CEWG Super Critical CO2 Compilation of Previous Discussions

Assembled by Mark Bennett, Facilitator 1-29-14

The following information was compiled from these sources, available on the CEWG web site:
- Meeting summaries--7/20/05, 8/17/05, 9/21/05 (missing from web site, scanned from hard copy), 10/27/05, 11/14/05 (missing from web site, scanned from hard copy), 2/21/07,
- 2004-2006 Short Report to the Community

2/21/07 Meeting Summary

Super Critical CO2

Frank Gallegos provided a brief status of the supercritical CO2 technology.

- While Intel is continuing to evaluate the technology, it will not be included in the next node. The technology is not ready for high volume manufacturing.
- Tool suppliers are slowing down the development of tools, but the reason is unknown.
- Universities are continuing to do research in the area.

2006 Short Report to the Community

9. **Task Force Recommendation:** *Intel should reaffirm their commitment to actively look into conversion to the new clean process (Super Critical CO2) as soon as possible, as a promise to the community to reduce both their emissions and their use of water.*

To better understand the state of the SCCO2 technology, the Working Group hosted an expert panel discussion in October 2005. Approximately 50 residents, working group members and Intel staff attended the meeting. Panelists were:

Craig Taylor, Los Alamos National Laboratory

Richard Reidy, University of North Texas

Gunilla Jacobson, Stanford University According to the three national experts, supercritical CO2, a new technology which may reduce water and chemical use, is not ready to use in the computer chip industry. Key problems the experts cited were:

unavailability of tools to manufacture chips using the new technology

questions of chemical compatibility with other processes

higher costs than current cleaning methods, a little more or perhaps

three times more All the experts believed the problems can be solved and the

technology could be used when chip makers retool to make wafers described as "32-nanometer" in the future. Intel continues to fund and participate in the development of the SCCO2 and other technologies which will reduce water and chemical use during the manufacturing process.

From the 11/14/05 Meeting Summary

See .pdf files

From the 10/27/05 Meeting Summary

WELCOME

John Bartlit, CEWG Acting Chair, welcomed attendees and explained that the meeting would serve as both a regular meeting of the working group and a special informational meeting on supercritical carbon dioxide (SCCO2). He noted that the working group uses an experimental approach in which the group seeks to make continuous environmental improvements. Membership is open to anyone who wants to help accomplish this mission.

Theresa Gunn asked the working group members to introduce themselves. She reviewed rules for a good meeting and the meeting agenda, explaining that the purpose of the meeting is to provide the audience with an understanding of SCCO2 and Intel's position on the new technology.

Bartlit noted that the working group provided questions to the panelists in order to understand all aspects of the technology. He previously invited a tool manufacturer to participate on the panel, however, that representative stated there aren't any manufacturer's currently developing tools for this process. He encouraged the audience to judge all aspects of the information presented and the working group itself.

SUPERCRITICAL CO2 PANELISTS OPENING REMARKS

Panelists provided information on the background and potential of SCCO2, including the current state of the industry.

Craig Taylor, Technical Staff Member supercritical Fluids Team, Los Alamos National Laboratory

There is a technical challenge in getting water or solvent into the very small areas of a wafer to clean it.

Supercritical is the phase beyond the boiling point (critical point).

A supercritical fluid does not have surface tension, therefore it can reach these tiny

areas.

SCCO2 removes particles and residues.

It avoids the water washing and alcohol drying processes.

SCCO2 uses chemicals that are less hazardous, and smaller amounts of chemicals in general. With the elimination of the use of many solvents, comes the elimination of solvent disposal as well.

This technology is earning awards and accolades.

Industry likes this technology, but it is not mature enough to be the method of choice for the next retooling to meet the upcoming 65 nanometer technology node.

Richard Reidy, Associate Professor, Material Science and Engineering Department, University of North Texas

There are large capital expenses associated with a shift to SCCO2.

It is unclear whether SCCO2 offers an improvement over the baseline methods currently used. There are contamination issues with the technology that have not yet been resolved.

In a chip, wire is covered by an insulating material. The use of porous materials as an insulator creates better insulation, but causes challenges due to its porous nature.

SCCO2 creates less damage in the removal of the photo resist layer than traditional use of plasma technology. The technology is an aid in keeping metal out of the insulating pores.

