

ELECTRODEIONIZATION EVALUATION IN A SEMICONDUCTOR FAB RECYCLE SYSTEM

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Abstract

Recycling of water in semiconductor fabs has become an attractive option for meeting the aggressive goals of the SIA's *Roadmap*¹ for reduced water consumption and waste stream discharge. However, the recommended system configuration for recycling more than 50% of fab rinse water usually includes pretreatment of recovered water, with Ion Exchange (IX) beds, to bring it to reverse osmosis (RO) product grade. Alternately, recovered water can be returned to the ultrapure water (UPW) generation stream at a pre-RO point, but this involves an upsized RO system, the possible introduction of high levels of sulfate (a problem with feed water with calcium present), increased cost of ownership (COO), and rejection of up to 40 % of the water recovered.

A technology that utilizes an electric current and ion exchange resins, and needs no chemical regenerations, electrodeionization (EDI) has been used in place of primary loop IX resins for many years. Its properties in this application are well known, and articles continue to be published touting its merits.²

The perception that fab rinse water properties are not well known and fluctuating has kept EDI from being more than a curiosity in recycle engineering. However, knowledge about recovered water has recently increased significantly through projects with International Sematech and Sandia National Laboratory. Contrary to current opinion, the appropriate EDI unit could allow

water recovery well into the 90 % range with little effort, and bring with it a concomitant reduction in water usage and discharge, and an impressive COO reduction. This paper presents the results of an EDI installation into a water system that had already been recycling, using classical IX resins. New water recovery percentages and economic figures show the merits of the application of this technology.

Introduction

For years, water conservation efforts in the Semiconductor Industry have been focused on using the inevitable wastewater from ultrafiltration, reverse osmosis, and fab rinse processes, to feed scrubbers, chillers, and horticultural efforts. Recently, fabs are recycling (returning to the fab, not just reusing) much more water because of its strongly positive impact on COO. Recycling has the effect of lowering contamination levels in polish loops, and it has helped achieve success in meeting feed and discharge limitations imposed by environmental concerns (such as in the San Jose Bay area).

Surprisingly, the decision to recycle has been a difficult one. Comparisons of the positive results of conservation efforts to the negatives of not conserving have lacked good quantitative data. Too frequently, proposed conservation programs are victims of management decisions based on outdated or incomplete accounting models. DI and Process Engineers trying to promote projects that incorporate process improvements and environmental awareness are frustrated by the cumbersome project cost justification required to move forward. Incontrovertible results with an amazing return on the investment are needed for quick approval.

Heretofore, methods of water conservation promising and delivering more impressive results have been limited to a few options, and all on the 'upstream' end (reducing point of use water consumption). One such method is in elimination of strong chemicals needing extended rinsing (e.g., ozonated UPW replacing sulfuric acid for cleaning and stripping photoresist). Also, some tools using spray technology for chemical and rinse processing are particularly successful. Another method being implemented in fabs with current immersion tank-style wetbench equipment is Rinse Optimization. Finally, at least one equipment manufacturer has embodied

the principles of *Extreme Rinse Optimization*³. Reductions of water use approaching 90 % are attainable with the right rinse implementation.

Projects with strong financial advantages, when coupled with conservation efforts (for example, instituting a program in an existing facility, Design for Environment, or recycling), need disruptive technology to spearhead a new paradigm. This technology must have the hope of bringing radically new levels of performance to either a retrofit or a new design. When this paradigm matures, the decision to recycle would be as obvious as, for example, the decision to include reverse osmosis in a UPW train has been. It's conceivable that EDI in a recycle system can create just such a new philosophy.

Presented here is the 'downstream' end (at the drain) technology that fully complements, not replaces, all of the above methods of water use reduction. This work summarizes initial efforts to characterize EDI as an efficient, robust, and cost-effective means to either retrofit or install a new recycle system. A unit was installed in parallel with existing cation-anion exchange resin beds to compare results with only those components as significant variables. The challenge in this work is to drive rinse water recovery from tank process wet benches to an extreme. The Summary section will include a comparison of the COO from recycling with EDI to that of no recycling.

Experimental Results

A. Selection

EDI equipment has not been targeted for recycling water. The technology has invariably been specified for performance in a primary water loop application. Research and applications of EDI have been primarily, and possibly exclusively, on water generation, versus water recovery. For example, in ULTRAPURE WATER Europe '98, held in 9/98, the EDI papers dealt with lowering conductivity for on-line instrumentation needs, and generation of DI water, with a focus on carbonic, silicic and other weak acids. Marketing literature from the several EDI vendors typically includes claims on how EDI handles boron, silica, CFU bacteria, TOC and CO₂, and advances in achieving 18 megohm-cm (ultrapure) quality. Potential EDI customers are cited papers about replacement of primary IX beds; CO₂, silica and other ion removal kinetics; COO

of IX bed replacement² and applications in power generation (boiler feed). Feedwater, universally RO product, is almost always at a conductivity of less than 5-6 uS/cm.

