Monitoring

Measurement and Removal of Trace Levels of Urea in Semiconductor High-Purity Water

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Advancements in modern semiconductor processing chemistries can create new sensitivities to contamination that previously were of little concern. The recent discovery that trace levels of urea in high-purity water caused problems with semiconductor photolithography illustrates this point (1, 2). It is well known that ammonia, at part-per-billion (ppb) concentrations, can negatively impact the performance of the acid-catalyzed, chemically-amplified (CA) photoresists used in today's deep ultra-violet (DUV) photolithography processes (5). Urea naturally decomposes to ammonia through multiple possible pathways.

In early 2001, semiconductor fabrication facilities connected to the municipal water supply for Hillsboro, Oregon, experienced a series of total organic carbon (TOC) spikes in their high-purity water systems. It was observed the TOC excursions were either not detected, or measured inaccurately, with a traditional TOC analyzer, but were successfully measured with a new type of TOC analyzer. At the same time, semiconductor manufacturing engineers at one of the fabs correlated an influence on the CA-DUV photolithography process to the measurements from this new type of TOC analyzer (2). The primary component of the TOC spikes was determined to be urea (1). In an earlier comparative performance study of high-purity TOC analyzers, some analyzers were found to be blind to organic nitrogen compounds (including urea), but the new type of TOC analyzer was not (3).

Concern increased further when it was discovered that conventional high-purity water purification processes could not remove the contaminating urea (2). This discovery has lead to the recent development and deployment of a new method of urea removal for semiconductor high-purity water systems (13).

It is now understood that the urea contamination in the Oregon case originated from agricultural activities in the Hillsboro watershed (4). Since then, other urea spikes have been observed that originated from non-agricultural sources in Japan, Singapore, and Taiwan, and we are looking for additional urea or organic nitrogen contamination in other parts of the United States, Asia and Europe.

Interestingly, with the exception of one company, we have observed a general fear among water facilities operators to communicate situations to the fab manufacturing engineers' that are indicative of urea contamination. This behavior can obscure the manufacturing engineers ability to correlate problems to contamination events and use that new information to improve the semiconductor manufacturing process.

Background

Four major TOC spikes were observed in the spring of 2001 in final polish water at semiconductor factories using water from the Hillsboro water district in Oregon. Figure 1 shows the TOC responses from the two different types of total organic carbon analyzers on three of the excursions at one of these semiconductor factories. The different analyzers, using different analytical measurement technologies, produced dramatically different TOC results when measuring the spikes. Analyzer B[b] responds as one would expect a TOC spike to behave in an organically contaminated high-purity water system. Analyzer A[a], however, shows no response to the spikes except for periodically approaching zero or jumping to a value of 200 ppb. Similar TOC analyzer responses were observed and reported at the same time in another

Hillsboro area semiconductor factory (1, 2, 4). The manufacturing engineers at this site correlated an influence on the DUV photolithography process to the TOC spikes measured by Analyzer B (2). Because of this correlation, there was an aggressive effort to discover what were the organics in the TOC spikes and, once identified, how they could be removed. Conventional ultratrace laboratory analysis for organics in the spikes proved to be inconclusive (1). As we will see, the dissimilar TOC responses from the two different technologies proved to be a valuable clue for the determination of urea as the problem organic compound causing the spikes (1). Why did the two TOC analyzers respond so differently to the spikes?

TOC Analyzer Performance Comparisons

This question was answered by examining results from an earlier study comparing responses from different TOC analyzer technologies to injections of low concentrations of different organics into high-purity water. In this study compounds that were likely to be found in high-purity water were chosen for testing. Computer-controlled precision syringe and turbine flow meter were used to inject different levels of the organics into the high-purity water at known concentrations. The percent recovery for each compound was calculated by dividing the increases in TOC (delta TOC) response by the expected TOC increase and multiplying by 100. The different compounds' percent recovery was determined for each TOC analyzer.

Figure 2 shows the overall results of that study. Examination of this data shows that TOC analyzers A, C[c], and D[d] surprisingly did not respond to the low concentrations of urea, trimethylamine, or TMAH. These compounds are all organics that contain nitrogen. Analyzer B recovered the organic nitrogen compounds correctly.

From this study and comparing the two different TOC analyzer responses to the Hillsboro spikes, it was concluded there was a high probability that the TOC spikes in Hillsboro were composed of organic nitrogen compounds (1). Additionally, it was realized that farmers in the region were fertilizing their fields at approximately the same time the TOC spikes were occurring and that the most common fertilizer used was urea (4). The other two known organic compounds that were not measured by some of the TOC technologies, trimethylamine and TMAH, were both expected to come from sources internal to the factory. Trimethylamine is the primary functional chemical group on the strongly basic anion exchange resins used to deionize water and TMAH is used to strip photoresists in the fab. The TOC spikes seen at multiple semiconductor sites suggested the contamination was from an external source.

For these reasons, the focus was to determine if urea caused the contamination problems. A proprietary analyzer was developed to selectively measure for low-ppb concentrations of urea. Samples collected from one of the spikes showed over 95% of the organics contained in the TOC spike was from urea alone (1, 2).

Why do Some TOC Analyzers Not Measure Urea?

Organic nitrogen compounds behave unexpectedly in high-purity water at part-per-billion concentrations. They often are weakly basic molecules with the carbon and nitrogen atoms incorporated into the positively charged ion (cation). At low ppb concentrations they may not be detected using conventional TOC analyzers and typical conductivity sensors. As Analyzer A did not measure urea, trimethylamine was also not measured by Analyzers A, C, and D (3). Figure 3 shows a plot of the resistivity of trimethylamine as a function of concentration. Trimethylamine is the primary functional group on strong anion exchange resin. It is also the major organic to leach from the anion resin into purified water. Surprisingly, the addition of low concentrations of trimethylamine to deionized high-purity water initially causes the temperature corrected (25C) resistivity to increase above that of high-purity deionized water! As the TOC concentration of 1.5 ppb (as carbon) is surpassed the resistivity finally starts to decrease as expected and shown in Figure 3.

