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Mechanical assembly instructions for Picosun R-200 PEALD system

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Abstract

This thesis was made for Picosun Oy. Picosun Oy manufactures high quality ALD tools and develops new solutions for the semiconductor industry. The objective of this bachelor's thesis was to make assembly instructions for Picosun R-200 PEALD system. We agreed with Picosun Oy to keep the assembly instructions as confidential.

During this thesis many R-200 PEALD systems were assembled and they served as a basis for writing the assembly instructions. Before writing these instructions, we asked the assemblers for comments on what kind of instructions would benefit them the most. The instructions focus on work phases and how they are easy to understand though an extensive collection of pictures. The assembly was reviewed using lean manufacturing tools to locate any wastes.

Unfortunately, these instructions will only be used in production for a brief period because we have decided to upgrade the plasma source and the lifter. This will require major updating to the instructions, but we already have several tools of this model around the globe and they require maintenance instructions. These instructions will surely help our maintenance crews around the globe. In the future we plan to upgrade these instructions to include the new lifter and plasma source.

Keywords

ALD, ALE, lean, 5S, assembly instructions

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Opinnäytetyön aihe

Kokoonpano-ohje Picosun R-200 PEALD

28 Sivuja
2 Liitteitä

Tilaaja

Picosun Oy

Ohjaaja

Kalle Tarhonen

Tiivistelmä

Opinnäytetyön tilaajana oli Picosun Oy. Picosun Oy valmistaa ALD-laitteita ja kehittää uusia ALD-ratkaisuja puolijohdeteollisuuteen. Työn tarkoitus oli luoda kokoonpano-ohje Picosun R-200 PEALD -laitteelle. Olimme Picosun Oy:n kanssa sopineet että kokoonpano-ohjeet jäävät salaiseksi.

Työn aikana kokoonpantiin useita R-200 PEALD -laitteita, joiden perusteella pystyttiin luomaan hyvät kokoonpano-ohjeet. Ennen ohjeiden kirjoittamista asentajilta tiedusteltiin, minkälainen työohje heille olisi hyödyllisin. Ohje keskittyy työvaiheisiin ja niiden helppoon tulkitsemiseen kattavan kuvamateriaalin kautta. Työssä kartoitimme erilaisia hukkia lean työkaluja käyttämällä.

Ohje ei ehdi olla käytössä tuotannossa kovin pitkää, koska olemme päättäneet päivittää plasmalähdettä ja nostinta. Tämän mallin ALD-laitteita on jo maailmalla useita ja tämä kokoonpano-ohje tulee käyttöön huoltotoimenpiteissä. Tulevaisuudessa on ohjetta tarkoitus päivittää niin, että uusi plasmalähde ja nostin on siihen lisätty.

Avainsanat

ALD, ALE, lean, 5S, kokoonpano-ohjeet

CONTENTS

1 INTRODUCTION

This bachelor’s thesis is made for Picosun Oy. Its purpose is to make clear work instructions for the installation of Picosun R-200 PEALD system. Other goals for the thesis are to unify work methods, increase quality, create training material for new employees and service teams and to review the assembly by using tools from lean manufacturing. The instructions are meant to be easy to read, practical and they should contain lots of pictures to help visualize the assembly. We decided to keep the assembly instructions as confidential because they contain detailed pictures of the tool and Picosun Oy did not want to leak such material. Qualitative research method will be used to gather data. Data will be gathered by interviews and from my own experiences.

Picosun Oy is the leading manufacturer of Atomic Layer Deposition (ALD) reactors and it was founded in 1997. The main headquarters are in Espoo and production is based in Kirkkonummi. Since the beginning growth has been fast and Picosun now has 5 subsidiaries abroad which provide support for customers around the world. (Picosun 2019a.) In the fiscal year of 2018 Picosun had a turnover of 25.96 million euros. (Picosun 2019b.)

2 ALD

2.1 History of atomic layer deposition

ALD began with invention of atomic layer epitaxy (ALE) which was invented for electroluminescent flat panel displays. This was invented in Finland in the 1970s. The other origin of ALD comes from Soviet Union where it was called Molecular layering and it was invented a little bit earlier in the 1960s. Molecular layering inventors were Prof. Aleskovskii and Prof. Koltsov. (Puurunen 2014, 1.)