We first required that the unit accept feedwater conductivities of up to **250 uS/cm**, a value we considered sufficient to allow over 95% recycle. Monitoring at our site and others indicated that this level would represent the average high conductivity value resulting from moderate chemical processing. There would be enough dilution of rinse chemistries with trickle flows to keep the average conductivity of collected rinse waters at this relatively low level. Diversion of the first few quick-dumps from selected wet benches could also assist in keeping conductivity below an EDI's upper limit. With some extra capacity in the EDI, recycling of its product water to mix with the feed would also help during an occasional, particularly conductive event.

Coupled with this very high feed conductance tolerance, fortunately, was the much less stringent requirement that we needed EDI product water to only be better than RO product water. We set a **product conductivity target of one uS/cm** (1 megohm-cm) or better, versus fifteen megohm-cm, of which EDI is capable in a typical primary bed application. This value, though low, would prevent an increase of regenerations needed on the existing primary mixed beds--a poor trade-off for the elimination of regenerations in the recycle system.

A third requirement of the EDI was that it tolerates **high concentrations of sulfuric acid** and some **fluorides**. There are a few benches with strong fluoride mixtures. Most of the contamination in our collected rinse water is from SPM (sulfuric acid-hydrogen peroxide mixture) processing. When rejected to an EDI waste stream, it could reach quite low pH values (consider a 250 uS/cm stream of sulfuric acid increased by a factor of twenty in an EDI's concentrate stream).

The fourth requirement dealt with the volume of water to be handled. The unit had to have a **recovery rate greater than 90 %; output capability of 100 gpm**. A high recovery rate was needed to give us an overall recycle yield of greater than 90 %. The capacity of 100 gpm would allow us to recycle water from other sources on our site, and cover an increase in fab operations.

Fears were expressed from several EDI vendors. Not only were we asking for performance at a high feed conductivity, but also it was recycled water at that: perceived as containing unknown quantities of unknown chemicals, with large swings in concentration. Here's what they said, and our justification to feel optimistic:

<i>Issue:</i>	<i>Vendors' Consensus:</i>	<i>Recycle view:</i>
Feed stream contents	Conductivity too high	To Be Determined (TBD)
	Conductivity too variable	Variable, but 'too' is subjective. TBD
	Unknown components	Known components-unlike city water.
Concentrate stream conductivity	Too high--will deposit scale	Won't scale--no cations except ammonium ion, unlike city water.
	pH too low	TBD
Organics	Too many	Virtually none, unlike city water.
Iron contamination	EDI very sensitive	No Iron in our fab water!
Hydrogen Peroxide	Sensitive--must avoid	Removed in Carbon Bed.
COO	Should be OK	Should be impressive!

Table 1. Gap analysis: EDI vendors commented on the requirements for EDI when used as a replacement for primary resin beds. Compare that to the use of EDI in a recycle system.

After several interesting but unsuccessful discussions with other vendors, we were fortunate to find that our needs could be met with a unit manufactured by Ionics, Incorporated, of Watertown, MA. Although they had considerable experience with EDI applications in primary loops, they were now entering a regime in which they had none.

The correct size for our water system happened to be their smallest, the EDI 50, a 50 gpm product stream unit. The EDI 50 has a stated recovery of 95%, with a few gpm carrying concentrated reject ions to waste. Below is a table showing the feedwater characteristics for this EDI as intended to be used in a primary loop application, and an estimate of our actual feedwater characteristics. A good description of the basic requirements in a primary loop application can

be found in the reference to Ionics' web site⁴. The feedwater conductivity in recycle operation could be controlled somewhat by varying the fraction of rinse water recovered from the wet benches, since contamination is a strong function of the delay time from the start of rinsing.

<i>Parameter</i>	<i>Typical Feedwater Characteristics--Classic EDI</i>	<i>--Needs as Used in Recycle</i>
Conductivity	< 40 uS/cm	<300 uS/cm
Hardness	<0.25-1.0 ppm as CaCO ₃	No 'hardness' cations
TOC	<0.5 ppm	<100 ppb
Pressure	20-50 psi.	Dial-in
Temperature	10 to 35° C	Keep it <30° C
pH	4 to 10	Tolerate <2
Chlorine	<0.1 ppm	None
Fe, Mn, Sulfide	<0.01 ppm	None
CO ₂	<10 ppm	Highly variable, generally low

Table 2. Feedwater requirements as stated by EDI vendors compared to characteristics of the water collected for recycling.

Note that in this application, the specification for input conductivity was required to be low for the product water to meet that of a mixed primary bed IX. Since we wanted only to meet or exceed the quality of water at the point of injection to the RO product tank, we asked for only 1 uS/cm for an output specification.