That resistivity of high-purity water can increase above that of high-purity deionized water with the addition of low concentrations of cations other than H^+ is unexpected. This behavior is the result of the titration of the very conductive hydronium ion (H^+) by a much less conductive replacement cation. It is interesting to note that a similar type of the conductivity effect observed in this example may be a possible explanation for Analyzers A, C, and D's lack of response to organic nitrogen compounds at low concentrations. Analyzer A, C, and D are direct-conductometric based TOC analyzers. In this type of TOC analyzer, after UV oxidation of the water sample the resulting solution conductivity is measured and any conductivity increase above that of the initial high-purity water is correlated to TOC. This concept is schematically represented in Figure 4. In water with low dissolved oxygen, it is likely some reduced

compounds are formed during the intensive ultraviolet (UV) irradiation of organic nitrogen compounds in the TOC analyzers. Such compounds can ionize in water, forming organic cations which cause the conductivity to decrease and confuse the direct-conductometric method TOC analyzers A, C, and D. These analyzers would not measure the expected TOC increase and, therefore, would report a near-zero TOC concentration change as observed in the TOC comparison study. Figure 4 shows the cation labeled $N_XC_yH_z^+$ as an ion possibly formed from the UV irradiation of organic nitrogen compounds in the water sample. Therefore, if there are $N_XC_yH_z^+$ cations in post-UV irradiated water, then the conductivity change can be near zero and the resulting delta TOC result will also be near zero.

Conversely, Analyzer B employs a membrane-based conductometric TOC measurement method. This method uses a carbon dioxide (CO_2) selective membrane to allow the CO_2 to selectively diffuse into a separate deionized water chamber. The conductivity and temperature of this solution are measured and the TOC is calculated. This method is shown in Figure 5. Because the membrane allows only CO_2 to pass into the deionized water chamber, the resulting conductivity change is used to produce an accurate TOC measurement without interference from other ions.

Why is Urea a Problem for Chemically-Amplified (CA) Photoresist?

In previous papers (1, 2, 13), it has been clearly explained how and why urea can be a problem with the chemically-amplified photoresists. Advances in chemically-amplified (CA) photoresists have produced new sensitivities to contaminating compounds (1, 2). Ammonia adversely affects the acid-catalyzed, chemically-amplified photoresists that are used with the new deep UV (DUV) lithography processes required to achieve circuit dimensions near or below 0.5 microns (µm) (2, 5, 7, 8, 9). The negative effects of low concentrations of airborne molecular contaminants, such as low or sub-ppb levels of organic amines and ammonia, on the control of critical dimensions during the lithography of sub-0.5-µm line widths is widely known within the semiconductor industry (2, 5, 7, 10).

Chemically-amplified photoresists use a small number of photogenerated acid molecules to initiate a catalytic reaction that converts the exposed portions of the resist (for a positive resist) into a material that is easily removable during the development step (2, 9). If the photoresist is exposed to ppb-levels of organic bases such as amine and ammonia, the small quantity of acid generated during the DUV exposure is further reduced, significantly reducing the subsequent catalytic amplification reactions within the resist (2). The neutralization of this acid can then result in the partial or deformed features known as "T-Topping" on the wafer features, as modeled and shown in Figure 6 (2, 7).

"Chemically-amplified resists are particularly sensitive to contamination during the interval after the coated wafer is exposed to the DUV light and when the wafer is baked, which may be less than 3 minutes but could extend to 10 minutes or longer, depending on the tool loading methods (11). If this pause happens while the wafer is located where the ammonia contamination levels could be as much as 5 ppb, it is possible that a shift of a critical dimension by as much as 10-20 nm may occur (11). Others have reported that some chemically-amplified resists may be affected by airborne impurities at concentrations near 1 to 2 ppb" (2, 12).

The exact contamination pathway of the low-ppb levels of urea in the high-purity water to the photoresist was not presented in these papers, however, the papers did propose the following possible pathways (1, 2, 13).

Airborne basic gases are a problem for CA DUV lithography, and acid-impregnated activated carbon filters (to remove the basic organic components from the air) are now standard equipment on lithography tools. "With the acidified carbon filters on the air stream, the tools are protected from an incursion of airborne ammonia. However, it is possible that process streams, such as high-purity water that bypass these filters, could provide a source of organic nitrogen that could covert to ammonia. It is also possible that extremely small particles of non-ionic urea could pass through such protection filters (2)."

"If urea decomposed into ammonia and carbon dioxide on the inside of the tool and downstream of the activated carbon air filters it is possible that the ammonia could adversely affect the behavior of the chemically-amplified photoresist. The three most probable scenarios of exposing the lithography process to urea in high-purity water at this site are as follows: 1. Through rinsing steps where high-purity water is in contact with the wafer or where residual high-purity water may exist within the tool; 2. Through the humidification control for individual tools, which generally use a reservoir of high-purity water as a source for mini-environment humidification control; or 3. Through the humidification systems for the ambient cleanroom, which is generally supplied with high-purity water (2)."

“In Scenarios 1 and 2, the aqueous urea would completely bypass the activated carbon filters used to remove airborne contaminants, and if exposed to deep UV (DUV) light, convert into ammonia and carbon dioxide. In Scenario 3, high-purity water is supplied to the cleanroom makeup air handlers to control the cleanroom humidity. Since the makeup air handlers are not usually high-purity or sterile environments, it is possible that bacteria, which catalyze the decomposition of urea, may do so within the makeup air handlers, resulting in ppb-concentrations of ammonia inside the ambient cleanroom. Thus, depending on the nature of the wafer handling mechanisms within the cleanroom, the ppb concentrations of ammonia from urea may have an adverse affect on the chemically-amplified resists.” “Therefore, given the widespread use of chemically-amplified photoresists in the lithography processes of semiconductor manufacturing, it is now believed that urea and the family of nitrogen-containing organics, should be classified as critical contaminants in high-purity water systems (2).”

