Optics education for machine operators in the semiconductor industry -- moving beyond button pushing

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ABSTRACT

In the competitive semiconductor manufacturing industry, employees who operate equipment are able to make greater contributions if they understand how the equipment works. By understanding the "why" behind the "what," the equipment operators can better partner with other technical staff to produce quality integrated circuits efficiently and effectively. This additional knowledge also opens equipment operators to job enrichment and enlargement opportunities. Advanced Micro Devices (AMD) is in the process of upgrading the skills of its equipment operators. This paper is an overview of a pilot program that employs optics education to upgrade stepper operators' skills. The paper starts with stepper tasks that require optics knowledge, examines teaching methods, reports both end-of-course and three months post-training knowledge retention, and summarizes how the training has impacted the production floor.

Keywords: Semiconductor, stepper, exposure dose, Rayleigh equation, instructional design, equipment operator

2. THE STEPPER

A stepper is critical to AMD's large scale manufacturing of integrated circuits. The stepper gets its name from the step-and-repeat way in which the equipment exposes a silicon wafer. The stepper moves the wafer under the projection lens, exposes one small area in a single flash, and moves to another location. This process repeats until the whole wafer has been exposed. Steppers are made up of a general assembly with seven major subsystems: the projection lens, XY stage, focusing system, reticle handling, illumination, alignment system and wafer handling.

A stepper operator checks the work schedule, selects the wafers and the appropriate reticle, places the reticle and wafers on the stepper, pushes buttons to move the lot through the stepper, and insures that the wafers are logged as having completed "stepping." If a scheduled preventive maintenance procedure is due, or if anything out of the ordinary happens, the operator calls maintenance or engineering. If maintenance or engineering staff are working on another machine or problem, the operator waits and production is halted. Since the stepper is a constraint piece of equipment, halting production at the stepper is a significant problem. This was one reason AMD chose to pilot training on the stepper.

3. NEEDS ASSESSMENT FOR STEPPER-SPECIFIC TRAINING

Subject matter expert (SME) focus groups involving operators, maintenance technicians, engineers, and managers identified specific job enrichment and enlargement opportunities for stepper operators. Frequency, duration, and potential hazard to humans and the stepper were factors in selecting tasks. Stepper operators who learned to perform these tasks knowledgeably and skillfully would be eligible for promotion to Wafer Fab Technician (WFT).

An SME team agreed on the task list and developed learning objectives for each task. Then, they identified the gap between what current stepper operators knew and what they would need to know to perform the WFT tasks repeatedly and independently. One goal of the WFT program is to have the people who run the equipment take on more tasks and understand why each task is done. Table 1 identifies the optics theories needed to understand the "why" behind the "what" for specific stepper tasks. The SMEs then designed written and performance tests that would enable a stepper operator to demonstrate knowledge and skill levels.

Table 1: Stepper Tasks and Optical Concepts

Tasks	Optical Concepts
Daily Focus Test (Operator task)	Focal plane, Rayleigh Equation
Best Focus and Exposure (Operator task)	Integrator block, Collection optics, Condensor lens, Interfermometer, Rayleigh Equation, E = I*T
Lamp Change and Dose Matching (WFT task)	Integrator block, Collection optics, Condensor lens, Inferometer
Mirror Map (WFT task)	Integrator block, Collection optics, Condensor Lens, Interferometer, Overlay and overlay errors

4. CLASS DESIGN AND MATERIAL DEVELOPMENT

The pilot WFT training on the stepper involved thirty hours of group classroom/fab time and twenty hours of initial one-on-one hands-on training. There were eight to ten class meetings, spaced a week apart. At the beginning of each class, participants took a test over the material from the previous class. The SME groups worked with a learning specialist and planned ways to increase the stepper WFT trainees' learning and retention during the group training sessions.

4.1 Participant Materials

The SMEs developed a participant book that provided written and pictorial descriptions of the stepper and associated optical concepts. The equipment vendors gave AMD permission to use portions of the stepper manuals during the training; these pictures and diagrams were very helpful. Where possible, comparisons were used to illustrate optical concepts, e.g., explaining how the technology used by a stepper is similar to a camera, overhead, or camcorder.

The biggest challenge was preparing material at or below the tenth grade reading level. A prerequisite to participating in stepper equipment-specific training is the ability to read and compute at a tenth grade level. The SMEs did not find the stepper manuals helpful in preparing the written material as they were written at seventeenth grade level. The maintenance technicians and operators had an easier time preparing the written material than most of the engineers. An optics consultant worked with two engineers to scale back the reading grade level of their material

4.2 Participant Involvement in the Classroom

At the start of each training session, instructors invited everyone to participate. The instructor materials broke the sessions into ten minute segments. For each segment, the instructor had a list of questions that established participant knowledge level, checked for comprehension, or provided an opportunity for application, analysis, syntheses, or evaluation. Additionally, first time instructors received presentation and facilitation skills training.