ALE was invented by Dr. Tuomo Suntola. The idea matured in 1974 when Suntola came up with the idea of introducing elements that complement each other one at a time onto a substrate material. Atomic layers are formed if introduced elements bond with each other. This theory led to testing and to the first ALE reactor in the June of 1974. (Puurunen 2014, 2.)

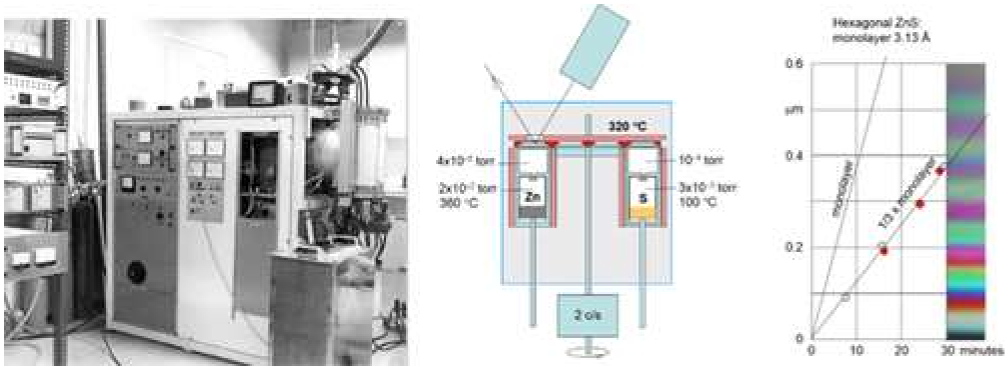

Figure 1 The first ALE reactor. (Suntola's private collection.)

The first test on ALE were made in August-September of 1974. Films were made by using Zn and S under vacuum and in temperature of 320 degrees Celsius. The tests were successful and film growth ZnS film growth was accomplished. Films were analyzed with by x-ray diffraction and by monolayer chart seen to the right side on figure 1. (Puurunen 2014, 4.)

After successfully testing the ALE method Suntola applied for a patent in November 29, 1974. The patent was granted in United states, Japan and more than 20 other countries. Closest reference to the patent came from a German patent from the 50's. It did not however contain the key element of ALE which is the saturation of the surface reactions. In the year 1977 or 1978 Suntola attended a patent hearing in Moscow where he defended his patent with only two local attorneys who were familiar with his work. The hearing focused about the extent of the claims. No prior art was presented at the hearing and the patent was applied as it was. (Puurunen 2014, 4.)

ALE continued to evolve with the change elemental reactants to compound reactants. This led to the use of more volatile reactants such as chlorides and H_2S. The first successful process with $ZnCl_2$ + H_2S was made in a reactor that was made from glass tubes. With the successful test with chlorides the development focused on them and on a new generation of inert gas reactors. (Puurunen 2014, 4.)