Removing Urea from High-Purity Water and Known Urea Decomposition Methods

Even before it was known urea was the source of the TOC contamination in the Hillsboro spikes, aggressive attempts were made to remove the TOC and to prevent future TOC excursions. Corrective actions applied at one semiconductor manufacturer included modifying the feedwater pH into the reverse osmosis (RO), increasing the ozone concentrations feeding into the ultraviolet (UV) “TOC reduction” reactors, increasing the vacuum in the degasification towers, and adding a new activated carbon tank to the high-purity water polish loop (1).

In all cases the results were very disappointing. The usual high-purity water purification processes of activated carbon, RO, microfiltration, ion exchange, electrodeionization, ozonation, degasification, and short wave TOC-reducing UV light were all ineffective at removing urea (1). These results are not surprising, considering the properties of urea. Urea is non-volatile, difficult to oxidize, ozone resistant, non-ionic, highly soluble in water, and has a low molecular weight of 60.

Interestingly, Analyzer B was able to completely oxidize the urea using UV light. Why do the typical high-purity water system “TOC reduction” UV reactors not do the same thing? Comparative analysis of the dosage of 184.9-nanometer (nm) UV shows that the TOC analyzer has a UV exposure 67,000 times greater that that available from even a de-rated high-purity water “TOC Reduction” UV reactor. In other words, typical TOC Reduction UV reactors produce UVC (both 254- and 185-nm UV light bands) doses of about 120,000 micro-watts seconds per square centimeter (μW-sec/cm^2) and can go up to 300,000 μW-sec/cm^2 (6). The UVC exposure in Analyzer B is greater than 20,000,000,000 μW-sec/cm^2. For an equivalent amount of UV irradiation used in the TOC Analyzer B, one would need to provide about 0.79 million watts of electricity to 67,000 typical “TOC Reduction” UV reactors for each 1,000 gallons per minute (gpm) of high-purity water processed!

Currently, the best way to remove urea from water is to hydrolyze or decompose it into compounds that can be easily removed using conventional water purification processes. Japanese patent applications, available for public viewing, show that the last four processes listed in Table A have been studied or developed in Japan to remove urea from high-purity water systems or the feed waters to these systems. When a water molecule reacts with urea to produce two ammonia molecules and one carbon dioxide molecule, this reaction is referred to as hydrolysis. Urea in high-purity water is known to decompose to ammonia or nitrogen, and carbon dioxide through the pathways shown in Table A. Of the last three reactions in the table, the NaOCl reaction is 100 times more reactive than the O_3 reaction and the NaOBr reaction is 1,000 times more reactive that the O_3 reaction.

A recent paper presented by a semiconductor manufacturer discusses the development and deployment of two new urea removal systems for high-purity water. The method used is based on the NaOBr-Urea hydrolysis reaction. These removal systems incorporate an on-line urea analyzer into a feedback control system. The method requires concentrations of NaOBr to be two to three orders of magnitude greater than the concentration of the urea for reasonable reaction times. A non-contaminating NaOBr removal process is required and described. And finally, these urea removal systems were demonstrated to successfully protect the manufacturing facilities from a large urea-based TOC excursion that occurred in the spring of 2002 (13).

Are TOC Limits in Semiconductor Factories Correct?

It is important to note that almost all the TOC specifications established in the semiconductor industry have been based on the technology of Analyzer A (2). Because Analyzer A does not measure organic

nitrogen compounds at low, but possibly fab-critical levels, the limits that have been established are only valid if there is no organic nitrogen in the water. It has been noted that urea can decompose to ammonia and should be considered a new critical contaminate in semiconductor high-purity water (2). These studies also raised questions about older Analyzer A-based TOC limits, as they did not account for the possibility of organic nitrogen in the high-purity water (2).

Analyzer A does not respond to urea concentrations less than 15 ppb as TOC (2). If Analyzer B is used for the final high-purity water quality measurement the new water system may very well not meet the TOC specification, if they were based on the Analyzer A technology (2). Reference 2 makes the following point; "The improved ability of Analyzer B to measure organic nitrogen compounds, previously not measured by Analyzer A, raises the question of what is the correct UPW TOC specification for an advanced semiconductor facility. The use of Analyzer B has demonstrated the need to reevaluate water treatment system control limits and to revisit UPW treatment system designs to develop methods to achieve total organic carbon removal. That is, if one implements the improved detection limits of a TOC analyzer such as Analyzer B, which detects previously undetectable nitrogen containing organic compounds, they should no longer expect to be supplied with UPW that meets a 1 ppb specification limit that was derived from Analyzer A. Something – a change of specification limits, control limits, and/or water treatment system processes – must be implemented in order to accommodate the more sensitive detection by Analyzer X."

If the final TOC is to be measured by Analyzer B, it is recommended that long-term comparison measurements be made between Analyzer B and the prior referenced TOC Analyzer (typically Analyzer A) to collect the necessary data to establish new TOC fab specifications. This comparison study should be done for at least a year to account for seasonal variations and to determine if urea spikes exist in the water system. This study between the different types of TOC analyzers is the easiest and most practical way to find the presence of urea or other organic nitrogen organic contaminations in the final high-purity water (1). Finally, the Analyzer B TOC data can be related to the performance of different semiconductor processes by the manufacturing engineers to find production improvements.

