Quentin McGaw *march 2013*
EE1

Professional Report:
Topic 2, on the "Micron 20nm MLC NAND flash 128Gb memory chip"

The following report answers your recent request about selling our "20nm MLC NAND flash 128Gb memory chip" as a green product. This one is now manufactured in large quantities by IM flash technologies for our company since May 2011, and adding to it the green label can only be beneficial to Micron. It would improve the marketing of the product, and this one would then replace all of the non-green competitive products. In order to verify and demonstrate our product is really 'green', it has to undergo the life cycle assessment. Described by the ISO 14040 since 2006, the life cycle assessment analyses the influences on the ecosystem, the human health and the use of resources of the product "from cradle to grave". It means from the product design and innovation, through the raw materials production and transportation, the product manufacture, its marketing, sales, procurement and use period, and until its disposal. This report first exposes what would a life cycle assessment bring to our company. The present advantages of our product in relation to the life cycle assessment will then be clarified. It then presents the relatively small issues with their solutions. The main issues to solve will then be explained and some solutions with a discussion for each one will follow.

The life cycle assessment that our product would undergo would actually give clear real facts about our product. It means no label and only consistent and transparent information from the life cycle of the product. We would then have some reasons to say our product is green, and our marketing department could focus on communicating the important environmental claims to our subcontractors. This transparency given by the life cycle

assessment could thus be really advantageous to make the promotion of our chip, but some issues have to be solved in order to obtain a positive result overall.

The memory our company designed and now sells and produces indirectly has some real advantages in comparison with traditional hard disk drives storage devices. Its reading and writing speed are three to five times faster, and it consumes four times less than a hard disk drive of the same capacity. In addition, its small size and the absence of moving mechanical parts make it the ideal storage for mobile devices such as tablets and smartphones. All of these use-period facts show an environmental potential. However, they are only a part of the situation, and don’t make a real difference with the other concurrent NAND flash memories produced from Intel or Samsung for example. In fact, the life cycle assessment makes an inventory of all the resources used and substances emitted during the total life of our product. The two following paragraphs describe the minor problems influencing slightly the eventual life cycle assessment of our product.

First of all, the end of life of the product can reasonably be assumed to occur because of the obsolescence of the device using it. The lifetime of our product is also limited by the maximum writing cycle number which is around 30,000 cycles for our MLC (Multi-layer cell) memory chip. This limitation is although high enough to make our product usable for tens of years in mobile devices applications. This means our product will overall still be functional when the device using it will be obsolescent, estimated in a maximum of five years. In order to improve the end of life of our product, this last one could be erased or reset and re-sold in a different domain requiring less performance, considering new technologies will appear. A specific recycling process could be settled to recycle our products in this way.

The other relatively small issues are the transportation and the use period of our product, but those ones already consume a

far reasonable quantity of energy and will not affect drastically the life cycle assessment's results. The global warming potential, also called "GWP", is an indicator measured in kilogram of carbon dioxide equivalent. According to some calculations from our marketing department, the transportation of one of our chips consumes around 0.008 GWP and its use consumes about 0.0001 GWP during its lifetime. This is relatively not necessary to improve as it would be expensive and not really productive. However, the main problems exposed in the following paragraphs to make our chip a green product are worth to be solved if we consider the previously described advantages the company could take from them.

The important issues are numerous: consumption of electricity, fab infrastructure impacts, chemical substances emissions and water use. The main issue is the electricity consumption due to the manufacturing of the product. Indeed, the present processes to manufacture our chip consume a large quantity of energy and indirectly emits a proportional amount of GWP. The next three issues are less important but have to be solved. The fab construction and infrastructure involves the consumption of a large quantity of materials and also some environmental issues -smog formation, acidification and eutrophication- as well as some human health issues with some cancer effects, due to the emissions from the fab infrastructure and construction. The chemicals substances emitted during the manufacture of our chip and the production of the raw materials are also high enough to be considered. The emissions of toxic substances, especially perfluorinated compounds, occur during the manufacture of our memories. The silicon used in our wafer, media to manufacture our chips, has to be purified to be usable in our manufacture. In order to purify this silicon, large quantities of chemical substances are emitted and a lot of electricity is consumed by the industry purifying it. Finally, large quantities of water are used in our manufacture and can be reduced. Each of the next paragraphs describes more deeply each problem and gives different solutions for them.