In the long term, there are befits of SCCO2 over the baseline process. For example, using SCCO2 for photo resist removal results in no ash damage.

Gunilla Jacobson, Research Associate, Stanford University

Supercritical fluids are used now for extraction in other industries, such as caffeine extraction, dry cleaning, and pharmaceuticals.

The technology is currently too expensive.

SCCO2 is not enabling for those who manufacture the tools that would utilize the technology.

It is difficult to introduce a new pressure-reliant technology on a factory-wide basis.

There are 15 chip manufacturers testing this technology.

The initial target for the use of SCCO2 was the 65 nanometer technology node (retooling began in 2005 and will be complete in 2007). The SCCO2 technology was not required to address this node. I think this is referring to the technology not being needed to address cleaning needs for this node as traditional methods were successful.

It is possible the 32nm node (retooling to begin in 2009, with use in fab by 2013) will make use of SCCO2. However, it is more likely that it is the 22nm node (retooling to begin in 2011, with use in fab by 2016) that will make use of SCCO2.

In addition to the hardware needed to use this technology, the chemistry must also be compatible with the equipment.

Engineers have to create equipment that works in current fab work spaces.

The current wet-clean process costs about $1/wafer. SCCO2 costs $3.50/wafer.

Increased through-put can reduce this cost per wafer for SCCO2.

Other solutions include the ability to purchase a less expensive tool and chemical compatibility. Chemical suppliers are now gaining expertise in this area. Several groups are working on building these tools.

SCCO2 must not just clean, but eliminate particles.

Chip manufacturer consortia will need to push this technology along, and work with chemical suppliers to solve problems such as cost of ownership.

Working Group Questions and Comments:

Why would chemical suppliers want to sell less chemicals? **Response:** The semiconductor industry will create a market by asking for chemicals associated with the use of SCCO2.

Isn't the cost differential resolved by economy of scale? **Response**: First, the technology has to be enabling. Then, there needs to be a lower cost in order to consider the retooling necessary to implement the technology.

Does the $1 cost include disposal? **Response**: Yes, as does the $3.50 cost. However, much research remains in the chemical area.

In that we have a mature technology competing with an immature SCCO2 technology, is there a danger that other countries will bury the U.S. by jumping into the new technology? **Response**: It is unlikely that others would be able to jump into the new tools necessary to utilize the technology. The semiconductor industry is the end user. However, end users are making demands for tools. Additionally, Intel belongs to the international consortium.

What about the chemistry associated with SCCO2? **Response**: SCCO2 chemistry is much less toxic than current technology. It avoids the water interaction, but needs careful disposal too. Chemical suppliers are attempting to use chemistries that are already considered "green."

Public Questions:

What effect would this have on the public? Is there a monitoring system? Is this a perfectly safe process? **Response**: Eliminating the rinse step reduces the use of water and energy. Isopropyl alcohol (IPA) is the main volatile organic chemical that would be eliminated from the process by eliminating the need for the drying process. The public is in turn reduced from exposure at the front end of the process. However, probably not all of the chemicals used in a SCCO2 process could be considered "perfectly safe." **Response**: John Bartlit noted that the working group strives to achieve continuous improvement.

What is the pressure that would be used? **Response**: The process requires 1,000-5,000 psi. This is a concern; however, it is being used in the decaffeination of coffee. A fab is accustomed to using a vacuum system, which is a completely different technology.

What would be the impact on water use? **Response**: We don't have the figures, but it would be accurate to say there would be a significant reduction, because the process would eliminate the rinsing step where it is used.

Are there any ethical or moral guidelines regarding retooling in the industry? There are values beyond the dollar amount. **Response:** The awards this technology has received shows some recognition of the inherent value. The decreased use of chemistry reduces exposure to the number of molecules and saves resources.

With respect to the costs involved, are there any patents held that would equate to the situation in the drug industry when a generic equivalent becomes available, and the price goes down? **Response**: There are many patents; however, none are preventing the cost from decreasing. There are no tools available yet to be sold to semiconductor plants.

What does enabling mean? **Response**: Enabling technology means it has to work better, or be a better process.