Other Organic Nitrogen Contamination of Semiconductor Water Systems

We have found that other semiconductor factories have detected urea or organic nitrogen TOC spikes in their final high-purity waters. In all of these cases Analyzer A did not detect the TOC peak, but Analyzer B did. Figure 7 shows a typical organic nitrogen TOC spike; this one occurred in a semiconductor factory in Taiwan. This spike was caused by contaminated water delivered to the factory by a truck during a drought. The TOC spike was confirmed to be from urea. A fab in Japan confirmed a urea spike resulting from a winter storm in the area. Urea, which is used as a deicer for roads in Japan, leaked into the feedwater to the water purification system. Another fab in Taiwan observed a one-week-wide TOC spike on their TOC Analyzer B, but not on Analyzer A. This change was finally correlated to the recent installation of a new epoxy floor in a non-fab area of the factory. In all the above cases, Analyzer B read the correct TOC, while Analyzers A or C did not measure any TOC change.

We are studying additional semiconductor factories in the United States, Japan, Korea, Singapore, and Europe for the presence of urea or organic nitrogen and the occurrence of TOC spikes from the same. We have observed that most, but not all of the high-purity water systems contaminated with organic nitrogen, were being feed with urea-contaminated surface waters.

Data Reporting to the Fab

Except for one semiconductor manufacturer, we have observed that the high-purity water facilities operators do not usually communicate TOC data indicative of urea or organic nitrogen contamination to the fab manufacturing engineers. Two major reasons have been given for not reporting these events. First, is the lack of confidence generated when one observes two different TOC technologies producing dramatically different results. Second, there is a perceived lack of a cost-effective urea removal process to control the situation. It is understandable that few people would want to inform the fab of a water contamination problem if they are not sure it exists, and, even if it did exist, they would have no way to correct it. This behavior can prevent the manufacturing engineers from correlating production problems to measurable contamination events and from improving the semiconductor manufacturing process. It also delays the development and adoption of new and improved technologies to solve problems.

Only in one case, where manufacturing engineers directly observed a correlation between TOC from Analyzer B (urea) and an influence on the photolithography manufacturing process, did this fear of

communication not exist (2). However, it was only possible to find this correlation because this company was comparing both TOC technologies side by side and reporting both sets of data to the manufacturing engineers in the fab during the occurrence of urea TOC spikes (1, 2). As already mentioned, this same company recently reported the deployment of a new urea removal process (13).

Conclusions

Low part-per-billion levels of urea should be considered a new critical contaminate in high-purity water for fabs using chemically-amplified photoresist in their photolithography processes (2).

Nitrogen cations in high-purity water could cause "direct-conductometric" TOC analyzers to measure organic nitrogen compounds incorrectly. TOC analyzers that use the "membrane-based conductometric" TOC method do not have a problem with these cations and can measure the TOC of organic nitrogen compounds and chlorinated organics accurately (2, 3). Because of this effect, the "direct-conductometric" TOC analyzers A, C, and D can not measure critical concentrations of urea below 15 ppb TOC in high-purity water (1, 2, 3). The membrane-based conductometric TOC Analyzer B can correctly measure low levels of urea in high-purity water (1, 2, 3).

Urea is very difficult to remove from high-purity water using conventional water purification processes (1, 2). Ultraviolet light irradiation alone is not an economical removal method. Urea removal methods and chemistries found in scientific literature are being applied to the development of new urea removal systems for high-purity water (2, 13).

Almost all TOC specification limits have been established using the "direct-conductometric" TOC determination method (2). When new high-purity water systems for fabs are being designed and commissioned there is a risk that the true TOC is higher than the previous TOC specification and a "membrane-based conductometric" TOC method analyzer may not allow the system to meet older TOC specifications (2). Long-term, on-line studies comparing both the "membrane-based conductometric" TOC method and the "direct-conductometric" TOC method are recommended for determining if urea or other organic nitrogen compounds exist in the final highly purified semiconductor waters. In the semiconductor industry the monitoring and removal of urea and other organic nitrogen compounds from the final highly-purified water can prevent unexpected results in photolithography (2, 3, 13).

Other organic nitrogen compounds, such as amines in high-purity water, are a potential risk for the fab as they can also interfere with the chemically-amplified photoresist development process (2, 5, 8, 9, 11, 12). They are not measured by the "direct-conductometric" TOC analyzers, but are correctly measured by TOC analyzers using the "membrane-based conductometric" TOC method (3). Trimethylamine was shown to be able to hide at low concentrations in the high-purity water without detection by Analyzer A and without detection by conductivity meters even though it is a weak base, ionic, and conductive in solution. Trimethylamine is a possible concern in high-purity water as it is present as the primary active functional group on the strongly basic anion-exchange resin commonly used in semiconductor water systems. If this resin is defective or of poor quality, it can leak trace levels of trimethylamine into the high-purity water without detection, if the wrong TOC analyzers are being used.

Urea and organic nitrogen spikes are being observed worldwide in semiconductor high-purity water systems through the comparison of Analyzers A, C, or D to Analyzer B TOC results. In all cases, it was observed that Analyzers A, C, and D do not detect critical low concentrations of urea or organic nitrogen compounds, but Analyzer B successfully measures them.

We have observed that high-purity water system operators do not commonly share with the semiconductor manufacturing engineers any data suggesting the presence of urea or organic nitrogen in the water, except in the case of one semiconductor company (1, 2, 13). Hopefully, this article will encourage the communication about urea or trimethylamine contaminated semiconductor high-purity water between water treatment professionals and manufacturing engineers.