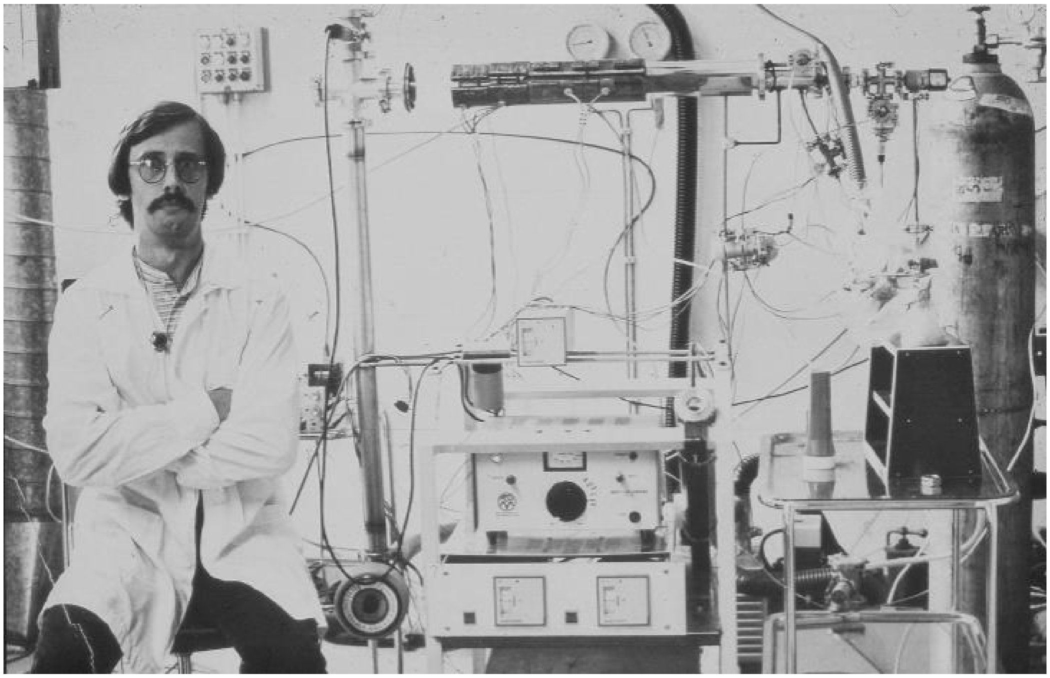

Figure 2 Sven Lindfors next to the Glass ALD reactor which was used to demostrate $ZnCl_2$+H_2S process taken in 1978. (Suntola's private collection.)

The new films produced in new generation inert gas reactor and with $ZnCl_2$ + H_2S =ZnS process had excellent dielectric strength above 4 MV cm^{-1} compared to conventionally produced thin films. The excellent dielectric properties of the film allowed effective excitation of the light emitting ZnS monolayer. Excitation of the monolayer produced a radiant yellow light. This light was later used in electroluminescent flat panel displays. (Puurunen 2014, 5.)

Figure 3 Dr. Ralf Greaffe Next to the pilot production test display module in Helsinki-Vantaa underground cave in 1983. (Suntola's private collection.)

In the year of 1983 pilot production of electroluminescent panels was started and alternative film tests were done. The choice of film that were going to be used was down to 3 candidates Al_2O_3, ATO (aluminum-titanium oxide nano-laminate) and Ta_2O_5. ATO was chosen for the pilot production because of its dielectric properties were the best out of the 3 candidates. Pilot production test panels turned out to be a great success with the test panel running for 15 years continuously without a single character module being replaced. This was the first proof on concept for ALE electroluminescent panels. (Puurunen 2014, 6.)

Figure 4 The first commercial ALD reactor model F-120 (Suntola's private collection.)

In 1987 Tuomo Suntola founded Microchemistry Ltd. as a subsidiary for Neste Oy. Suntola began developing ALE based solar panels for Neste Oy. This work began with an upgrade to the previous reactor because the previous reactor was considered inefficient and too big. Tuomo Suntola and Sven Lindfors designed a new rector model F120 which was smaller and became the first commercial ALD reactor. (Puurunen 2014, 8.)

ALE began to spread around the world in the 90's with the gradual interest for major semiconductor manufacturers and in 1997 Microchemistry Ltd. stopped working on solar panel development and started focusing on ALE business development. There was already interest for ALE reactors, and they were sold to customers in USA, Japan and South Korea. Tuomo Suntola left Microchemistry Ltd. in 1997. Last thing he did there was to rename ALE to ALD because of the controversy on the epitaxy part of the name meaning single growth crystal only. The practical choice was to rename ALE to ALD (Puurunen 2014, 9.)

Now after 40 years Dr. Tuomo Suntola has been awarded with the Millennium Technology Prize for the innovation of ALD. The President of Finland Sauli Niinistö presented the award in Helsinki on 22 May 2018. (Technology academy Finland 2018.)

2.2 Definition of atomic layer deposition

ALD comes from the term atomic layer deposition and it is a thin film deposition technique. Chemical precursors are applied to the substrate material sequentially to form sub-monolayers of film. Chemical reactions happen when chemical precursors are introduced to the substrate material and they form bonds that form monolayers. (Akbarzadeh et al. 2019.)

