RPTScheduler

RPTScheduler: A Scheduling Algorithm for Semiconductor Reliability Testing Labs

Programm / Ausschreibung	FORPA, Forschungspartnerschaften NATS/Ö-Fonds, InDiss FZOE 2022	**Status**	laufend
Projektstart	01.03.2023	**Projektende**	28.02.2026
Zeitraum	2023 - 2026	**Projektlaufzeit**	36 Monate
Keywords	Scheduling, Partial Rescheduling, Disruptive Events, Mathematical Optimization, Multi-Objective Function, Power Semiconductors, Reliability Testing		

Projektbeschreibung

In der Halbleiterindustrie führen die sogenannten Reliability Product Testing (RPT)-Labore Produktqualifizierungstests, Produktüberwachungstests und Tests zur Technologieentwicklung durch. Für all diese Tests werden Hightech-Geräte und speziell ausgebildetes Personal benötigt. Derzeit wird die komplexe Zuordnung der erforderlichen Tests zu den jeweiligen Geräten und deren Bedienern manuell geplant. Es wird erwartet, dass die Halbleiterindustrie in den nächsten Jahren weiter an Volumen und Vielfalt zunehmen wird, so dass der Ansatz der manuellen Planung kaum in der Lage sein wird, den erhöhten Testaufwand und die Komplexität zu bewältigen, was zu einem hohen Risiko von Engpässen, längeren Leerlaufzeiten und verpassten Terminen führt. Kurz gesagt: Mit dem derzeitigen Planungsansatz kann die effiziente Nutzung der vorhandenen Ressourcen nicht garantiert werden.
Die voraussichtlichen Herausforderungen bei der Ablaufplanung in RPT-Laboren können mit Mathematik und Daten bewältigt werden. Eine Machbarkeitsstudie mit einem reduzierten Datensatz bestätigte, dass eine Variante des Multi-Ressourcen Job Shop Scheduling Problems (MRJSSP), die auf dem makespan als Zielfunktion basiert, ein guter Ausgangspunkt für die Lösung des vorgestellten Problems ist. Der in der Machbarkeitsstudie untersuchte optimale Ablaufplan ist statisch, aber in der Realität muss sich ein Ablaufplan dynamisch an störende Ereignisse in einem Labor anpassen, z. B. begrenzte Ressourcenverfügbarkeit, Maschinenausfälle, Krankheitsausfälle usw.
Im theoretischen Teil dieser Doktorarbeit werden partielle Umplanungsansätze untersucht, die in der Lage sind, mit störenden Ereignissen umzugehen und die Stabilität der Arbeitsabläufe zu gewährleisten. Außerdem werden verschiedene Zielfunktionen und Mehrzielfunktionen erforscht, denn die bekannte Zeitspannenoptimierung für JSSPs reicht nicht aus, da auch Anforderungen wie die Minimierung von Verspätungen oder die Maximierung der Maschinenauslastung berücksichtigt werden müssen.
Der praktische Teil der Doktorarbeit konzentriert sich auf die Anwendung der theoretischen Lösungen und des Know-hows in den RPT-Laboren von Infineon Technologies. Dieser Teil umfasst die Analyse und Vorverarbeitung der realen Labordaten, die Implementierung einer datengesteuerten Planungsroutine, die die Komplexität in den RPT-Laboren abdeckt (der "RPT-Scheduler"), und die Entwicklung eines digitalen Zwillings zur Simulation und Bewertung der Leistung des „RPT-Schedulers“ in Bezug auf verschiedene dynamische Ereignisse und stochastische Störungen.
Durch die Entwicklung einer mathematikbasierten optimalen Planungsroutine für die Ablaufplanung können die RPT-Labore

alle Vorteile der datengesteuerten Planung nutzen. Sie können dynamisch auf störende Ereignisse reagieren, Ressourcen nachhaltig nutzen und so mit der steigenden Nachfrage und Produktvielfalt der Halbleiterindustrie fertig werden.

Abstract

In the semiconductor industry, Reliability Product Testing (RPT) laboratories conduct product qualification tests, product monitoring tests and tests accompanying technology development. All of these tests require high-tech equipment and specially trained operators. Currently, the complex allocation of required tests to the respective equipment and operators is scheduled by domain experts in a manual way. In the next years, the semiconductor industry is expected to continue its growth in volume and diversity and thus, manual scheduling will hardly be capable to deal with the increased testing effort and complexity, leading to a high risk of creating bottlenecks, longer idle times and missed deadlines. In a nutshell, with the current scheduling approach, the efficient use of given resources cannot be guaranteed.

