Active contamination control for high-tech equipment and substrates

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Active Contamination Control for High-tech Equipment and Substrates

Particle Generation

Executive Summary

October 2019

Mohammad-Reza Homayoun

Where innovation starts

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Eindhoven University of Technology
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Public Executive Summary

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The design that is described in this report has been carried out in accordance with the rules of the TU/e Code of Scientific Conduct.

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Abstract

Constant high demands on the accuracy and productivity of high-tech equipment in semiconductor, photonics, healthcare and similar industries have led to strict requirements on the contamination level. The main source of particles is wear generated by tribo-pair where two surfaces in relative motion interacting with each other. This is influenced by the contact force and the material and surface properties. To control and minimize wear of tribo contacts, it is essential to understand the mechanisms of debris generation.

Owing to roughness, contacting surfaces are composed of numerous small asperities ranging from micro- to nano-meter scale. In general, the contact only occurs at the apex of local asperities. Therefore, by performing single asperity scratch tests against another asperity/flat surface, the wear process takes place in a controlled environment, allowing the wear mechanism to be isolated and studied independently. Computer modelling combined with experimental validation of a single asperity scratch test could potentially unravel the mechanism behind the wear process.

Wear mechanisms could be investigated via *in situ* single asperity scratch testing. Direct observation inside a Scanning Electron Microscope (SEM) elucidates deformation/fracture processes occurring at the sliding interface. By conducting such an *in situ* experiment, the influencing parameters such as tip radius, tip geometry, the normal and tangential load could be isolated and optimized independently for controlling the particle contamination. The results potentially provide deep insight into the material's behaviour under simultaneous normal and lateral stresses, augmented by direct observation electron microscope imaging and surface topography imaging.

Keywords: Particle; Contamination; Defectivity; Scratch; Single asperity

Foreword

Particle contamination control is a very important aspect for some of the customers of VDL Enabling Technologies Group (VDL ETG). To aid in the development of high tech industry modules, a competence program with respect to particle generation, particle transport and the removal of particles has been started. The work of M.R. (Saeid) Homayoun is the first step towards understanding the mechanisms behind the particle generation subject. He gathered a lot of useful knowledge and practical information which provided guidance into the wide scope of tribology related aspects of wear. The amount of effort, determination and persistence Saeid has to be mentioned and is gratefully appreciated. Thank you, Saeid!

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September *9th* 2019

Preface

The report "Active Contamination Control for High-tech Equipment and Substrates: *Particle Generation*" has been written to fulfil the graduation requirements of the Professional Doctorate in Engineering (PDEng) program in Automotive/Mechatronic Systems Design at the Eindhoven University of Technology (TU/e). The content presented in this report was developed under the direct partnership of VDL Enabling Technologies Group (VDL ETG) and TU/e.

The main aim of this work was to propose a method and tool to experimentally simulate the process in which the contamination particles are being generated. This will provide a deeper level of understanding of the processes in which particle contamination is generated for equipment designers and manufacturers in order to guarantee sufficient cleanliness in the production processes of contamination sensitive equipment.

This report covers the explanation of the process in which contamination particles are being generated, the derivation of fundamental requirements needed to experimentally simulate such a process, introducing commercially available instruments capable of performing desired experiments, performing and analyzing preliminary experiments, and identification of parameters that could directly/indirectly influence the experimental process.

Due to the reviewers time constraint, as requested by VDL ETG, the report is structured in a way to have a short main body and extensive appendices containing all the details. The structure was approved by TU/e supervisor. The interested reader is referred to appendices for comprehensive information.

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Acknowledgements

This project was a challenging experience as well as a journey through self-discovery and both personal and professional growth, for this, I have many to thank. I have not travelled in a vacuum on this journey. This work has been kept on track and been seen through to completion with the support and encouragement of numerous people including my family and friends, supervisors, colleagues and various institutions.

I would like to express my deepest appreciation to all those who provided me with the possibility to complete this project. A special gratitude I give to my supervisors dr.ir. J.P.M. (Johan) Hoefnagels and ir. Kasper van den Broek whose contribution to stimulating suggestions and encouragement, helped me to coordinate my project. My thanks extend to the entire Technology and Development (T&D) Team of VDL ETG, in particular, Luuk Berkelaar and Ton Peijnenburgand for all the collaboration and ultimately creating a friendly environment in which this work grew.