2.3 Principle of atomic layer deposition

In ALD process chemical precursor are introduced to the substrate in cycles one at a time. Precursors can be divided into 3 different categories liquid, solid and gas. Liquid and solid precursor are vaporized before being introduced to the substrate. For good quality of film growth, the substrate needs to be under vacuum conditions and on the right temperature. When making metal oxide films precursors are usually a metal source and an oxygen source. Film growth happens because of self-saturating reactions with available surface atom groups and the growth is therefore self-limited to available groups on the surface. (Akbarzadeh et al. 2019.)

Figure 5 ALD process with DEZ and H_2O as precursors making ZnO film. (Akbarzadeh et al. 2019.)

ALD cycle process goes as follows:

1. Pulse DEZ into the reactor chamber onto the substrate.
2. Purge excess DEZ from reactor chamber using inert gas.
3. Pulse H_2O into the reactor chamber onto the substrate.
4. Purge excess H_2O from reactor chamber using inert gas.
5. Repeat from step 1 until you have desired film thickness.

General system description R-200 PEALD

R-200 PEALD system is a plasma enhanced ALD tool. The tool is a vacuum chamber where precursors can be introduced to the substrate with precise control. Precursors can be Solid, Gas, liquid or plasma enhanced gases. Tool can run 50-200mm wafers and 3D-objects. Max process temperature can be 450 Celsius and the tool can be fitted with substrate heater that can achieve 650 Celsius temperature. (Picosun 2019a.)

Figure 6 R-200 PEALD System (Picosun 2019a.)

3 LEAN METHODOLOGY

3.1 History and goals of lean manufacturing

Lean methodology began in 1950’s with Taiichi Ohno and Kiichiro Toyoda when they invented Toyota Production System. The Idea came from Ford’s original thinking. This production system helped Toyota to became one of the biggest car manufacturers today and many companies today copy this method of production today. (Lean Enterprise Institute 2019.)

The four most common goals of lean manufacturing are to increase quality, reduce wastes, reduce time and reduce total costs. There are many ways to improve quality and lean thinking can help with that by reducing unnecessary wastes. Better quality products will give the company an edge in the markets. Reducing wastes also gives companies time and money to spend on other things like quality. Reducing wastes also increase overall efficiency of the production by having less waste and disorder in production facilities. Reducing production time reduces total costs allowing companies to stay competitive. (Monroe engineering 2016.)

3.2 Tools of lean Manufacturing

The 3MU

The 3MU is a tool that aims to balance capacity and workload. With the right amount of workers, materials and machines 3MU focus is to balance production with demand. (Chiarini 2013, 18.) 3MU gets its name from Japanese words *muda, mura, and muri* and their definition are as follows:

- Muda = more capacity than workload (real waste)
- Mura = capacity that swings around fixed target
- Muri = more workload than capacity

The 4M

The 4M method is based on the cause and effect diagram invented by Kaoru Ishikawa in the 1950`s. The 4M has divided wastes into four different categories: man, material, machine and method of work. Nature is often used as the fifth M when temperature and humidity are involved. The diagram in (Fig. 7) will explain what kind of wastes the categories can contain. (Chiarini 2013, 18.)