The SMEs and the learning specialist incorporated activities and demonstrations into the training. Demonstrations made use of the overhead and stepper parts. The trainees enjoyed examining the lens, mirrors, and other parts not visible from the stepper's exterior. When the class covered the Rayleigh Equation, the instructor distributed calculators and had trainees use the formula to "make adjustments," using data similar to that used in the fab. Participants reported this exercise was very helpful in making a theory more than words on a page.

4.3 Support on the Job

Because of space and production restrictions, most of the hands-on training occurred in the fab with a mentor. First the trainee watched a mentor explain and perform a task. Next, the trainee assisted the mentor in performing the task. When the mentor and the trainee felt the trainee was ready, the trainee would solo. If the trainee did the task perfectly, the mentor would sign the trainee off on the first solo performance. If the trainee did not do the task perfectly, the mentor would coach the trainee, and the trainee would solo later. To be promoted, trainees had to successfully solo at each task twice. Between class sessions, the instructors told the trainees to work on hands-on training that related to that session's topic.

5. PILOTS

Two fabs (factories where integrated circuit manufacturing occurs) offered the pilot stepper equipment-specific course. In total, sixteen WFT trainees participated from the two fabs. The trainees completed their performance checksheets and were promoted to stepper WFTs within two to five months after completing the formal training. The stepper WFT trainees were only allowed to solo on a task when it was due to be performed. On some shifts, because of a delay in the hands-on training and the number of trainees on a shift, it took longer for people to fulfill all the stepper equipment-specific course requirements.

6. EVALUATION

Kirkpatrick's (1960, 1975) name is often associated with measuring behavioral transfer from a training class to the workplace. Kirkpatrick divides evaluation into the four levels indicated in Table 2. For the stepper equipment-specific training, AMD used levels one, two, and three for formative evaluation purposes.

Table 2: Kirkpatrick's Levels of Evaluation

Level	Description
One	Did the participants like the training? Assessed at the end of class through discussion or survey.
Two	Did the participants learn the material? Assessed through a test or application event.
Three	Are the participants applying the training on the job? Assessed some time after training. Often involves participants and their work group.
Four	Return on Investment in Training Rarely assessed because of expense and impact of other, non-training variables.

6.1 Level One Data

AMD uses a standard level one questionnaire for all classes. The questionnaire asks participants to rate several aspects of the course on a scale from 1 (poor) to 5 (excellent). For the question, "What is your overall rating of this course?", both pilot groups gave the stepper course a composite rating of 4.6. The pilots differed in their ratings of the question, "How much has this course increased you ability to do your future job?" One pilot group gave a composite rating of 4.9, and the other ranked it a 4.4. Several comments from the open-ended section of the level one evaluation form addressed the optics training:

- It explained a lot of things, the "hows" and "whys" of the process. The hands-on was very helpful.
- Add more training aids like the old parts.
- I would like to take a course that teaches me more about optics.

6.2 Level Two Data

The course development process facilitated written test content validity. Passing the written test was a prerequisite to starting the hands-on training. Since the tests were first given during the pilot, a test validation process was used. All test questions were some form of multiple choice (standard multiple choice, matching, fill in the blank, or true/false). Questions ranged from simple identification to application. After a test, the instructors and a learning specialist conducted an item analysis. Items that more than 75 % of the test takers got wrong were tossed for grading purposes. Items that 50 - 74% got wrong were examined: How was this material covered in class? Is there anything unclear about the test item wording? How clearly does the participant book explain this? After analyzing the test item, the instructors and learning specialist made a judgment call. Then, test scores were averaged. The cut off scare was the number two standard deviations below the mean or 80%, whichever was lower.

After grading the tests, the instructors returned them to the trainees and reviewed the test items to make sure everyone understood the material. Individuals who did not pass made arrangements with the instructors for re-tests and for additional tutoring if needed. Three people needed to retake some of the knowledge tests. Trainees could retake up to two of the seven knowledge tests. If a trainee failed a test, the trainee had to pass the re-test on the first re-test attempt. Any trainee who failed a re-test or who failed three first attempts at knowledge tests would have been withdrawn from the class. No one withdrew from the stepper equipment-specific pilots.

The performance tests occurred in the fab when both the procedure was due and the trainee was ready to solo. The mentor was the maintenance technician or the engineer who would be giving up the specific task to the stepper WFT. The mentors broke each task down into discrete steps. As the trainee performed each step, the mentor would ask the trainee questions to verify that the trainee understood the finer points of the task. When the trainee performed the task perfectly two times and the mentor was sure the trainee was competent, the mentor would sign the trainee off on the task. The task then became the trainee's responsibility. When the trainee was signed off on all the stepper WFT tasks, the trainee became eligible for the promotion to stepper WFT.