Also of concern was the reject stream make-up. Our original desire was to provide the water for this from other sources, perhaps UF or RO reject, so as to maximize overall rinse water recovery. However, our other sources generally derive from untreated city water, with typical hardness cations. As we expected to discharge sulfate-containing water, which would likely cause frequent episodes of scaling, the collected rinse water was used instead.

B. Installation

The EDI unit was installed in a temporary location next to the existing recycle line. The connections to the line are shown in Figure 1. If needed, the original IX resins could be manually selected to treat the water, or even both the EDI and IX could be used for added capacity.

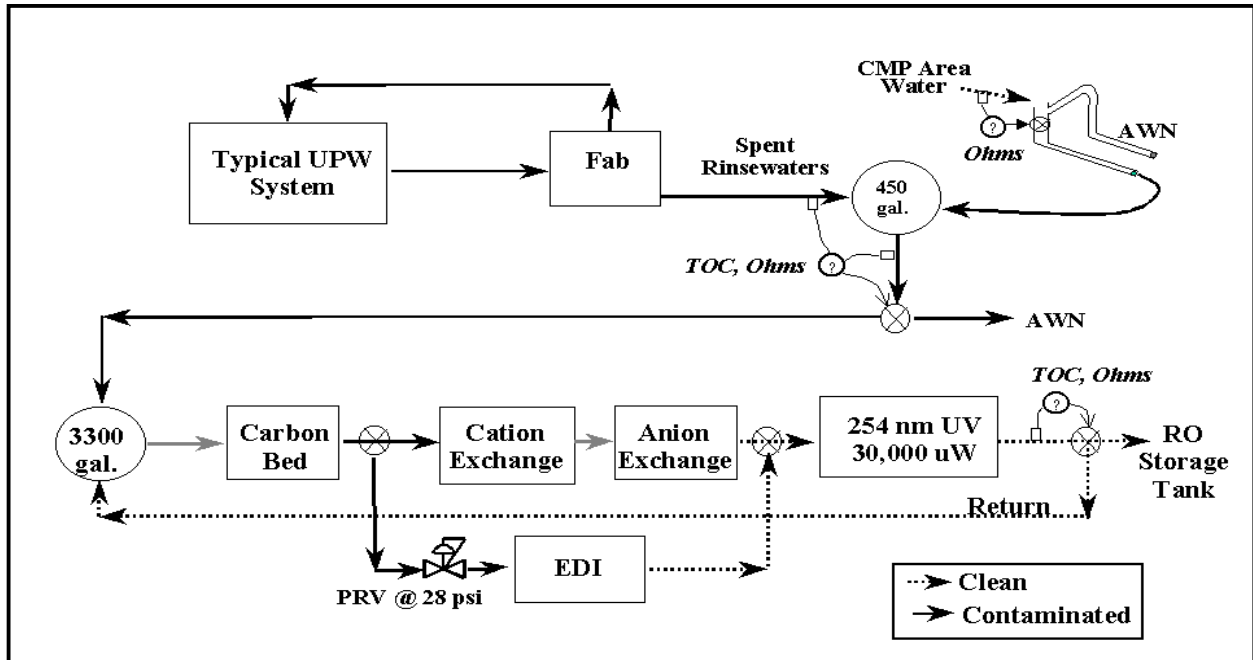


Figure 1. Plumbing of the EDI in parallel with existing IX resins. Feed pressure was dropped to meet EDI specifications. Italics are measurement points; values exceeding limits force water to AWN.

The interface to the EDI was fairly straightforward. The existing recycle system pump provided almost twice the pressure needed for the stack to operate, so a regulator was added.

Figure 2 shows an overview of the plumbing internal to the EDI, supplied by the vendor. It generally illustrates a product path, a concentrated reject stream path, and electrical power for the stack. The output pressure from the EDI was adequate to deliver the water to the RO storage tank. A check valve was also installed in the product line in an attempt to minimize changes in product line resistance that would be reflected back through to the stack output.

