

![Diagram](image)

- Feed Rate $v_f$
- Spindle Speed $n_s$
- Contact Zone
- Grinding Wheel
- Wafer
- Wafer Speed $n_w$
Temperature Measurement
Principle Setup for Monitoring and Control in Rotational Grinding
Temperature Measurement
Test Bench Setup for Silicon Grinding Developed by Pähler
# Outline

1. **Introduction**

2. **Temperature Measurement**

3. **Sensor Requirements**

4. **Experimental Setup**

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6. **Grinding Tests**

7. **Conclusions and Outlook**
Sensor Requirements
Optical Transmissivity of Sapphire and Wien’s Displacement Law

- Sapphire window temperature
  - 20 °C
  - 200 °C
  - 400 °C
  - 600 °C
  - 800 °C

Wiens’s Displacement Law

- $\lambda_{\text{max}} \cdot T = b$

- Relation between spectral intensity, wavelength and temperature
**Sensor Requirements**

**Selected IR-Camera**

- Jenoptik VarioTherm
- Detector type: PtSi
- Detector wavelength: 3.4 – 5 μm
- Detector resolution: 254 x 254 pixels
- Detector frequency: 50 Hz
- Accuracy < 100 mK
- Focus distance: 300 - 600 mm, depending on object size
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Experimental Setup
Test Bench Setup – Front View

Hembrug Slantbed CNC Hard Turning Machine Tool

Grinding wheel

Machine tool control

Test bench

IR-Camera control

Test bench control
Experimental Setup
Test Bench Setup – Back View

Test bench

IR-Camera control

Air cooler

Test bench control

Coolant pump

Coolant

Coolant flow rate control

Hembrug Slantbed CNC Hard Turning Machine Tool
Experimental Setup

Test Bench Setup – Front View

Existing part of test bench

Extended part of test bench

IR-Camera

Grinding Wheel

Electric power and air supply

Coolant nozzle
**Experimental Setup**

**Test Bench Setup – Camera Direction View**

![Image of experimental setup with labeled parts: Chuck spindle, Sapphire wafer, Belt drive, Chuck motor, IR-Camera.](image-url)
Experimental Setup
Test Bench Setup – Process Area

Grinding wheel
Sapphire wafer
Wafer chuck
Coolant nozzle
Experimental Setup

Test Bench Setup – Process Alignment

Contact area
Sapphire wafer
Wafer chuck
Grinding wheel
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System Calibration
Calibration Setup – Influence of Abrasive Layer

Grinding wheel
Abrasive layer
Thermo couple
Heater
IR-Camera
System Calibration
Measurement Results – Influence of Abrasive Layer

![Graph showing the influence of different abrasive layers on grinding layer temperature.](image-url)
System Calibration
Calibration Setup – Influence of Wafer Thickness and Wafer Surface

1. Double side polished wafer, $t = 500 \, \mu m$
2. Double side polished wafer, $t = 5 \, mm$
3. Wafer, $t = 500 \, \mu m$, one side polished, one side lapped ($Ra \approx 700 \, nm$)

- Cold wafer (20° C)
- Heated and cooled down abrasive layer
System Calibration
Measurement Results – Influence of Wafer Thickness and Surface

- Muedia D46
- thin polished wafer
- thick polished wafer
- lapped wafer
**System Calibration**

Calibration Setup – Influence of Wafer Temperature

1. Setup
2. Focus on heated wafer
3. Focus on abrasive layer

- Heated and cooled down wafer
- Abrasive layer with constant temperature (50 - 55°C)
Analogy Tests on Test Bench

Calibration Setup – Influence of Wafer Temperature

![Graph showing the Influence of Wafer Temperature](image)

- **polished wafer**
- **lapped wafer**
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Grinding Tests
Frame Content Depending on Grinding Kinematics and Detector Speed

| detector frame rate = 50 Hz | spindle speed $n_s = 4000$ $1/\text{min}$ |

Grinding wheel position frame $n$  
Grinding wheel position frame $n+1$

During recording of 1 frame, 72 segments pass 1 measurement spot  
average “background” temperature
Grinding Tests
Grinding Test Results – Rough Segmented Porous D46 Wheel

Grinding conditions
- Metal bond D46 wheel
- \( n_s = 3000 \) 1/min
- \( n_c = 50 \) 1/min
- \( v_f = 60 \) \( \mu \)m/min
- Brittle material removal mechanism
- Good cooling conditions

Result
- Maximum detected background temperature \( \sim 45 \) °C
Grinding Tests
Grinding Test Results – Fine Segmented D5 Wheel

Grinding conditions

- Metal bond D5 wheel
- \( n_s = 3000 \text{ 1/min} \)
- \( n_c = 50 \text{ 1/min} \)
- \( v_f = 20 \mu\text{m/min} \)
- Ductile material removal mechanism
- Bad cooling conditions

Result

- Maximum detected background temperature
  ~ 130 °C
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Conclusions and Outlook
What Did We Learn and How Can the Results be Applied?

Conclusions

- The proof of concept for IR-based temperature measurement in rotational grinding of sapphire wafers was successfully achieved.
- Due to the limited detector frequency, the so called “background temperature” of the abrasive layer is measured.
- Highest temperatures of about 130 °C were detected while using a fine segmented wheel with small grit size and low porosity.

Outlook

- Development of a sensor integrated vacuum chuck system able to measure background temperatures on wafers down to 20°C.
- Application of a faster IR sensor (> 6 kHz) for the detection of peak temperatures which are expected to be much higher.
Thank you for your attention!

Questions?

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