It sounds as if there has been a missed opportunity. **Response**: SCCO2 was introduced in 1999 as a method for cleaning weapons (is this right? I don't remember this). We expect the technology to ramp up soon to be ready for the 2010 timeframe. The international semiconductor community believed it would be needed for use at the 65 nm node, but this was not the case. Because the quality of the insulators wasn't at issue for this node, the industry was able to get by without insulator improvement at the 65 nm node.

Working Group Questions and Comments:

I can see that a new technology creates serious challenges inside a fab***.***

SCCO2 will not be used alone. What waste or other contaminant abatement and monitoring will be used? **Response**: The chemicals that would be added are easier to collect and separate out. CO2 does eventually enter the atmosphere, and there is a small percentage of impurity included. *Chemicals used in this process would decrease anywhere from 20-100 percent. This sentence doesn't make sense and I can't find it in my notes. I think it refers to the amount of co-solvents that might be needed were 20-100% less than the amount of chemicals currently used in these cleaning steps.*

What about the safety in using this type of pressure in a fab? **Response**: Because smaller tools are used, they require less energy. The overall pressure is high, but in small volumes at the tool, this allows for safety.

Public Questions:

Will SCCO2 do what Intel needs it to do? **Response**: Yes, this is why industry is embracing SCCO2 for the next technology node.

Are there any tax incentives figured into the cost per chip figures? **Response**: No.

It is laughable that the technology exists, but is not being used because a hypothetical window has closed. This community is suffering from water use and pollution, and deserves the absolute best technology available. **Response**: The tool needed to utilize the technology can't be purchased today.

It seems that if industry demanded it, someone would make a tool. **Response**: Every chip manufacturer asks for and tests alpha and beta tools. The industry needs more time.

INTEL'S POSITION ON SCCO2 Ken David, Director of Components Research Group for Intel Corp., reviewed Intel's background and position on SCCO2. Presentation highlights included:

Our research group has about 150 people who work in applied research. We work with others who do the fundamental research to determine if a technology is ready for

process development. We collaborate with vendors and commercial suppliers

We see potential in SCCO2.

We spent 1 1⁄2 years in research to develop a single application using SCCO2. This process must be customized for various film layers. As the materials technology changes, so must the chemistry and specific recipes that are required.

Areas that must be worked on in order to use SCCO2 include:

o We must get equivalent results when using SCCO2 compared to current technology.

o Hardware will need to be further developed. We can't allow metal contamination. o There are currently material incompatibilities. The interaction between the seal

on the pressure tools and the chemistry must be resolved. o The industry is learning and the technology is still immature.

We continue to review technical advances and encourage suppliers to focus on technological roadblocks.

Intel has hosted an alpha tool, but found many deficiencies.

At this time, SCCO2 offers no performance advantages and has been unable to meet chip contamination specifications.

There is a global assessment of equipment underway, as well as work with chemical manufacturers regarding capabilities and readiness.

We are working on an internal strategy about how to implement this process at Intel, as well as on an industry-wide focus on implementing SCCO2.

Of the five suppliers we have worked with who would produce tools, all five have reached roadblocks and have put these projects on hold or stopped work.

The tools needed to retool a fab represent $100-200 million in capital investment.

Intel doesn't build tools. The tool builders represent the cutting edge research.

The industry wants this technology because it cleans fragile, lowK ILD (this is the same as the porous insulator – I know Ken used this term but it may be good to show they are talking about the same thing), and is a great advancement over the wet-clean process we use now.

There is not currently an emerging market.

No single customer can change the direction of industry. Intel only represents about 10-

15 percent of that market.

We believe SCCO2 has an advantage over traditional processes and continue to research and look for opportunities to use this technology.

Working Group Questions and Comments:

How do you balance cost versus the environment? **Response**: We are still trying to assess whether the technology will work. The price doesn't affect our ability to continue research.

If all of the technical issues were resolved and the costs were equivalent, what method would be the method for determining environmental benefit? **Response**: There is a separate effort at Intel to forward environmental benefits. Environmental engineers set goals as to how to implement environmental benefits. The ITRS (International Technology Roadmap for Semiconductors) offers information and procedures on environmental safety and health issues under sematech.org, by selecting the ITRS roadmap link. This section can give people an idea of what the process looks like.

The CEWG is working to get the Intel mission statement to include some of these concepts.

Public Questions:

Are there any Chinese companies producing a product competitive with Intel's product?