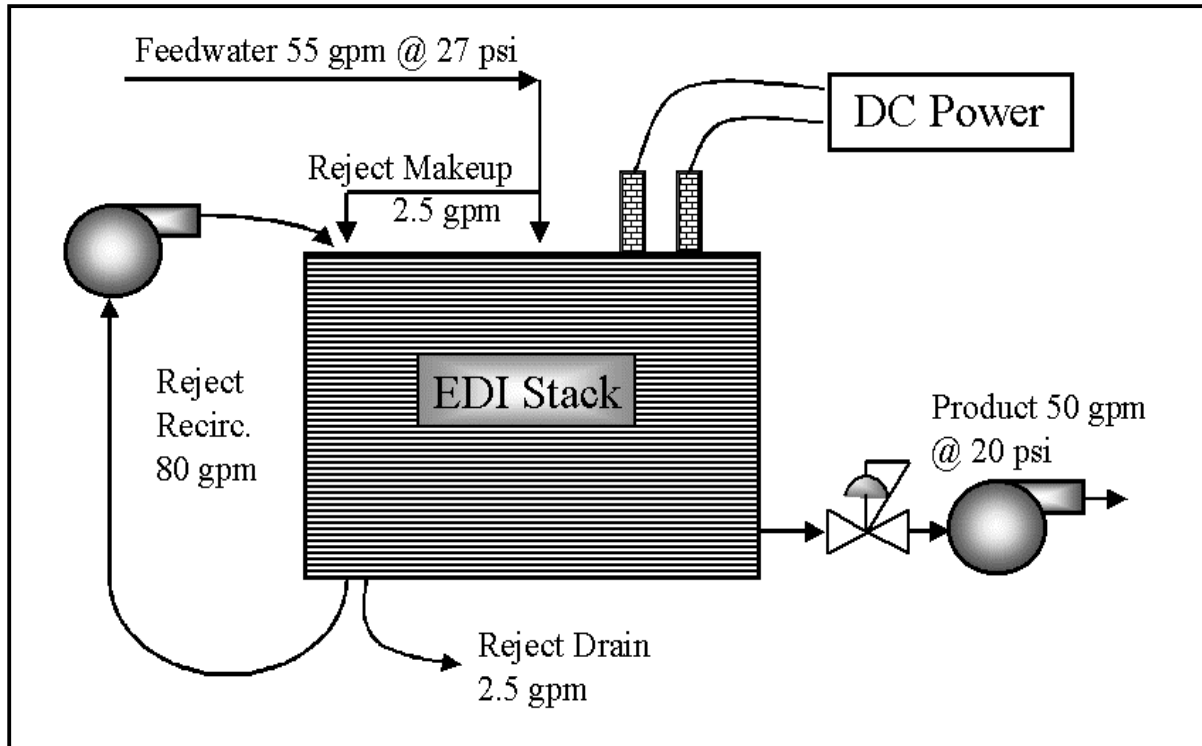


Figure 2. EDI plumbing supplied by the vendor. A constant pressure drop across the stack must be maintained with concentrate recirculation and feed/product streams.

C. Startup and Running

At initial startup, the input pressure was adjusted to provide about 55-gpm flow. Simultaneously, the concentrate stream recirculation flow was adjusted to set the input side pressure to a few pounds less than the product feed pressure. To avoid an extreme pressure difference in the event of an EDI shutdown, the feed pump in the existing recycle system was wired to the EMO of the EDI. If the EDI shut down, all water flow would be stopped.

Data were recorded about three times daily, except for special events. Figure 3 is a chart of some of the recorded values obtained from monitoring the unit's various parameters. The scale on the left is logarithmic to cover the ranges of the three important variables. Feed conductivity (diamonds) ranged from a low of 3 to a high of 1500 uS/cm. Product resistivity (squares) is in kilohm-cm; the highest value reached is almost 18000 kilohm-cm, or 18 megohm-cm. Stack power (X's) is in kilowatts.