References

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Endnotes

[a] Analyzer A, the A-1000 is manufactured by Anatel Corp., Loveland, Colo.
[b] Analyzer B, the “PPT”, is manufactured by Ionics Instruments Business Group, Boulder, Colo.
[c] Analyzer C, the A-1000XP is manufactured by Anatel Corp., Loveland, Colo.
[d] Analyzer D, the Thornton 502P-SX is manufactured by Mettler-Toledo Thornton, Waltham, Mass.

Author Richard Godec, is the Ultrapure Water Product Development Manager at the Ionics Instrument Business Group of Ionics, Inc. He has more than 23 years’ experience in the design, development, and manufacturing of analytical instrumentation for process and laboratory applications in the pharmaceutical, semiconductor, power, and petrochemical industries. He has been solely or jointly responsible for the development of new analyzers for measurement of TOC and TOx in water, trace boron in water, trace urea in water, and organic sulfur in petrochemicals. He holds over 28 US and international patents in these fields. He has a BS degree in chemical engineering from the University of Colorado.

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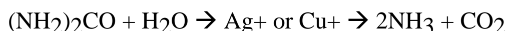
Key words: INSTRUMENTS, MONITORING, ORGANICS, SEMICONDUCTORS, TOC, UREA

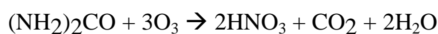
TABLE A


$(NH_2)_2CO + H_2O \rightarrow Ag+ \text{ or } Cu+ \rightarrow 2NH_3 + CO_2$

$(NH_2)_2CO + H_2O \rightarrow DUV \rightarrow 2NH_3 + CO_2$

$2(NH_2)_2CO \leftarrow \text{Heat } (132° C) \rightarrow H_2NCONHCONH_2 + NH_3 + 2H_2O \rightarrow 2\ CO_2 + 4\ NH_3$

$(NH_2)_2CO + H_2O \rightarrow \text{enzymes/bacteria} \rightarrow 2NH_3 + CO_2$


$(NH_2)_2CO + 3O_3 \rightarrow 2HNO_3 + CO_2 + 2H_2O$

$2(NH_2)_2CO + 3\ NaOCl \rightarrow 2NH_3 + N_2 + 2CO_2 + H_2O + 3NaCl$

$2(NH_2)_2CO + 3\ NaOBr \rightarrow 2NH_3 + N_2 + 2CO_2 + H_2O + 3NaBr$

Figure 1. TOC spikes measured by different TOC analyzers.

Figure 2. Average recovery of different organics (TOC< 5 ppb) (Reference 3).

Figure 3. Resistivity of low concentrations of trimethylamine in high-purity water.

Figure 4. Schematic of Analyzer A's direct-conductometric TOC method.

Figure 5. Schematic of Analyzer B's selective membrane-based conductometric TOC method. The interfering ions are prevented from interfering with the conductivity measurement of the CO_2 dissolved in deionized water.

Figure 6. Computer simulated T-topping effect resulting from the exposure of an optically exposed chemically-amplified resist to a basic gas. The left-hand schematic shows how exposure to airborne ammonia or amine can impact the resist development, shown in the 3-D view on the right side of the graphic.

Figure 7. Urea Spike in Taiwan measured by Analyzer B.

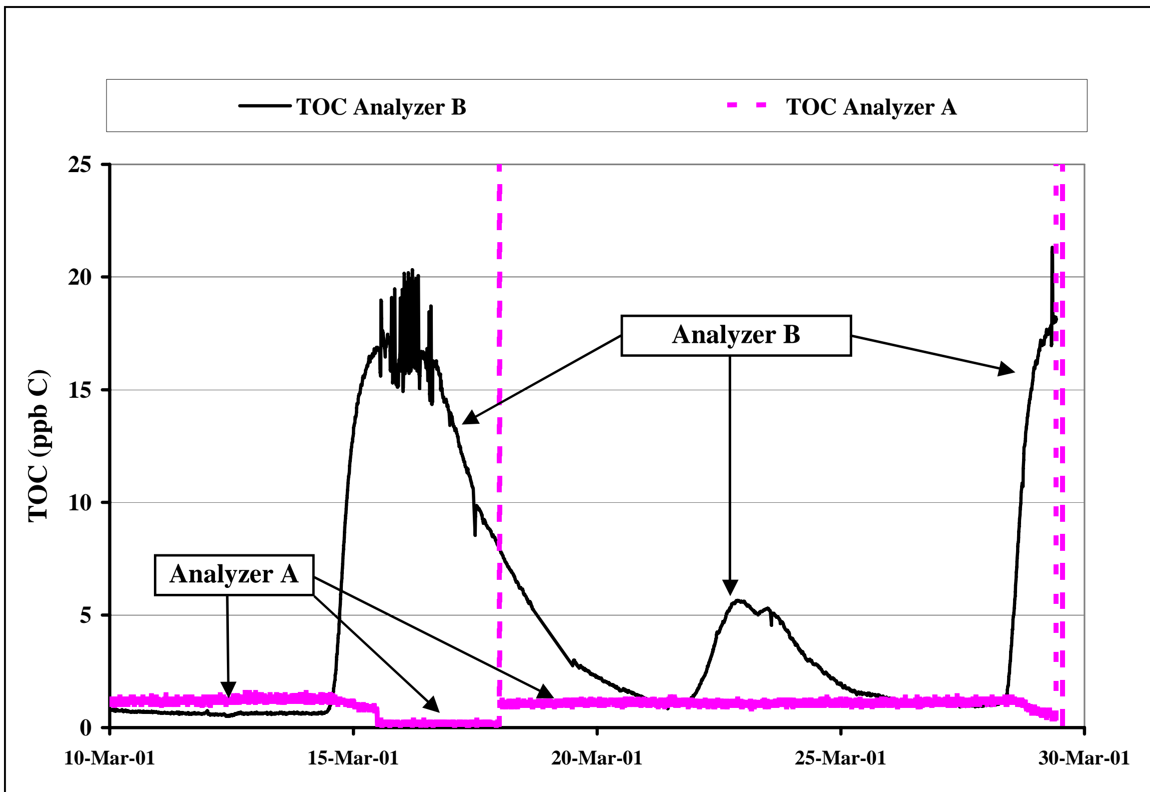


Figure 1. TOC spikes measured by different TOC analyzers.

