Chuck System for Integrated IR-Based Temperature Measurement in Rotational Grinding of Sapphire Wafers

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Abstract

Single crystalline sapphire wafers are used as a substrate for semiconductor and optoelectronic applications like gallium nitride-based LED light sources. In the optimization of the manufacturing chain, rotational grinding plays a mayor role by substituting the conventional lapping process in order to reduce cost intensive efforts in downstream polishing steps. Due the material properties of the sapphire and in particular its hardness of 9 on the Mohs Scale however, it is difficult to establish a stable finishing process. For this reason, the detection of in-process variables like the grinding temperature distribution in the contact zone between the wafer and the grinding wheel are of significant interest. On the one hand, the acquired data increase process understanding, enhancing grinding wheel and process development. On the other hand, real-time processing of the measurement data enables direct control of the process in order to achieve optimum stability. Within this paper, a novel chuck system for the measurement of contact zone temperatures is presented. The general behaviour of the realized system is examined in preliminary calibration tests and grinding tests are performed to prove the feasibility of the chuck system under common machining conditions.

1 Introduction

Although several different approaches based on the principle of thermal conduction or radiation are known today, temperature measurement in abrasive processes is generally considered to be difficult due to limited accessibility to the contact zone [1].

The tool or work piece sided integration of thermocouples and sensors or fibre optics for infrared (IR) detection require high installation efforts [2]. In addition, these approaches are often limited to a measurement only close to the contact zone. IR-thermography and pyrometry basically offer the advantage of contactless analysis. A direct view into the contact zone is, however, obscured by the grinding wheel or the work piece. In addition, the view onto the areas adjoining the contact zone is hindered by the use of coolant [3].

2 Developed chuck system

The developed chuck system presented in this paper is principally based on a measurement setup introduced by Pähler [3]. It offers an innovative solution to the difficulties mentioned above by exploiting the optical properties of the sapphire substrate. Not only does the substrate appear transparent to visible light, it also offers excellent IR-transmissivity for wavelengths below 5 µm. Hence, the infrared radiation emitted in the contact zone between the grinding layer and the wafer is able to pass through the substrate material, making it detectible on the backside of the wafer. A schematic diagram of the measurement setup and its possible extension towards a temperature based closed loop control system is presented in Figure 1.

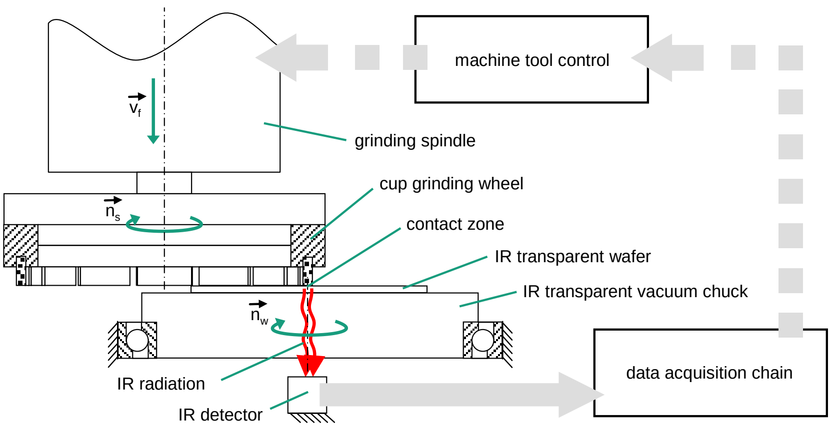

Figure 1: Schematic diagram of the temperature measurement and control system

Following this principle, the core element of the chuck system, a 4” IR-transparent vacuum chuck made of single crystalline sapphire, was developed. Mounted on a hollow spindle, the chuck offers free IR-optical access to the entire wafer surface. In this way, three single-colour pyrometers installed at the rear end of the spindle are able to measure grinding temperatures down to room temperature in any preferred position on the wafer. The realised system is presented in figure 2.

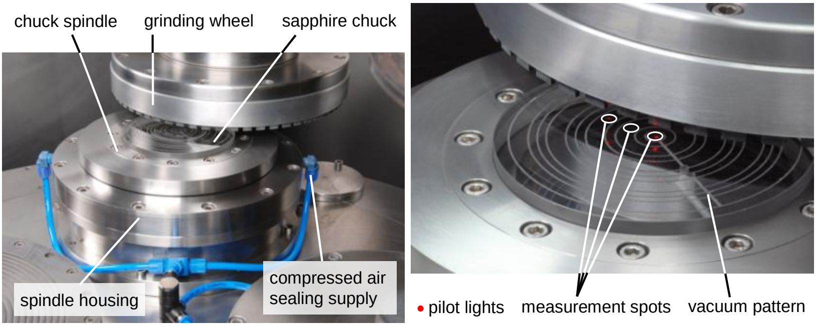

Figure 2: Realised wafer chuck system

The new chuck system is designed in such a way, that its primary functions like clamping and rotating the wafer remain unchanged. This prevents the grinding process from being affected by the superimposed measurement function. The outer dimensions of the chuck system correspond to those of a standard system applied in a commercially available grinder in order to ensure their interchangeability.

3 System calibration and first grinding tests

In order to determine temperatures from the detected IR radiation directly, the emissivity coefficient ε of the examined body must be set on the pyrometers. For the examined grinding layer, this parameter is unknown. In addition, the vacuum chuck as well as the wafer act like a filter, depending on their geometrical and surface properties. In order to consider all of these effects, system calibration was performed by determining calibration curves for a variety of configurations. The calibration curves describe the relation between the measured temperature value T_{pyr} for $\varepsilon = 1$ and the real grinding layer temperature detected by a thermocouple attached to it.

First grinding tests were performed in order to analyse the general behaviour of the chuck system. As the sample measurement in figure 3 shows, the pyrometer signals offer high sensitivity. Similar to the spindle power signal, the different phases of the grinding process can clearly be distinguished from the pyrometer signals.

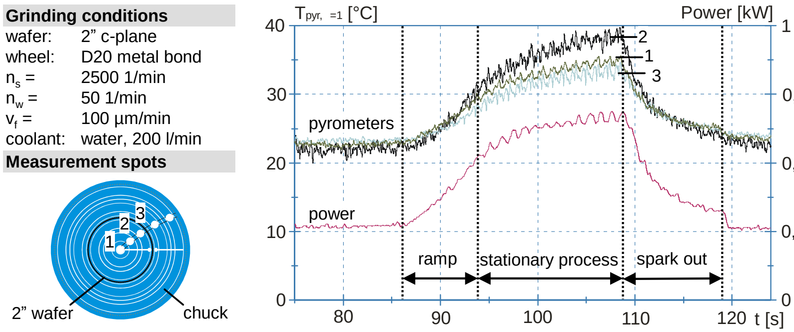

Figure 3: First grinding tests – sample measurement

4 Conclusion and outlook

The results of first grinding tests show that the measurement concept applied in the developed chuck system enables the direct measurement of process temperatures in rotational grinding of sapphire wafers under conventional machining conditions. These findings open the way for enhanced process development and closed loop control based on energetic considerations directly related to the acquired temperature data. In current research activities, the authors take up both challenges.

The presented work was supported by the Seventh Framework Program of the European Commission within the project entitled “ThermoGrind”.

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