The manufacturing of our product requires many high electricity consumption intensive processes. This is a problem since the electricity IM flash technologies' manufacture is consuming comes from an electricity generation using some fossil fuels, which release some heavy elements like mercury and arsenic. These elements emitted are totally responsible of the ecotoxicity and we are indirectly responsible. They also contribute to the carcinogenic impacts on the human health. In order to solve this, the manufacture processes can be enhanced to consume less energy, but this improvement would be a waste of time and money as it wouldn't reduce the electrical consumption to more than ten percent. These processes are already consuming as low as possible, so we have to assume they will consume a large quantity of electricity, as there is no better solution at the moment. However, the global warming potentials are some electricity generation related emissions. Furthermore, installing a renewable energy sources grid using wind turbines for example would drastically reduce the GWP arising from the electrical consumption of our manufacture. This enhancement costs but would give the advantages described at the beginning of the report as well as an energy independence. In the long term, this could also bring a less expensive energy consumption solution and would make easier for the future products of Micron to be 'green'. I highly recommend this improvement as it would reduce the total GWP of our product to more than forty percent and thus would allow promoting our product easily. As IM flash technologies manufacture is a shared venture between our company and Intel, we should propose to Intel to invest in this new grid, as it would also be beneficial for them. If Intel declines this proposition, our company could install the grid and make Intel company pay the same price as they are paying now: this is a reasonable solution in this case.

The fab infrastructure is involving several environmental and health problems. It emits some gaseous substances with some environmental effects and cancer and non-cancer effects on the

human health. The emissions of oxides of nitrogen related to the present fab infrastructure are the main reason of the environmental acidification and eutrophication, as well as they are mostly responsible of the smog formation. The oxides of carbon emitted also participate to the smog formation. These oxides of carbon and nitrogen are emitted mostly from the fab infrastructure, and can be reduced.

The emissions of formaldehyde during the manufacture of the wafers and the lead emissions resulting from the fab infrastructure are mostly the cause of the carcinogenic human health effects. IM flash technologies manufacture is located in the Utah, and the American HR2420 directive has prohibited the presence of lead in any electronic product to a concentration superior of 1000 parts per million (ppm), as well as the European 2002/95/EC directive, if our products are exported in the European Union. Indeed, the HR2420 directive states that "*no electroindustry product shall be manufactured after July 1, 2010, that contains a concentration value greater than 0.1 percent by weight of lead*" [1] and the 2002/95/EC directive, also well known as the restriction of hazardous substances or "RoHS", states that any " *'producer' means any person who, irrespective of the selling technique used, including by means of distance communication according to Directive 97/7/EC of the European Parliament and of the Council of 20 May 1997 on the protection of consumers in respect of distance contracts: imports or exports electrical and electronic equipment on a professional basis into a member state*" [2]. The lead concentration of our product fits under this limit; however, the lead emissions from the fab infrastructure are high, and it would be hypocrite and a negative fact to a life cycle assessment to leave these lead emissions aside.

One general solution for the emissions of toxic substances from the fab infrastructure is simply to renew the materials of the fab. This would be expensive but would reduce most of the emissions coming from the manufacture. On the other hand, if this solution seems too costly, one other solution would be to build another fab for the next technology generation of products as we will probably need to renew all of the processes. This would be more productive and would make our future products green for a

less expensive investment.