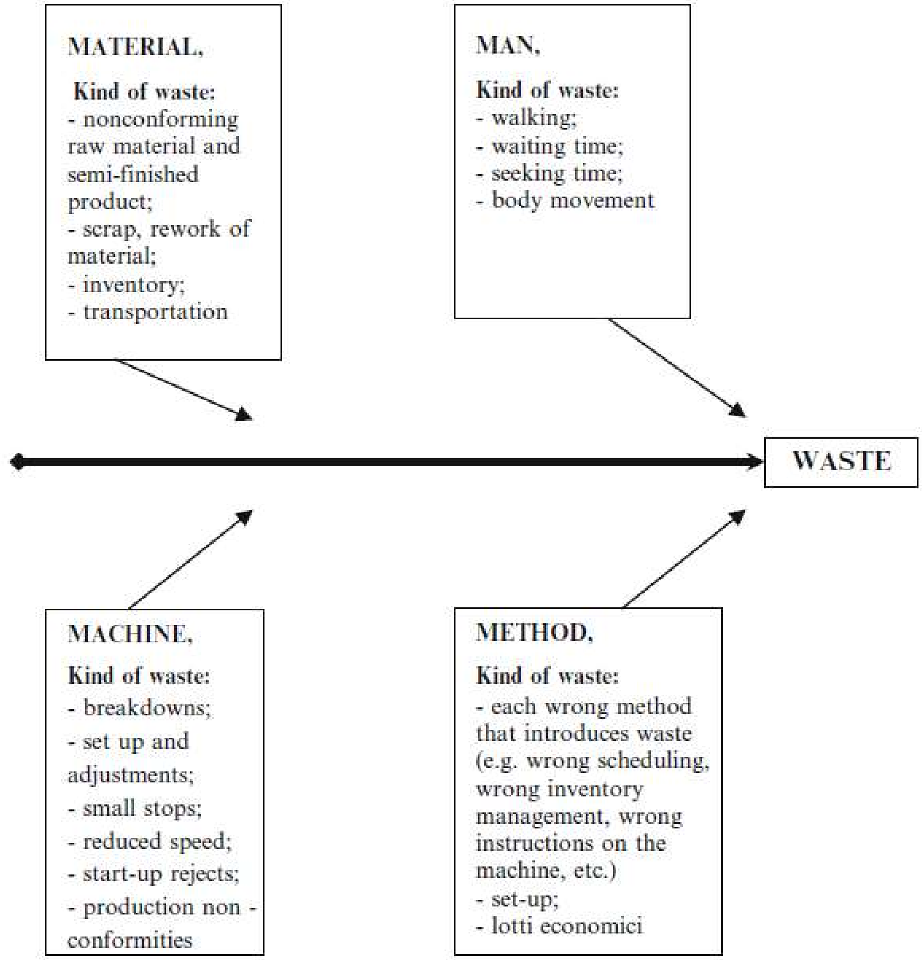

Figure 7 Examples of waste according to 4M (Chiarini 2013.)

The Seven Wastes

The seven wastes method is the most common lean method. It was directly developed by Toyota. This method helps to find core problems in production by analyzing the flow of production. (Chiarini 2013, 19.) The seven types of wastes are:

1. Overproduction

   Overproduction is a big problem in manufacturing. Producing more than the demand can lead to overproduction. This can happen when managers trust that the demand will come. Here are some negative effects of overproduction:

   - Increased stock. Storing too much stock is a waste.
   - Extra inspections.
   - Increased hauling.

- Production flexibility going down.
- Production slowness

Common reasons for overproduction:

- Producing big batches for economic reasons.
- Producing without demand or before.
- Production lines are hard or slow to setup.
- Creating extras to make up for defects.
- Too much manpower
- Machines are producing too fast

Overproduction can be avoided by analyzing production flow and making production estimates. Production estimates can be compared to demand forecasts. Balancing capacity and workload are the key to eliminating overproduction. (Chiarini 2013, 21.)

2. Inventory

Inventory is a common waste in production facilities and is related to overproduction. Inventory wastes can come from having too much raw material, semi-finished products and finished products. Here are some reasons that can lead to having too much inventory:

- Long changeover times.
- Producing big batches of products for economic reasons.
- Producing without demand or before.
- Raw materials are hard to obtain, and they cause bottle necks in production if ran out of stock.
- Production is faster at the begin causing semi-finished products to stack up.

Lean tools to avoid excess inventory are:

- Balancing production activities.
- U-Cells, group technology.
- Quick changeover operations.
- Pull production using Kanban.

Analyzing production flow and measuring stock are common ways to avoid excess inventory. Checklist can be created to company needs to help with this. (Chiarini 2013, 22.)

3. Motion

Unnecessary movement of workers is a waste. Worker might be looking for tools that are not in the vicinity of their workstation. Here are some reason and causes of unnecessary motion:

- Poor layout
- Unskilled workers / lack of training.
- Poor commitment from staff.
- Lack of order and cleanliness.
- Work phase must be done out of work area.

Unnecessary movement of employees can be minimized with:

- U-shaped production line.
- Educate workers / improve skills.
- Increase awareness to the wastes of movement.
- Set order and cleanliness standard with 5S method.
- Review instructions and procedures regularly. (Chiarini 2013, 23.)

4. Defectiveness

When product or service does not pass the quality, requirement set by the customer or the company itself product then becomes a defect. Quality defects add material costs and affect customer happiness. Reasons for quality issues might be:

- Wrong materials.
- Poor working method / lack of instructions.
- Unskilled workers / lack of training.
- Unsuitable equipment or machines.