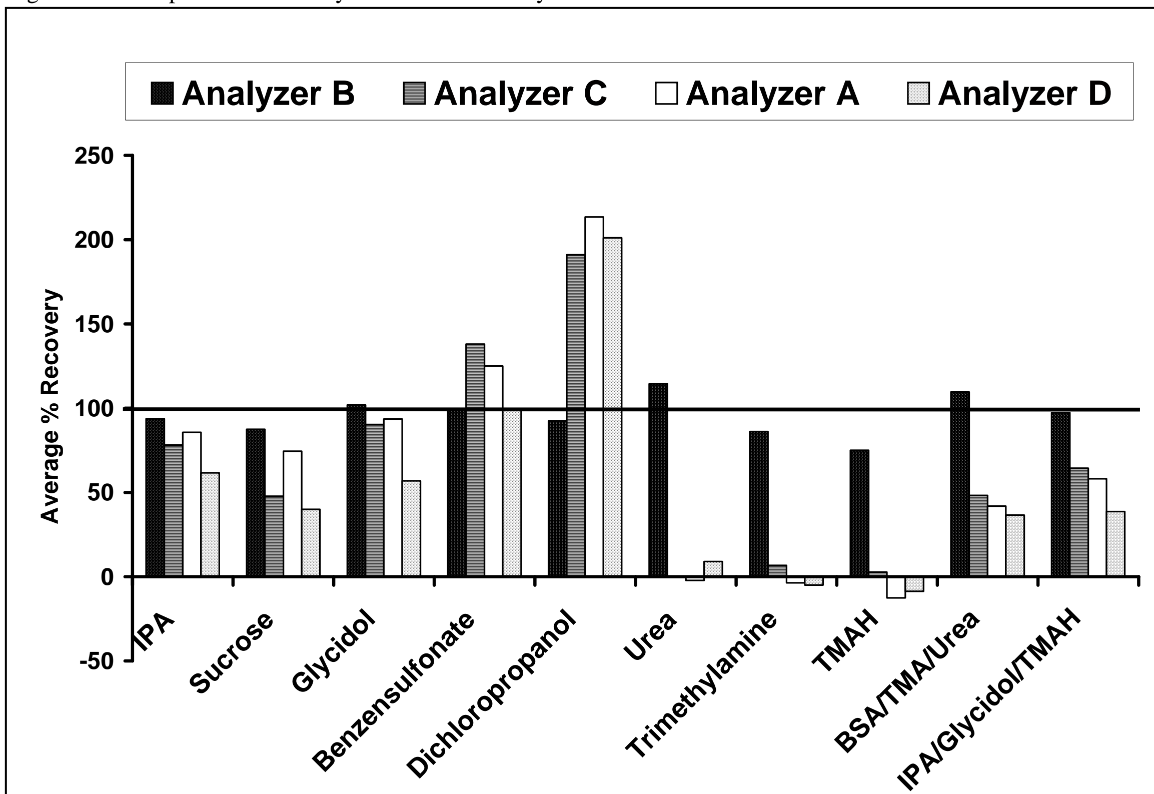


Figure 2. Average recovery of different organics (TOC< 5 ppb) (Reference 3).

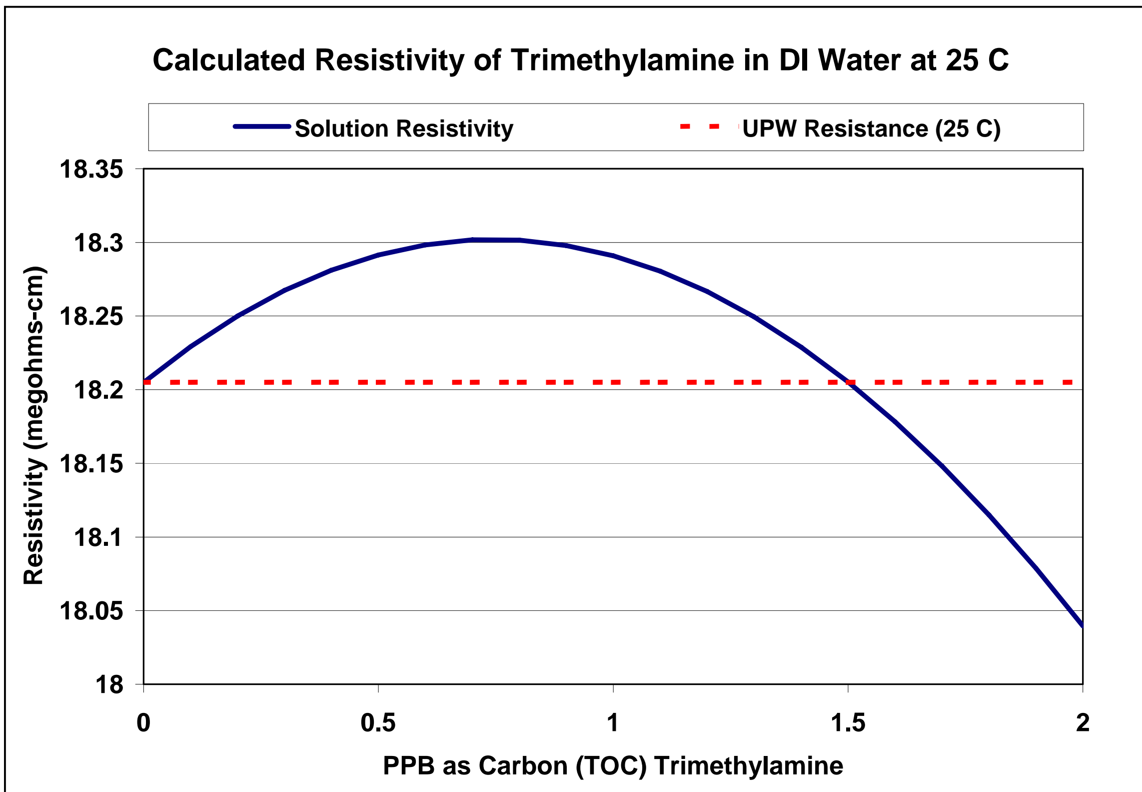


Figure 3. Resistivity of low concentrations of trimethylamine in high-purity water.