Finally, the emissions of fluorine compounds, especially perfluorinated compounds, are primarily responsible of the non-cancer health impacts. They happen during the etching process on the wafers of our memory chips. Perfluorinated compounds are a family of chemicals used for the etching of the wafers as they are relatively stable, non-corrosive and low cost. However, their high infrared absorption and their resistance to water and stain make them dangerous for the environment. The environmental protection agency ("EPA") of the United States stated that "*Long-chain perfluorinated compounds are bioaccumulative in wildlife and humans, and are persistent in the environment. They are toxic to laboratory animals and wildlife, producing reproductive, developmental, and systemic effects in laboratory tests.*" [3] and this agency "*Continue with the 2010/15 PFOA Stewardship Program to work with companies toward the elimination of long-chain PFCs from emissions and products.*" [4]. These emissions can be reduced by adding to our wafer's manufacture the last technology of "point-of-use" plasma abatement which would reduce the emissions of at least 95 percent. The journal of vacuum science and technology published that "*A promising strategy for reducing Fluorinated compounds emissions from etch processes in the semiconductor industry is the point-of-use plasma abatement. In this approach, a high-density plasma is generated by a device installed downstream of the process chamber in the foreline that dissociates the fluorinated compounds effluent species and recombines the resulting fragments with additive gas fragments like water or oxygen to create by-products that are either environmentally benign or scrubbable.*" [5]. Hence buying this new technology would also lower the global warming potential of our product.

The Silicon used for the substrates of our wafers can be produced in a better way. At the moment, this silicon is brought mainly from Australia in the form of sand. It then needs to be purified to a level of one impurity per ten billions, also called

to an “electronic grade silicon”. To purify this silicon, several chemicals substances are used and a large quantity of energy is required. First of all, we could propose to the Silicon furnisher of IM flash technologies to use our previously described eventual future renewable grid, for the same price as they are paying now. This wouldn’t change anything for the Silicon production industry, and would be beneficial for our product as well as for our future products. The renewable electric grid could be more expensive than today, but on the other hand our products would bring back some larger benefits. However, limit the emissions of chemicals substances used for the silicon purification might be hard to accomplish. First, the industry furnishing the silicon to IM flash technologies is an independent industry, and secondly, there is not any viable solution to limit these emissions. I think our company should only focus on limiting the electricity generation related emissions at this stage.

The last issue concerns the water use. The water is mostly used again by the electricity generation but also during the wafers manufacture. The evident solution is again the grid based on renewable sources which would reduce by a large amount the quantity of water consumed. The water used in the manufacture of our chips is necessary to rinse the wafers. However, some solutions exist in order to reduce the water consumption. The first solution is to install some more precise automated systems that would control the flux of water in the manufacture. Another solution would be to heat the water, because hot water is more effective in rinsing than cold water. This would consume some electricity but would not affect the life cycle assessment because of our future renewable sources based grid. The final solution would be to install a water recycle system in order to re-use as much as possible the water. Many solutions to this recycling already exist, and are apparently profitable, according to this citation “*Recycling of water that was previously purified to an ultrapure level and then used to rinse-off ultrapure chemicals from clean wafers, provides many advantages, including an improvement in final water quality. This alone justifies the efforts associated with the implementation of a recycle strategy.*” [6] from John Degenova and Farhang Shadman, working

respectively at Sematech and at the Center for Environmentally Benign Semiconductor Manufacturing. A last solution would be to install a filtration system in order to remove the chemicals impurities from the water, allowing sending back the water to the public surrounding areas. The water consumed in the industry would then be fully recycled and non-wasted. This would be a strong argument in favor to the 'green' property of our product.

To summarize, there are several reasonable and feasible solutions to the issues described in order to successfully accomplish a life cycle assessment. The transportation and the use phase of our product shouldn't be an issue to a life cycle assessment. The end of life of our product could be a bit improved, by settling a specific recycling system for our memory chips. Most of the important issues come from the manufacturing phase. The main solution would be to install a renewable sources based grid that would provide electricity to IM flash technologies' manufacture and maybe to the silicon production industry. There are also several other solutions to improve the life cycle assessment: renew the fab as well as some abatement technologies, in order to reduce the perfluorinated compounds emissions for example, and install a water recycling system in our manufacture. By investing in some of these solutions, Micron's marketing department would be able to highlight the important points explaining why our memory chips are green, and this would make the difference with the other concurrent memories or storage devices in general.