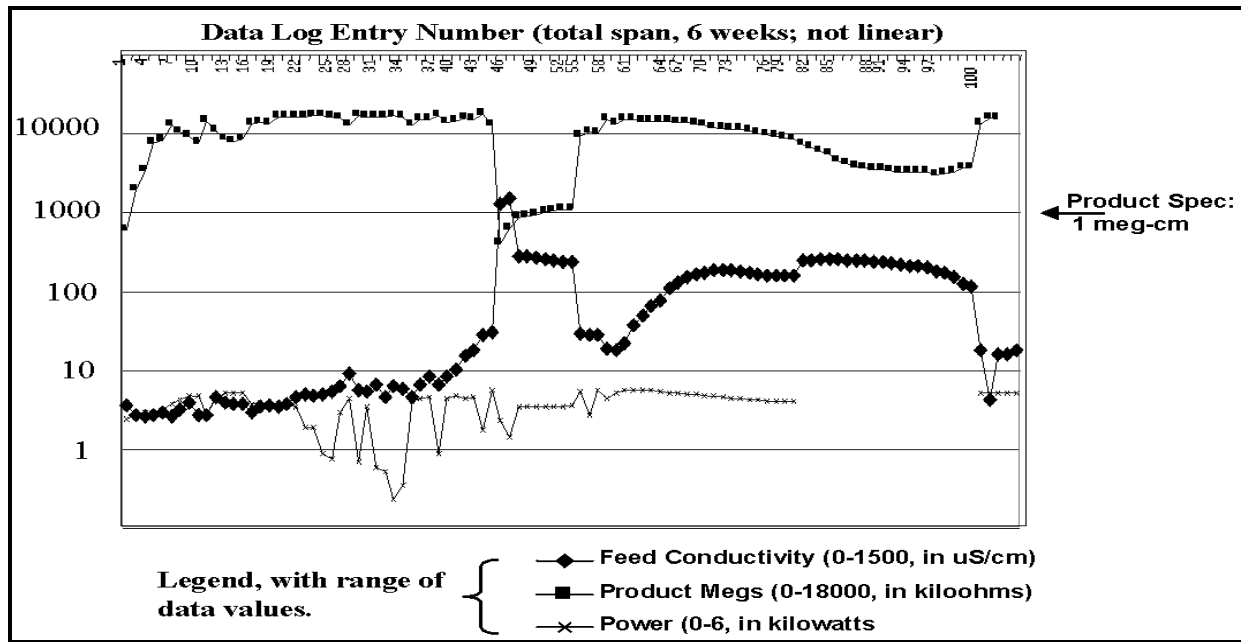


Figure 3. Data Log Chart (DLC) of EDI performance over six weeks. Our feed conductivity spec was chosen to be that which produced one megohm-cm water. Power is calculated from DC volt- and amp-meters. It includes only stack power dissipation.

Operating data were taken right from the initial turn-on. The first 14 points on the Data Log Chart (DLC) were roughly 1/2 hour apart. Within a very few minutes, product water resistivity was approaching one megohm-cm, initially low due to the ion loading of the as-purchased stack resin. Over several hours, the ions in the new stack were removed by the current flow. By the next day, we were seeing values of resistivity over 17 megohm-cm.

For several days (DLC points 15-35), feed water conductivity was running in the 2-10 uS/cm range, unusually low even for our low-use fab. Because of the extra capacity of the EDI at 50 gpm, occasional recirculation of the product to the collection tank also contributed to the low feed conductivities. During this time, the chemical balance internal to the stack shifted, causing a marked decrease in the amperage through the stack. Since it normally operates in a 'constant voltage' mode, the stack consumed much less power during these intervals, averaging about 2 kilowatts. Typically, about six kilowatts were consumed for the rest of the range of feed conductivities.

Feedwater conductivity remained low, so we had the good fortune of being able to increase it

under control to test the EDI. The first trials required two system changes. First, at the 450-gallon collection tank (see Figure 1), the diversion criteria based on conductivity was removed. That is, all water was acceptable (based on conductivity). Second, the remainder of wetbenches in our fab were connected to the recycle system. These benches had known process chemistry leaks to the water collection drain. If plumbed to the recycle system before EDI, unacceptable levels of contamination would have elicited much too frequent IX regenerations.

Conductivity at the first collection tank increased to a fairly consistent 60 uS/cm for a few days. The feed conductivity to the EDI, because of the recirculation around the recycle system to absorb the extra capacity of the EDI, settled in at around 30 uS/cm. The data during this time (DLC points 40-43) showed a slight drop in product resistivity, averaging around 15 megohm-cm. Power consumed during this period may have fluctuated due to changing chemistries within the stack prior to taking data readings, which will be discussed in the Summary section.

Next, to stress the EDI to the maximum feed conductivity the vendor estimated to be the EDI's capability, chemistry was administered to the system. For over an hour, at about five-minute intervals, about 200 milliliters of sulfuric-peroxide mix, buffered etch chemistry, 5% HF, phosphoric acid, and/or RCA chemistry were dumped into drains scattered around the fab. All of this water was collected in the 450-gallon tank, pumped to the 3300-gallon tank, and sent through the EDI.

The event is shown in Figure 3., DLC points 43-54. The conductivity in the 450-gallon tank was above 10,000 uS/cm at times, a level we did not intentionally wish to create. Feed to the EDI reached about 1500 uS/cm, about six times the conductivity we expected as a maximum feed value. The product resistivity at the maximum was still over one megohm-cm, but after another hour, the ionic load in the stack, or in the concentrate stream, drove the output conductivity up to just under 2 uS/cm. Shortly, the feed conductivity improved to just under 300 uS/cm (DLC point 45). For the next six points, as the feed conductivity swept through 260 uS/cm over about 45 minutes, product resistivity rose above 1 megohm-cm, just as the vendor had stated. The data after that event show a gradual increase in resistivity to levels prior to the over-stress test.

Another experiment, between points 57 and 93, shows that as the feed conductivity increases, product resistivity decreases, but with some lag. For example, the first jump in feed conductivity at points 57-65 shows the product resistivity barely dropping. When the feed is held at about 150 uS/cm for points 69-77, the product resistivity continues to drop. Then at point 79, the feed was abruptly increased and held steady. However, product resistivity still dropped through the range of points 80 to 95, even towards the end where feed decreased to 110 uS/cm. This behavior will be explained below.

A final experiment was run to chemically challenge some of the components internal to the stack. A specific mixture of chemistries was introduced to the rinses in the fab, bringing EDI stack feed conductivity up to about 90 uS/cm. Samples of the feed and reject stream were sent to Balazs Analytical Laboratory for 68-element scans. The following table summarizes all detected species.