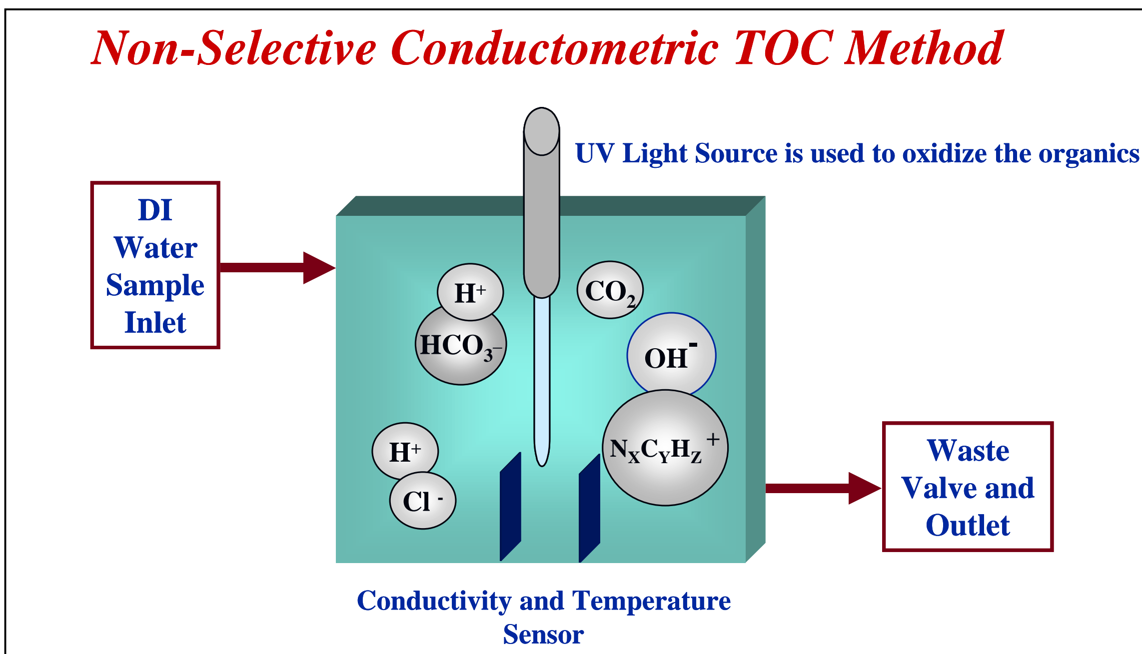


Figure 4. Schematic of Analyzer A's direct-conductometric TOC method.

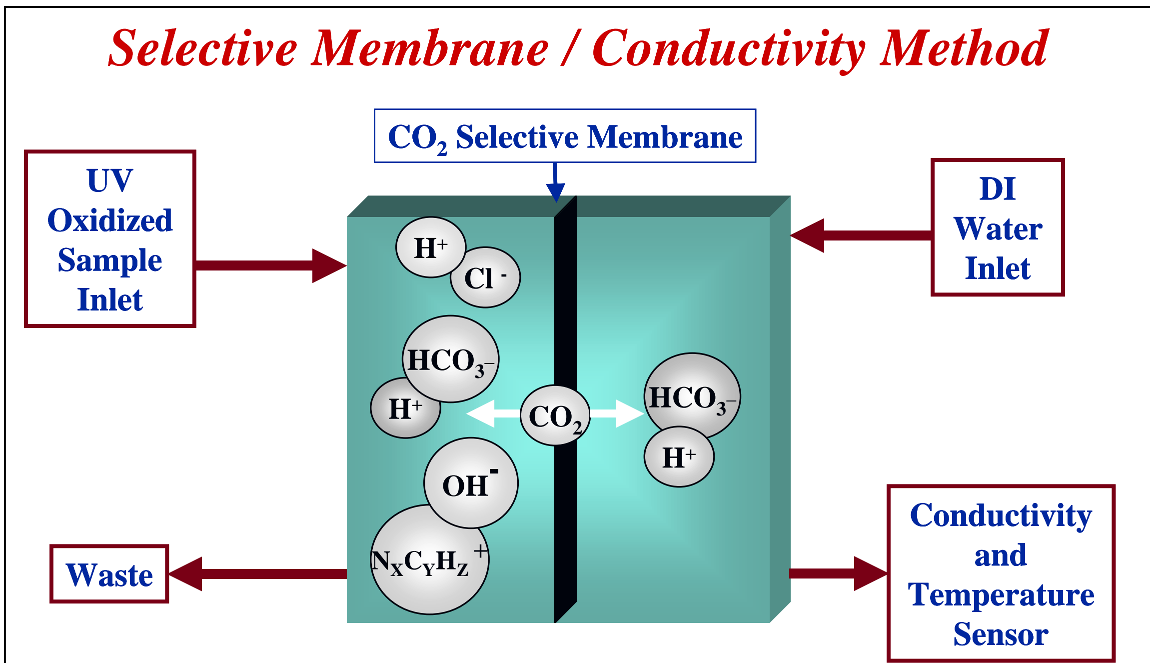


Figure 5. Schematic of Analyzer B's selective membrane-based conductometric TOC method. The interfering ions are prevented from interfering with the conductivity measurement of the CO_2 dissolved in deionized water.