REFERENCES:

Green labels? It's time to get real, *by Ramon Arratia.*
http://www.greeneconomycoalition.org/know-how/green-labels-its-time-get-real
Micron MLC nand memories
http://www.micron.com/products/nand-flash/mlc-nand
MLC vs SLC: Which flash SSD is right for you? , *by Manek Dubash*
http://www.computerweekly.com/feature/MLC-vs-SLC-Which-flash-SSD-is-right-for-you
IM Flash technologies website
http://www.imftech.com/locations/
Life-cycle assessment of NAND flash memory, *by Sarah Boyd, Arpad Horvath and David Dornfeld*
http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=05601793
RoHS Compliance Definition
http://www.rohscompliancedefinition.com/
Directive 2002/95/EC (RoHS)
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:037:0019:0023:EN:PDF
Chemicals Policy, H.R. 2420 (May 14, 2009)
http://www.chemicalspolicy.org/downloads/HR2420.pdf
Washington toxics coalition, Perfluorinated compounds (PFCs)
http://watoxics.org/chemicals-of-concern/perfluorinated-compounds-pfcs
Environmental Protection Agency (United States), Long-chain perfluorinated chemicals action plan summary
http://www.epa.gov/opptintr/existingchemicals/pubs/actionplans/pfcs.html
Perfluoronated Compound (PFC) Abatement for the SC Industry: Results from a Catalytic Method, *by Tim Decker*
http://www.future-fab.com/documents.asp?d_ID=629
PFC Abatement in the semiconductor industry 2009, *by Joe Van Gompel*
http://www.seshaonline.org/regions/ssatexashillc/March09/Van%20Gompel_PFC%20Abatement%20in%20the%20Semiconductor%20Industry.pdf
Journal of Vacuum science and technology A: Inductively coupled, point-of-use plasma abatement of perfluorinated compounds and hydrofluorinated compounds from etch processes utilizing O2 and H2O as additive gases, *by Eric Tonnis, David Graves, Victor Vartanian, Laurie Beu, Tom Lii.*
http://scitation.aip.org/getpdf/servlet/GetPDFServlet?filetype=pdf&id=JVTAD6000018000002000393000001&idtype=cvips&doi=10.1116/1.582199&prog=normal
Recovery, reuse, and recycle of water in semiconductor wafer fabrication facilities - Degenova - 2006 - Environmental Progress - Wiley Online Library
http://onlinelibrary.wiley.com/doi/10.1002/ep.3300160414/pdf

CITATIONS REFERENCES:

[1]: Citation from **Chemicals Policy, H.R. 2420 (May 14, 2009)** **(**http://www.chemicalspolicy.org/downloads/HR2420.pdf)

[2]: Citation from **Directive 2002/95/EC (RoHS)** (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:037:0019:0023:EN:PDF)

[3] and [4]: Citations from **Environmental Protection Agency (United States), Long-chain perfluorinated chemicals action plan summary** **(**http://www.epa.gov/opptintr/existingchemicals/pubs/actionplans/pfcs.html)

[5]: Citation from **Journal of Vacuum science and technology A: Inductively coupled, point-of-use plasma abatement of perfluorinated compounds and hydrofluorinated compounds from etch processes utilizing O2 and H2O as additive gases**, *by Eric Tonnis, David Graves, Victor Vartanian, Laurie Beu, Tom Lii.* *(*http://scitation.aip.org/getpdf/servlet/GetPDFServlet?filetype=pdf&id=JVTAD6000018000002000393000001&idtype=cvips&doi=10.1116/1.582199&prog=normal)

[6]: Citation from **Recovery, reuse, and recycle of water in semiconductor wafer fabrication facilities - Degenova - 2006 - Environmental Progress - Wiley Online Library** (http://onlinelibrary.wiley.com/doi/10.1002/ep.3300160414/pdf)