6.3 Level Three Data

Three months after the stepper operators completed training, individual interviews were conducted with those promoted to stepper WFTs, their maintenance technicians and engineering mentors, and their shift managers.

6.31 WFT Responses

Fourteen of the original sixteen stepper WFT trainees were still performing the stepper WFT job. Two of the original trainees had been promoted to maintenance technician positions. An interviewing aid was used to gather specific data from the stepper WFTs about optical concepts. During the interview, the interviewer asked the stepper WFT to review Figure 1. The interviewer probed for specific examples of application.

Figure 1: Follow-up Interviewing Aid

OPTICAL CONCEPTS

Review the following optical concepts.
Have any helped you perform you job as a stepper WFT?
If so, which ones have been helpful -- and how?

Focal Plane and What Affects It

Purpose/function of :

Integrator block	Collection optics
Condensor lens	Interferometer

E = I * T

Rayleigh Equation Factors

Resolution	Depth of focus
Wavelength of Exposure Light	Numerical aperture

Overlay and overlay errors

Table 3 reports the stepper WFT responses to the optical concepts portion of the follow-up interview. Responses fell into five broad categories: know and use the concept, know but do not use the concept, knew the concept before training, do not understand the concept, and no clear response about the concept was available from the interview data.

Table 3: Follow-up Stepper WFT Self-reports on Knowledge and Application of Optical Concepts

	A. Focal Plane	B. Integrator Block Collection Optics Condensor Lens Interferometer	C. E = I * T	D. Rayleigh Equation	E. Overlay and Overlay Errors
Know & use	1	0	7	8	8
Know but do not use	2	8	1	0	0
Knew before training	2	0	0	0	0
Do not understand	1	0	0	2	0
No clear response	8	5	6	4	6

Some of the responses that fell into the "Know but do not use" category were enlightening. Two responses to column B indicated:

- These are all just a part of the machine. Reps or maintenance use, not really me, particularly not hands-on. . . If they were down I wouldn't be able to work on it, but I would know why the stepper was down.
- This whole part we don't use. It is, however, helpful. For example, yesterday we ran a test wafer for a lot and found that the focus field was bad at the center, which has to do with these four items. I cannot adjust them; I can just report them. so at least I know what he is talking about.

Three others expressed appreciation for an explanation of exposure dose (column C).

- The exposure dose has been a big help because when we do OAI -- that's something else we do -- you have to know the exposure, the intensity and the time.
- It is good to understand exactly what we were adjusting. Before the class I thought we were adjusting the lamp intensity and what we were really adjusting is the shutter time. And that is something that is done on a weekly basis on some of the steppers. They went over that pretty well in class.
- I'm better versed in what exposure is. I know how to set exposure now. I know there's a formula. Now I know I am responsible for setting the exposure and doing it right. The value is already there in FoxPro and we just have to take it and set the correct value in the machine.

Responses to column D ranged from confessions of forgetting to insight.

- I don't even remember what I learned about the Rayleigh factors.
- This stuff is valuable in doing a PM or running a stepper. It explains the concepts of what the machine does. It's like if you know what goes on in an internal combustion machine, you will be able to work with it better. It's the same thing with the Rayleigh Equation factors.

Some stepper WFTs reported not thinking about optical concepts as they performed their duties:

- When you are taking the class, it seems interesting, but as far as what we do, it doesn't really have a whole lot to do with it.
- I don't use these (optical concepts) in my everyday job.
- It is my opinion that you could do the WFT stepper tasks without knowing this stuff. However, if we have a problem -- something unexpected pops up -- you would need to know this stuff before you could even attempt to identify what is causing it.

In general terms, the interview data indicates that just over half of the stepper WFTs think about optical concepts as they perform their duties.

6.32 Maintenance Technician, Engineer, and Manager Responses

From a performance perspective, this group reports great satisfaction with the stepper WFT equipment-specific training. In each work group the stepper WFTs now perform the lamp changes and mirror map tasks. One work group, anticipating the training, had begun training its stepper operators to do the lamp changes before the actual training. Maintenance technicians, engineers and managers from each of the six work groups who had stepper WFTs in the pilot classes were interviewed. Below are some of the comments collected from the fifteen interviews.

6.321 Stepper WFT Mistakes

When asked about mistakes the stepper WFTs made during their first three months on the job, the maintenance technicians, engineers, and managers were surprised at how few mistakes had been made. Follwoing are the comments made about stepper WFT mistakes.