The foreseen scheduling challenges in RPT labs can be tackled with mathematics and data. A feasibility study on a reduced set of data confirmed that a variant of the multi-resource job-shop scheduling problem (MRJSSP) based on the makespan as objective function is a good starting point to solve the presented problem. The optimal schedule investigated in the feasibility study is static, but in reality, a schedule needs to dynamically adapt to disruptive events in a lab, e.g. limited resource availability, machine breakdown, sick leaves, etc.

In the theoretical part of this PhD, partial-rescheduling approaches, which are capable to deal with disruptive events and ensure stability regarding workflows, will be investigated. Additionally, different objective functions and multi-objective functions are researched, because the well-known makespan optimization for JSSPs is not sufficient since requirements like the minimization of job tardiness or the maximization of machine utilization need to be considered as well.

The practical part of the PhD focuses on the application of the theoretical solutions and know-how in the RPT labs from Infineon Technologies. This part includes the analysis and pre-processing of the real lab data, the implementation of a data-driven scheduling routine covering the complexity in the RPT labs (the “RPT Scheduler”) and the development of a digital twin to simulate and evaluate the performance of the RPT scheduler with regard to different dynamic events and stochastic disruptions.

By developing a mathematics-based optimal scheduling routine for the test planning, RPT labs can take advantage of all the benefits of the data-driven planning. They can react dynamically to disruptive events, utilize resources sustainably, and thus cope with the increase in demand and product diversity of the semiconductor industry.

Endberichtkurzfassung

The RPTScheduler project aimed to enhance the operational efficiency of Infineon Technologies’ Reliability and Product Testing (RPT) laboratories by developing and deploying advanced, mathematically grounded scheduling methods. The primary objectives were to increase productivity, improve cycle times and utilization, and promote more sustainable resource usage by minimizing waste and environmental impact.

The project consisted of different work packages, focusing on different development, implementation, and validation steps. It started with the requirements-engineering, the data foundations, and the formal definition of the mathematical scheduling problem. Major efforts focused on method development for exact, heuristic, and hybrid scheduling strategies tailored to lab constraints. While investigating these constraints, a unique subproblem emerged related to the stress machine environment that has not yet been studied in literature. This problem under investigation exposed special elements, distinguishing it from the well-studied p-batching problem. Based on this, a disjunctive graph model was developed and implemented, representing a solution for this complex mathematical problem.

In addition to the method development, a digital twin of the RPT laboratory was developed and implemented to evaluate the scheduling logic under realistic stochastic conditions (like machine breakdowns, arrival of high-priority jobs, etc.), enabling robust benchmarking on a rolling-horizon rescheduling concept. Dedicated triggers were discussed and defined with domain experts to reflect the typical workflow in the laboratory as accurately as possible. With this approach it was possible to simulate the dynamic behavior of the practical environment and to evaluate the scheduling and rescheduling performances in the complex RPT scenario.

The last technical work package focused on the implementation of a prototype of the RPT Scheduler by using an Infineon internal standardized optimization framework. This was performed by connecting it to the manufacturing execution system of the RPT laboratories, establishing an operational data interface and enabling standardized and IT-maintained schedule generations. Unfortunately, data quality and availability remained until the end of the project, preventing the full-feature deployment. The solution was the development of a staged rollout, starting with the so-called Basic Scheduler, alongside a structured data-improvement program, with the ultimate goal of realizing the full RPT Scheduler in all its complexity.

The last work package covered dissemination and exploitation activities on diverse internal and external channels. Through continuous knowledge-sharing and cross-domain working meetings, and by intensified efforts to develop several scientific papers, it was possible to enable substantial contributions to both practical and academic environments. Toward the end of the project, in addition to the prototype, all project-related information was handed over to the parties responsible at the RPT laboratory. This included documentation, runbooks, diverse code libraries, and the detailed rollout plan to finally have the full RPT Scheduler in place.

The RPT Scheduler project successfully combined scientific contribution and practical impact. It addressed a novel scheduling subproblem, completed key method-development milestones, validated performance in a high-fidelity digital environment, and transitioned a full-functional prototype. In the long term, the laboratory can expect higher throughput without new assets, faster and more predictable cycle times, and reduced material and energy waste. The project and its results can therefore be considered a complete success, both in practical and scientific terms.

Projektpartner

- KAI Kompetenzzentrum Automobil- und Industrieelektronik GmbH