<i>Element</i>	<i>Detection Limit, ppb</i>	<i>Concentration in feed, ppb</i>	<i>in Brine, ppb</i>
Al	0.5	6.4	7.8
B	2	2.9	480
Cu	0.5	nd	5.9
Mg	0.2	nd	0.7
Si	20	nd	850
Si	1 (in-house analyzer)	424 in feed, 2.76 in product	1134
Na	0.6	35	260
Sn	0.2	nd	0.9
Zn	0.5	1.0	0.8

Table 3. Summary of detected elements in stack feed and brine streams during a corrosive chemical challenge. Sodium is left over from an initial charge of salt when the EDI was purchased.

Discussion

A. Technology

The EDI unit was able to meet our specifications in terms of treating high levels of conductivity, as anticipated. Its response can be categorized broadly as follows:

- At low levels of feed conductivity (0-6 uS/cm), the unit drew relatively small amounts of current and produced water of 13-17 megohm-cm resistivity.
- At moderate levels of feed conductivity (6-50 uS/cm), the unit still produces high resistivity water (>10 megohm-cm consistently), and draws more amperage from its power supply. In a primary loop application, the vendor supplies a salt injection tank and pump to optionally add ions to the concentrate stream. We chose not to introduce more ions, but instead tried throttling the reject stream flow down to maintain an ionic level optimum for operation. As

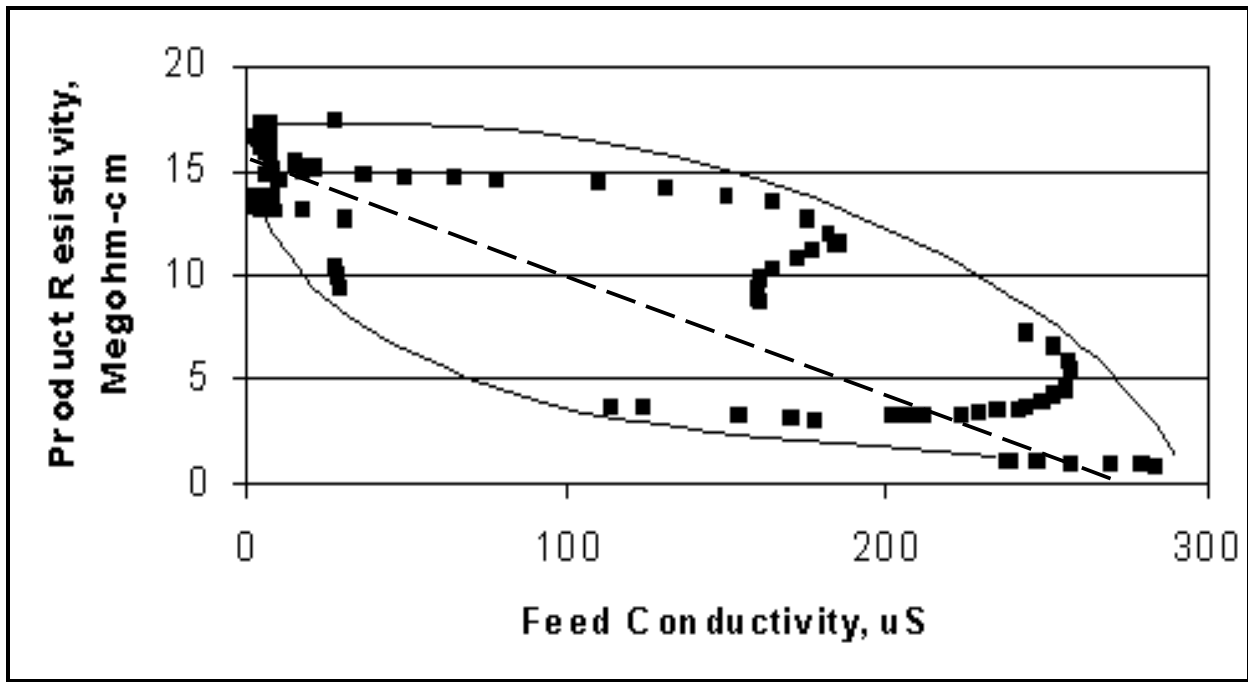


Figure 4. Product water resistivity in megohm-cm versus feed conductivity in uS/cm. The

upper curve bounds the product resistivity when the feed conductivity is increasing (arrow to right); the lower curve, when it is decreasing (arrow to left). The dashed line approximates the equilibrium product resistivity achieved only after several hours of constant conductivity feed water. The lag in response between feed water conductivity and product water resistivity accounts for the large area between the two solid curves.

shown in a Figure 5, system performance indicated we did *not* want higher conductivities in the concentrate stream.