Quality can be improved by:

- Good quality raw materials.
- Provide instructions / training on critical work phases.
- Raise quality awareness.
- Design system for mistake proofing zero tolerance for defects.
- Pre-emptive quality analysis for production line.
- Inspections. (Chiarini 2013, 24.)

5. Transportation

   Having too much inventory leads to unnecessary hauling within the warehouse. This does not add value to the company and is a waste of time. Hauling semi-finished products to warehouse and not to the next workstation is also a waste. Transportation issues may be caused by:

   - Production area has a bad layout design.
   - Production area is too big. Next workstation is too far.
   - Unskilled workers / poor instructions.

   Redesigning production layout usually helps with unnecessary hauling.

   The following lean tools can help with this:

   - Value stream mapping analysis.
   - Design U-cell production layout.
   - Multiskilled workers / educate workers. (Chiarini 2013, 26.)

6. Over processing

   Over processing is often related to procedures that are unnecessary or not demanded from the customer. These procedures should not be mistaken for activities that are necessary for manufacturing but produce extra products. Reasons for over processing are:

   - Poor process design.
   - Poor activity analysis.
   - Procedures has not been standardized properly.
   - Poor machines, equipment or automation of process.
   - Poor raw materials.

   Over processing can be prevented by:

   - Redesigning production flow.
   - Analyzing production methods.
   - Automation of production line.
   - Reviewing procedures / making instructions.
   - Value analysis on activities. (Chiarini 2013, 27.)

7. Waiting

   Waiting applies to both machines and workers. It is common for employees to wait for a machine to finish its operation this waiting does not bring more value to the product. Worker could be doing some other procedure at the same time as the machine is working. Machine downtimes are linked to waiting, system breakdowns are usually considered inevitable. Main reasons for waiting are:

- Lack of balance on production line.
- Sloppy maintenance protocols.
- Production in big batches.
- Lack order and cleanliness.
- Lack of instructions and training.

Waiting can be prevented by:

- Balancing the production line.
- Redesigning layout.
- Regular maintenance.
- Order and cleanliness 5S.
- Multiskilled workers. (Chiarini 2013, 29.)

3.3 5S-Method

The goal of 5S is to maintain order and cleanliness at work. The name 5S comes from stages that are named in Japanese as*: seiri, seiton, seiso, seiketsu and shitsuke*. This method can increase productivity, quality, safety and security by organizing production areas. This reduces journeys made by employees by having everything organized and available at the workstation. Possible quality mistakes are easier to notice in an organized workspace. (Chiarini 2013, 82.)

Seiri means choosing and separating. This is the first step of 5S and requires employees to separate what is useful and what is not useful in their designated work area. Unnecessary tools and equipment can cause employees to waste time looking for the right tools. Working around a mess can also decrease productivity and cause accidents. The seiri stage frees up space by discarding tools and equipment that no longer useable. (Chiarini 2013, 84.)

Seiton means tidying up the area. The idea of this stage is to designate a place for each object in the workplace. With everything organized it becomes easier to identify shortcomings in each area of production. When everyone knows where every object is placed can every employee participate in maintaining cleanliness. This is Visual control. (Chiarini 2013, 85-86.)

Seiso means cleaning and maintaining. During this stage every area is thoroughly cleaned and first check-ups on the areas are reviewed. Employees review their areas order and cleanliness systems. Check list are good for this purpose to maintain the level of order and cleanliness. Standard to cleanliness and order must be set and responsibilities and methods how to maintain these standards should be described. It is good to raise awareness among the employees to keep their areas up to standard. (Chiarini 2013, 86-87.)

The purpose of Seiketsu stage is to standardize order and cleanliness to the everyday routine. Instructions and procedures need to be written down and defined. Instructions should contain photos, so they are easy to interpret. (Chiarini 2013, 87-88.)

The final stage shitsuke is to maintain the level of order and cleanliness. Maintaining this stage has proven challenging after longer periods of time. Daily routines often are forgotten when there is orders with tight schedule and the employees feel that they do not have time to perform their daily routines. Good method to counteract the decline of order and cleanliness is to make periodic and systematic checks. (Chiarini 2013, 88.)