It seems this is an issue of limits of the technology node, versus the community in limiting the use of water and preventing illness. How do you make these two areas compatible? **Response**: We are also looking at other ways to save water and energy in other tools and continually look for viable options. Craig Taylor also noted that these types of meetings are useful in pushing companies along regarding issues.

What will be the result in emissions in refitting Fab 11? **Response**: There will be the same improvements as those seen in Fab 11x. Less water and energy will be used per chip, and there will be some reductions of chemicals used.

I have noticed the water level in my well has gone down and I need a new well. What about reinjecting water? The area does not have the infrastructure for reinjection.

When do the environmental supercede other issues? **Response**: We appreciate that the community keeps pushing us. However, SCCO2 is not ready. We have a responsibility to continue working on a variety of methods. We reinject water in other communities because this is the preference in these communities; in this community, the preference is to reinject water into the river.

Working Group Questions and Comments: As a result of CEWG efforts, Intel has added $6.7

million upgrades to scrubbers and thermal oxidizers, made equipment changes that resulted in 10-fold reduction in the emission of methanol and implemented a quicker maintenance procedure.

Public Questions:

Aren't you increasing water use by increasing the processes? I hope Intel waste water is not going to be reinjected into the aquifer. **Response**: The next meeting of the CEWG, which will be held November 14(not too sure if we said we would address water in Nov.), will be to address water issues, including cooling towers. We encourage you to attend the next meeting to work on solutions to these issues.

I don't like the idea of having to push Intel. **Response**: This method does work, and Intel has responded to community concerns.

How involved are you in a decision about whether a chemical is used? **Response**: We evaluate any chemical before it comes to an Intel site and review the safe and correct use of any chemical.

Does this include how emissions come out of the stack? **Response**: We monitor equipment and model effects.

How does thermal inversion affect this site? **Response**: The New Mexico site has distributed a risk assessment which is available to the public. Dispersion work is done at the site, with additional efforts occurring with corporate development.

Is there an example of a recommendation accepted regarding not using a chemical? **Response**: Glycol ether used to be used; however, this is no longer the case.

Working Group Questions and Comments:

SCCO2 needs to mature. The status quo may be okay for Intel, but it is not beneficial to the community. The working group continues to meet and we encourage you to attend and participate. We have had three specific improvements come out of this group, and we encourage you to join us to find additional solutions. **Response**: (Craig Taylor): I disagree that wet processing will continue for 10 years. SCCO2 is a baby, but the technology is not 10 years out. Companies are not yet comfortable with the technology, but it is not a dead technology.

Public Questions:

When a smaller node is introduced will it require a new technology? **Response**: I believe so, whether it is SCCO2 or some other technology.

What will Intel do if vendors back off this process? **Response**: In the semiconductor industry, you can never be sure what technology is right around the corner. There may

be other, better alternatives available.

When we as a community push, Intel pushes back. They are resistant to monitoring air, for example. I think they should change to this process regardless. **Response**: The technology is not yet ready. Intel has not given up on SCCO2 and is continuing to work on this and other options. Funding for this research continues internally, through suppliers, and in academia.

WRITTEN COMMENTS *(verbatim from cards submitted by participants) Should these be answered here, even though they were not read and answered in the meeting?*

Specifically, which CO-solvents? Are they being tested by the same standards as medicines?

Are there any ethical or moral guidelines for the industry? Which commissions?

Why is push more being done to inject the water back into wells or use it more times and pull up less from ground?

The quoted cost per chip – $1.00 vs. $3.50 – does the former include costs of chemical disposal issues?

From the 9/21/05 Meeting Summary

See .pdf files

From the 8/17/05 Meeting Summary

UPDATE SUPER CRITICAL CO2 MEETING The Working Group discussed plans for a special working group meeting to discuss Super Critical CO2. After discussion, the group agreed to the following:

Panel format: Theresa Gunn will moderate

Is it possible to record or videotape the session?

Questions to be discussed: What is the information and how is it used? What is Intel's position and future plans? What is state of art? What does it cost?

Intel's Role: Speak after the panel discussion. Have someone available who can answer the

community's questions.

Time of meeting: 7:30-9:30 pm.

7/20/05 Meeting Summary No substantive information. Brief planning comments about the logistics