- At high levels of feed conductivity (60-300 uS/cm), the EDI draws maximum current. Product resistivity stays relatively high even with an increased load to the system, falling between the two curves shown in Figure 4. The power supply to the stack showed signs of reaching its maximum capacity at the high end of this range, as both voltage and current drop.
- With an abnormally high conductivity event (>300 uS), the EDI performed very well (the two data above 1.4 milliSiemen/cm are not plotted on Figure 4 to keep the other data easier to read), though the output conductivity exceeded our 1 uS 'limit'. When the event passed, the EDI recovered fairly quickly and resistivity improved.
- When the feed conductivity increases rapidly from a low level, the product resistivity predictably drops, but slower than expected. The concentrate stream builds up ions, and will soon be at the ionic strength determined by feed/reject stream flow ratios. This response, product resistivity staying high out of proportion to the reject ratios, is a result of the concentrate stream conductivity being lower than the reject ratios predict until equilibrium is reached. As conductivity of the concentrate stream rises, the resistivity of the product falls, even if the feed conductivity held constant. This can be seen in Figure 4 at 165 uS, where the feed conductivity was held between 155 and 165 for an hour, during which time the product resistivity dropped from 12 megohm-cm to just over 8. During this time, the concentrate conductivity rose from about 600 uS/cm to 1200 uS/cm, which *fully* accounted for the product resistivity change (see below, Figure 5 and explanation).
- Conversely, when the feed conductivity drops from an elevated level, response by the product stream is somewhat lagging. Even though the concentrate stream is fully charged with conductive ions, and the unit can pass current at its maximum, the high ionic levels in the concentrate stream effect product resistivity more than the feed conductivity. The product resistivity will stay lower than the equilibrium value, generally following the lower curve in Figure 4, as feed conductivity decreases from right to left.

Figure 5 shows the strong correlation between *concentrate stream* conductivity and product resistivity. Product resistivity is related to *feed* conductivity only after equilibrium (after hours of constant feed conductivity). The figure shows that the product water resistivity and concentrate stream conductivity data fit a (six-degree polynomial) trend line extremely well.

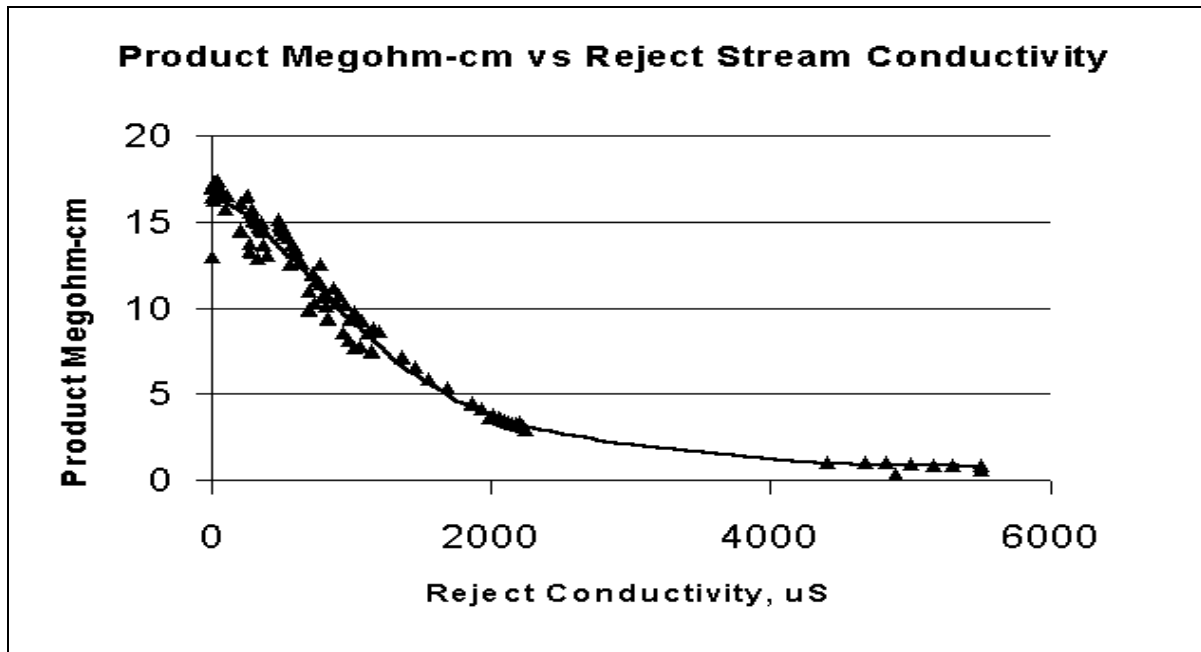


Figure 5. Relationship between product resistivity and concentrate stream conductivity. The excellent fit to the trend line ($R^2=0.975$) indicates a direct relationship between concentrate and product ionic strength. A simple exponential curve ($R^2=.91$) is also close.