4 ASSEMBLY INSTRUCTIONS

4.1 Assembly and background for the instructions

To manufacture a product, you have to assemble different components, parts and sub-assemblies together to make a product. Usually products are made from sub-assemblies that are brought together to make a product. (Järvinen et al. 2011, 11.) When a tool is brought to Picosun production assembly takes around 1/3 of the time the tool spends here for factory testing.

Some assembly work cannot be automatized or is not financially wise to automatize, therefore most assemblies are put together manually. Most parts can be manufactured using automation, but usually assembly work has lots of unnecessary work phases or other time and resource consuming procedures. Therefore, making instructions and standardized work methods are important. (Järvinen et al. 2011, 11.)

Assembly is an important work phase because it merges all the information of the product into a finished product. There are a lot of information about different parts and how they can be manufactured so that all the requirements about that part are fulfilled, but information regarding the assembly is usually limited. Problem is that there is no one right way to assembly all the products or the design team forgets the importance of easy assembly. Assembly is the result of the design phase and without carefully planned assembly the product does not work the way we want. (Järvinen et al. 2011, 11.)

When manufacturing assemblies it is good to remember that from good quality part can be made into a non-functioning product and even from bad quality components can be made into a good assembly. This makes defining quality a little more complex than defining quality for a single part. (Järvinen et al. 2011, 12.)

The goal of the assembly instructions is to make assembly easier and speed up the assembly process and to guarantee quality good quality to the manufactured product. Instruction should represent what should be done and to visualize the correct work order. The most important part of the assembly instructions are good pictures, exploded assembly pictures and 3D models that demonstrate what should be done. The best way to make assembly instruction is to work together with the assembly workers this will improve production speed and reduce mistakes and quality defects. (Eerikäinen 2015, 23-24.)

4.2 Review of the assembly using lean tools

Here are some wastes I found during my review of the R-200 PEALD systems assembly. Listed for most important to least:

- Lack of instructions
- Lack of unified work methods
- Incomplete facility connections
- Long delivery times on spare parts
- Lack of order and cleanliness
- Workers loaning tools from the closest tool cart

First, I noticed that lack of order and cleanliness. Disassembled components that are just laying on tables. Workers loaning each other’s tool and not returning them after they are done with them. This causes unnecessary motion in the workstations and mixes components from different projects. To counteract these, we have implemented 5S in production and we are in the sort phase. Workers have been educated to disassemble components into boxes and mark them. Boxes should also be put in their designated project carts and project carts are to be stored in the warehouse area when not used.

Some facility connections are incomplete. Workers were informed that they should make these connections when needed and they were provided with the necessary parts.

Long delivery times on certain important parts may cause delays to the shipping of the tool. Plasma generator and ozone generators have long delivery times. We have established an emergency stock for these items in case we experience a breakdown of these items.

5 DEVELOPMENT OF THE INSTRUCTIONS

5.1 Starting point

Picosun did not have any kind of previous assembly instructions and in production they assembled the tool with the help of a 3D-model. Picosun requested that the instructions that I made were not to be made public and were to remain only to be used by Picosun. The instructions were tailored according to the needs of the production team. There was no need to modify the workstations and every worker in production already has easy access to 3D-models and every work instruction through the internet hard-drive including these instructions that I made. The objective of the instructions was to speed up the assembly process and to unify work methods, so that the quality of Picosun products is the best it can be.

5.2 Production areas

The production team implemented 5S method of order and cleanliness in the production areas. Every workstation and pathway was marked according to 5S. Places for personal tool carts and project carts were designated. This will prevent mixing parts and tools between carts and remove unnecessary motion in the workstations. 5S is still in the second phase the sort and needs to be standardized and maintained. Maintaining 5S will help when looking for certain tools and keep the workspace safe.