A special thanks go to Prof.dr.ir. Marc Geers, who has provided invaluable insight into this project. I would like to acknowledge the valuable activities of people who spent a lot of time and effort into my experiments including M.P.F.H.L. (Marc) van Maris from the multi-scale lab (TU/e), dr. Ude Hangen from Bruker (Germany) and all the staff of GETec Microscopy GmbH in Vienna.

My sincere thanks also go to dr. Peter S.C. Heuberger who provided me with an opportunity to join the Professional Doctorate in Engineering (PDEng) program in Automotive/Mechatronic Systems Design. I would especially like to thank Ellen van Hoof-Rompen, the management assistant of the program for her never-ending help.

Last but not least, my gratitude goes to my family and friends for their never-ending support in each moment of my life. سپاسگزارم از لطف و محبت شما; Dziękuję wam wszystkim; bedankt iedereen!

M.R.(Saeid) Homayoun
Eindhoven, The Netherlands
September *13th* 2019

Executive Summary

For the past decades, the electronics industry has been driven by what is called "Moore's Law" which states "*The number of transistors incorporated in a chip will approximately double every 2 years* [1]." Transistors are the fundamental unit that powers our electronic gadgets. By simultaneous size reduction of the integrated circuits (IC) and an increasing number of transistors being squeezed on the IC, particle contamination could cause a short circuit. Therefore, in order to ensure high accuracy and productivity in high-tech equipment within the semiconductor, photonics, healthcare and similar industries, strict requirements on the contamination level have been defined.

Contamination is defined as a foreign material at the surface of the material (i.e. silicon wafer) or within the bulk of the material. Contamination control during processing is paramount to obtaining yielding devices in order to make device manufacturing economical. The yield and hence the cost of manufacturing such devices are directly dependent on the density of defects. Defects are generated by the presence of such contamination. The contamination can be particles or ionic contamination, liquid droplet etc. Therefore, particle contamination can directly impact the accuracy and productivity of high-tech equipment by killing a die or by introducing the cost of cleaning. Hence, a deeper level of understanding of the process in which particle contamination is generated is essential for the equipment designers and manufacturers in order to guarantee sufficient cleanliness in the production process of this contamination sensitive equipment.

In theory, the best strategy to control the particle contaminants is to locate the producing origin and to eliminate the releasing source. The main source of particles is wear at the tribo-pairs where two surfaces in relative motion come in contact with each other. This relative motion is the result of the vibration of each counter-part. This tribo-pair is influenced by the contact force, the material and the surface properties, etc. The wear process is a dynamic process and there are many wear mechanisms involved in the process. The wide variety and often contradictory wear mechanisms suggested by many authors are due to the fact that the material removal process in a tribocontact is dependent on operating parameter (such as load, speed, time, temperature, contact geometry), material intrinsic properties (such as toughness, hardness, Young's modulus, thermal expansion coefficient, and specific heat etc.), and microstructure or defects (such as grain size, pores, residual stress, and microcracks etc.). Wear mechanisms may change when some of the parameters are changed.

Along the route which wafer is being carried out, the surfaces are brought into contact by applying a normal load on the lower block and simultaneously the lower block is dragged with respect to the upper block due to vibration which poses an opposing force to the motion of the block. Due to the small contact force and the microscopic surface roughness, the contact occurs at the peaks of the surfaces called asperities. The interactions of the asperities should be studied for a clear understanding of the particle generation mechanisms. Therefore, by performing *in situ* single asperity scratch tests against another asperity/flat surface, the wear process takes place in a controlled environment, allowing the wear mechanism/operating conditions to be isolated and studied independently. Consequently, a single sliding asperity study could potentially help to unravel the mechanism behind the generation of contamination particles. This understanding helps to build single asperity computational model that can be extended to a multi-asperity model which represent the actual contact.

Consequently, different methods of experimentally simulating wear process were proposed and set of requirements were derived to experimentally perform them. This was followed by identification of commercially available instruments capable of performing such experiments. The competency of different instruments was analyzed against derived requirements using a set of tests and one of the instruments was suggested for procurement purposes. In the preliminary experiments conducted, the emphasis was put on checking the capability of instruments along with studying the generated contamination particle in the material removal process (wear) of the silicon. Finally, via preliminary experiments and analysis, initial conclusions were drawn and suggestions were given for the optimization of particle contamination generation process. Further experimental and numerical work is required for obtaining a quantitative method of the optimization of particle contamination generation as wear modelling of this type is in an infant stage and improvements can be made in the direction of fundamental understanding.

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Bibliography

[1] Moore GE. Cramming more components onto integrated circuits 1965.

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