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# Application of Observer Design for a Nonlinear Heat Equation to Semiconductor Wafer Processing

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## Description

The demand for semiconductor components is rising globally as a result of the increasing demand for computing power and data storage space. The imposed demands on device performance and the rapid advancement of technology present new challenges for the semiconductor industry. Ion implantation, photolithography, and etching are just a few of the hundreds of steps that go into making modern microchips. These actions are frequently repeated. Single-wafer handling is preferred to clump processes for the development of complex coordinated circuits because these cycles empower much better elements. Heat and mass transfer mechanisms frequently occur in a number of silicon wafer production steps, and the temperature of the involved process fluids or materials frequently has a significant impact on the quality of the final product. The wafer must frequently be heated to a predetermined temperature during single wafer spin clean or wet chemical etching, such as to chemically treat the silicon wafer surface with highly reactive gases or to remove condensation prior to processing. The latter are a part of rapid thermal processing (RTP), which typically requires temperatures between 300 and 400 °C or higher. Baking is the removal of condensation at lower temperatures, typically around 150 degrees Celsius. Heating is provided by a large number of high-power LEDs or halogen lamps embedded beneath the wafer. To avoid thermal stress in the wafer during heat up, large temperature gradients within the wafer must be avoided. To resolve this issue, temperature control is required. However, the foundation of a criticism temperature regulator is challenging due to the lack of contactless in-situ temperature estimation of the entire surface temperature in many applications. Thermal imaging cameras, for instance, are unable to precisely measure the temperature of low-doped wafers because of their low emissivity. For the majority of RTP or low temperature thermal processes, the temperature cannot be measured at all or only pointwise on the wafer surface [1].

However, full state information, such as the temperature measured at multiple points along the wafer's radius or the entire radial surface temperature, is frequently required for the design and implementation of a feedback controller. As a result, a state observer, also known as an estimator that derives the spatial and temporal evolution of the wafer surface temperature from available measurements, is frequently required for the implementation of such controllers in a production tool. A distributed parameter system (DPS) is the phenomenon by which the temperature of the wafer surface changes over time and space. Partial differential equations (PDEs) are the governing equations that control a system's dynamic behavior. An observer for a DPS can theoretically be designed based on an approximation via a lumped parameter system or directly using the PDE when following a model-based design paradigm. The first strategy, also known as early lumping, typically comes with the loss of pertinent system dynamics information. The fact that stability results obtained for finite-dimensional approximations may not necessarily apply to the PDE model makes this issue delicate. Additionally, the system order of the finite-dimensional approximations is typically high. In many design approaches, the observer's order is also determined by the order of the model. This can result in computationally intensive high-order algorithms for PDE approximations with finite dimensions [2,3].

Lately, late lumping has been widely evolved as a charming option in contrast to early lumping plan as the previously mentioned disadvantages don't exist. At the implementation stage, the approximation, which is ultimately required for real-time setup implementation, is performed. The original PDE model's robust stability holds for the lumped model as long as the approximation produces stable and robustness-preserving results. Therefore, the particular PDE structure can be utilized for the observer and controller design without regard to the final approximation method. The associated theory for 1D spatial domains for linear DPSs has been well-developed. Back stepping modal (or spectral) decompositions modal (or spectral) decompositions and high-gain observers are among the specific methods discussed here. A number of spatial dimensions have also been included in the back stepping strategy. Literature is less abundant for nonlinear and semi linear PDE models. An extended Luenberger observer design has been proposed. Methods for estimating variable structures have been developed. Researchers looked into absolute stability and observers based on nonlinear evolution equations. In asymptotic observers have been addressed for transport–reaction systems whose reaction rates are unknown. In high-gain observers were utilized, and matrix inequality-based designs were examined [4].

For some classes of semi linear and quasilinear systems, the backstepping method has been extended. Approaches to observer design based on dispersion have been discussed. Even though these results show that late-lumping design methods have a lot of potential, they all involve a lot of preliminary analysis and design steps that necessitate a thorough understanding of PDE theory. The pointwise measurement injection observer design, first proposed in for 1D semi linear heat equations, has been extended in to classes of semi linear parabolic systems, and in to a class of 1D parabolic transport–reaction systems with unknown inputs. It is a relatively straightforward design strategy that only requires fundamental knowledge of PDEs. A reduced-order observation scheme from finite-dimensional systems that imposes measurement information in the form of an algebraic constraint is similar to the design. A single in-domain measurement and a flawless, unperturbed model have already been taken into consideration when applying this strategy to nonlinear heat equations. A Kirchhoff state transformation was used to create the observer design and a retransformation was used to get the temperature estimate. In this paper, an eyewitness for frameworks represented by a nonlinear bothered 1D intensity condition in tube shaped facilitates with in-space estimations is planned. The observer's design is necessary for estimating the temperature of silicon wafers in semiconductor production; however, its use is obviously not restricted to this particular instance [5].

The pointwise measurement injection observer described is extended by the proposed observer, which takes into account a variety of nonlinearities. Forcing essentially sensible suspicions on the framework elements, the eyewitness assessment blunder combines to zero dramatically which is officially demonstrated by Lyapunov procedures. Pointwise disturbances acting directly at the sensor location have no effect on the observer's robustness. The

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estimation error dynamics are shown to be input-to-state stable in the presence of non-vanishing bounded distributed disturbances. Finally, an experimental validation of the proposed observer scheme on a semiconductor processing tool is carried out. In order to accomplish this, a mathematical model of the procedure is created. It is based on the model that was suggested. In this model, the focus is on modeling the input shape functions that relate the electrical power that is supplied to the heating device, or actuator, and the heat flux density that is introduced into the wafer.

## Conclusion

The validation tool includes a thermographic camera that can measure the entire surface temperature of wafers with a high dopant level. A distributed radial temperature measurement can be used to compute the evolution of the estimation error over time and space. In addition, this arrangement is theoretically capable of simulating any number of pointwise sensors. The experimental results demonstrate that convergence speed and implementation effort are effectively balanced, that the stability analysis's assumptions are reasonable, and that the theoretical findings are supported. The design is carried out in the original coordinates, and the Kirchhoff transformation is only used for the convergence assessment, as opposed to the theoretical results being experimentally validated on a semiconductor wafer processing unit. In addition, multiple temperature measurements taken inside the domain are taken, a flawed model with distributed perturbations is looked at, and robust convergence in terms of input-to-state stability is established. Consequently, the current paper's findings add to, extend, and experimentally validate the preliminary findings.

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