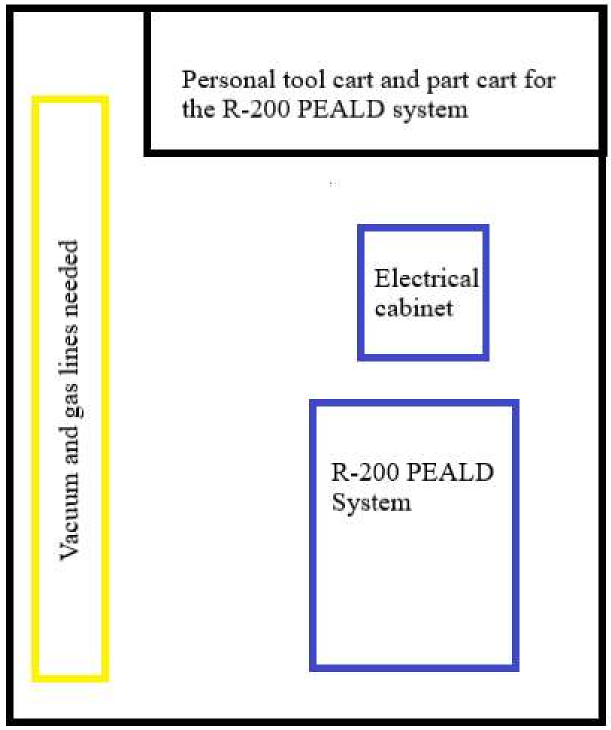

Figure 8 Standard workstation in Picosun production

5.3 Structure of the instructions

Studies have shown that assemblies are easier to be executed in phases, so that the instructions do not show every possible part junction. (Agrawala et al. 2003.) This assembly instruction was divided into ten work phases. Work phases have been set into optimal workorder and each phase contain description of the work phase. Work phases have photos and pictures from 3D-model. The assembly instructions can be viewed in appendix 1.

Example of a work phase: Plasma cone and lid assembly.
<Description of the work phase.>
<Overview picture of all the parts required. Picture also contain simple part numbers 1,2,3,4,5,6.>
<Picture of a sub-assembly. Picture has part numbers to help visualize.>

- Assemble parts 1, 2 and 3 according to picture 2.

- Insert picture 1 sub-assembly into the reactor and attach it to the reactor ceiling.

<Picture of a sub-assembly. Picture has number to help visualize.>

- Assemble parts 4, 5 and 6 according to picture 3.
- Attach reflector plate assembly.
- Check wafer holder orientation.
- Insert picture 3 sub-assembly into the reactor.
- Loosen picture 2 sub-assembly from the ceiling so that picture 2 and picture 3 sub-assemblies touch gently.
- Attach picture 3 sub-assembly to picture 2 sub-assembly with fixing nuts.

<Picture of fixing nuts.>

<Picture of reflector plate assembly.>

<Picture of the complete plasma cone assembly.>

The structure of the instructions are very straight forward with lots of pictures to help with visualize the assembly. Before I started making these, I asked everyone in production to give feedback on what is important to have on these instructions and it was clear that visual material was the most important aspect of the assembly instructions.

6 CONCLUSION

The main goal of my thesis was to create assembly instructions for R-200 PEALD system that were easy to read and use and to review the assembly using lean tools. This was achieved with good figures with assisting texts beside them. The second goal was the gather knowledge from senior employees. Reviewing and commenting were my way of extracting this knowledge for senior employees. Third goal was to unify working method to improve quality over time and to cut unsafe working methods from the production.

Making these instructions gave me a broad understanding how ALD tools work and how we assemble them. We will keep implementing lean manufacturing methods in production with 5S. These instructions are subject to change very soon because we have decided to update the plasma source and lifter. In the future we will update these instructions to include the new plasma source and lifter installation.

Making this thesis gave me a broad understanding of lean philosophy and how to apply it in my workplace. I will continue to push lean methods forward to increase production speeds and make my workplace safer and cleaner.

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Appendix 1

[Confidential]

Appendix 2

LISTS OF FIGURES OR TABLES

Figure 1. Puurunen, Riikka L. 2014. A Short History of Atomic Layer Deposition: Tuomo Suntola's Atomic Layer Epitaxy. WWW document. Available at: http://www.aldcoe.fi/publications/ald_history.pdf [Accessed 17 September 2019].

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Figure 3. Puurunen, Riikka L. 2014. A Short History of Atomic Layer Deposition: Tuomo Suntola's Atomic Layer Epitaxy. WWW document. Available at: http://www.aldcoe.fi/publications/ald_history.pdf [Accessed 17 September 2019].

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