- A few issues, some problems with lamps that weren't really normal. Once they install the lamp they have to tune it and there were some mistakes on the tuning. And we had some lamps melt. After the first few weeks that went away. (Engineer)
- It was not really a stepper WFT problem, but a problem with the software upgrade (for mirror map), even though the timing is concurrent with their training. (Engineer)
- Some mistakes have been made, which are to be expected. As far as setting something up correctly during PMs -- aperture blades and dose settings and a couple of machines returned to production out of spec. This was three months ago. No lots were scraped, no real jeopardy beyond having to rework some lots. As soon as we saw the problems, we got with the people and corrected them as kindly as we could. But the mistakes are not to the magnitude that I thought it would be originally when the stepper WFT concept came up.. . . In one case Engineering put in some aperture blade offsets that didn't belong there. That is something that may or may not have been caught if maintenance had done the task versus the WFT. This caused 6 - 8 lots to be reworked. (Maintenance Technician)
- The stepper PMs were signed off as completed when they actually failed. This happened at least 3 times. I re-emphasized the procedure about 60 days ago and the problem has gone away. Truthfully, maintenance Technicians haven't been following procedures either. So it was being negatively reinforced. The stepper WFTs have just highlighted problems that were already in existence. (Manager)
- There is a logistics type of problem. A stepper WFT did a PM and the lamp only had ten hours left. He should of changed it, but he didn't. so they had to put it back down after one lot. The stepper WFT on my shift follows the textbook. If the situation is any different he can't think through it. (Manager)

6.322 Stepper WFT Successes

Several success themes emerged from the interviews: solving problems, teaching others, and taking on special projects or extra responsibilities. The following comments include data from each of the workgroups.

- They don't ask nearly as many questions as they did when they were operators. If their weekly tests go well and don't run into unforeseen problems, they don't have to ask for help at all which is a real bonus. (Engineer)
- The WFTs do all of them (lamp changes and mirror maps). The maintenance technician will get involved if it's a really difficult fail on the mirror map. (Maintenance Technician)
- There are ten steppers. The WFTs are responsible for the lamp changes, mirror maps, system cleans, and Pms. If they have any problems they can't cope with, then they write it down to us. (Maintenance Technician)
- Some of the stepper WFTs are doing troubleshooting on their own -- trying to fix things on their own before asking for help which is really good. (Engineer)
- They are better educated about why they make certain adjustments. Before we would say turn the knob but only that far. They didn't know why they only turned it that far. Now they know why and so are better able to troubleshoot. (Engineer)
- The stepper WFTs have a better understanding of the machine which lets them locate problems and fix them. They can also better describe problems that they cannot fix. It's more than the old "It's just broke." (Maintenance Technician)

- The WFTs have learned new skills, but as they have learned new skills, they're teaching the others and pulling the stepper operators in as well. (Manager)
- I do ask them to do a dose check which they weren't able to do as operators. (Engineer)
- Yesterday a WFT did several focus matrixes for us. Prior to having WFTs this would have been done by engineering. (Engineer)
- Our stepper WFT is real good. He can communicate with maintenance and the Vendor Rep also. How is that related to the WFT training? Because he knows about the equipment. If the Vendor Rep asks him what type of problem is occurring, the WFT can answer. This saves time. (Maintenance Technician)
- I dump a bunch of work on him and tell him it is because he is a WFT. I get away with this.. . . He is learning more and more and getting more and more involved. (Engineer)
- He also works with the engineers on the target dose project. They outline what they want done and he goes and does it for them. He is taking on some of the engineering role. (Manager)

7. DISCUSSION

AMD used Kirkpatrick's level one, two and three data for formative evaluation purposes. Clearly the level one data indicated that at the end of the course, the participants had positive regard for their educational experience. Level two data indicated that at the point of the written or hands on testing, that each stepper WFT trainee could demonstrate the appropriate knowledge or skill level. The level three follow up data from the stepper WFTs was less optimistic. Three months after being promoted, only half the stepper WFTs had retained their knowledge of the "why" behind the "what." At the same time, the level three data from the managers, engineers, and maintenance was overwhelmingly positive -- perhaps because they had feared many more failures during the stepper WFTs' learning curve. The success comments singled out some of the stepper WFTs who were effectively using their optics knowledge on the job.

The SMEs and a learning specialist identified four action items to increase optics knowledge among future and current stepper WFT trainees:

1. In the classroom, develop additional strategies to stress the connection between the stepper WFT tasks and optical concepts.

2. In the fab, strengthen the connection between the optical concepts and hands-on training.
   Ensure that each fab mentor has a copy of the participant book.
   Develop a questioning aid for the mentors to use during the hands on performance tests.

3. At the end of the course, give a final test to check that the trainees are retaining the knowledge.

4. Continually, recognize current stepper WFTs who are applying their optics knowledge and therefore making greater contributions on the job.

8. ACKNOWLEDGMENTS

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