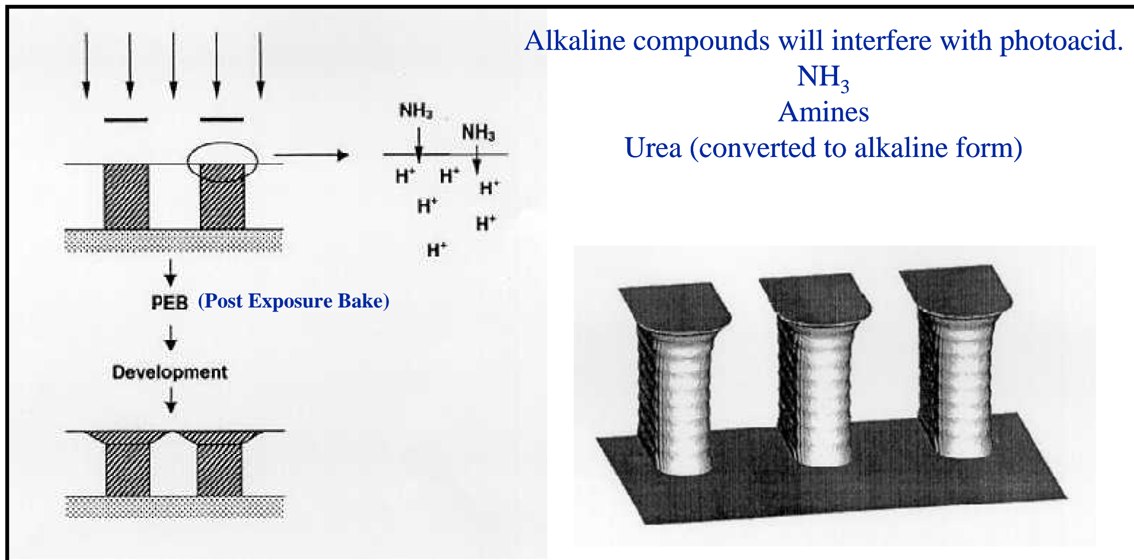


Figure 6. Computer simulated T-topping effect resulting from the exposure of an optically exposed chemically-amplified resist to a basic gas. The left-hand schematic shows how exposure to airborne ammonia or amine can impact the resist development, shown in the 3-D view on the right side of the graphic.

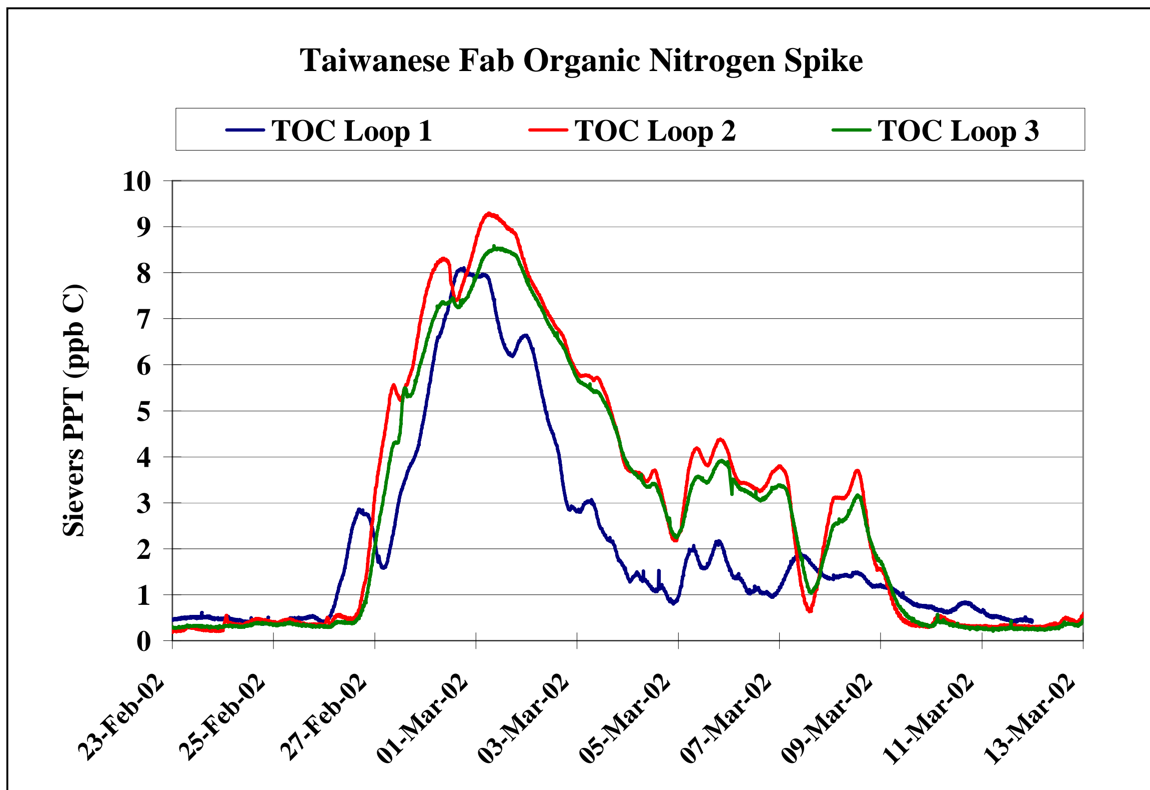


Figure 7. Urea Spike in Taiwan measured by Analyzer B.