The relationship between product resistivity and feed water conductivity has already been shown to be very dependent on the direction of the feed conductivity change (Figure 3). The curve in Figure 5, however, can be used to predict product water resistivity independent of the direction of change, or even magnitude, of the feed water conductivity. This unexpected strong dependence on brine conductivity result is likely explained by the physical arrangement of resins, flow paths, and differential pressures between paths. Further, the ions contributing to this lowered product resistivity are from dissociated sulfuric acid, which is strongly conductive, and not easily discriminated by ion selective membranes. More typically, mixtures of chemistries from a balanced semiconductor fab will have lower specific conductivities and higher membrane rejection, thereby producing higher product resistivities.

The non-linear characteristics described above do not affect the desired result of obtaining high resistivity water for recycling. These results may offer some insight for vendors of EDI equipment to enhance the design for operation in a recycle application.

Samples of feed, product and reject streams have shown only the constituents of rinse water from wafer processing. Analytical results from the two system output streams, shown in Table 3, show that, under conditions potentially conducive to severe corrosion, no elements constituting the materials of construction of the EDI unit have been detected at elevated levels. The EDI is able to remove silica and boron, a result seen in recent literature⁵ with another type of EDI device as well. TOC levels during events of high feed water conductivity and at steady state have shown at most a few ppb elevations.

Further experiments were run to determine the extent that the EDI can reject organics. A number of compounds were introduced into the water system during and after our fab shut down (an opportune time to test the water!). The carbon bed preceding the EDI was bypassed to make the response of the system more defined. Included were isopropyl alcohol, ethylene glycol, NMP (N-Methyl Pyrrolidone), TMAH, acetic acid, and some other compounds. The product water from the EDI was measured for TOC with a Sievers Model 800 Analyzer.

The results were very conclusive: ionized or slightly ionized organics were completely removed. A back-half solvent mixture used for resist and dielectric residue removal was eliminated through the EDI. Wafers that had been coated with resist were developed in TMAH; all the developer and rinse water was sent to the EDI, with no TMAH *or* resist residue detected. Further details are available at an EDI website the author maintains⁷.

B. Estimate of Economic Benefits

The following is an estimate of the some of the costs of operation of the relevant generation and recycling areas of our DI system. Some of the benefits are immediate; others are delayed (like

depreciation, which is not included), or very site-dependent (like labor arrangements, not included).

The biggest outlay, of course, was the EDI unit itself. As a direct replacement for IX beds in place at our site, minimum plumbing changes were needed. The installed cost was somewhat under \$100,000 for the 50-gpm capacity unit we purchased.

1. The reduced operating time of the RO would allow that \$12,400 per year for pre-RO filters would be avoided. The reduced operating time of the RO would allow that \$2000 per year for membrane cleaners would be avoided.

2. Elimination of the recycle IX beds and processing of higher resistivity water from the EDI would result in savings of \$14,400 for regeneration chemicals for the recycle system and primary mixed bed resins.

4. Electric charges for a 25 BHP pump are about \$3100/year (at \$0.042/kwh, using faceplate consumption values). Running at 100% of capacity (typical for a system with no recycle), the cost of electricity for the various pumps, is:

- a. Ultrafilter pump (booster): 15 BHP=>\$1800 per year;
- b. RO pumps: 25 BHP x2 => \$6200 per year.

Because these pumps don't operate when recycled water is used, electricity charge savings proportional to the percentage recycle are obtained. If they ran at 10 % duty cycle, yearly charges would be cut to \$800 from \$8000.

On the negative side, the EDI installation would need two 7.5 BHP pumps, and the stack itself. They would consume about 7.4 kilowatts/hour, or 144 kWh/day. At \$.042/kWh, this yields about \$7.45/day, or \$2723/year.

5. Last, the raw water supply and discharge costs are substantial. In our system, recycling 45 Kgpd reduces discharge by about 80 Kgpd, due to inefficiencies in the UPW front end. The cost

for this (\$4.64/Kgal for supply and discharge fees, Palo Alto) results in a savings of \$4.64 X 80, or \$387/day savings. This sums to \$141,000 per year.

<i>Item:</i>	<i>Cost without EDI</i>	<i>Cost with EDI</i>	<i>UPW Operation Savings</i>
Electric Power	\$6,200 + \$1,800	\$800 + \$2723	\$4,377
Chemicals (regen, cleaning)	\$16,000	\$1,600	\$14,400
Pre-RO Filters	\$16,000	\$1,600	\$14,400
Cost of water/discharge	\$156,666	\$15,666	\$141,000
Misc. items (maintenance)	\$3,000	\$3,000	0
M&L to install 50 GPM EDI		\$100,000	-\$100,000
Totals*	\$199,666	\$125,389	\$74,277
<i>Totals** with M&L upgrade to 100 gpm</i>	\$399,332 (twice the 50 gpm)	\$50,000 + \$125,789	\$223,543

Table 4. Summary of COO savings when Recycling with EDI. The totals shown are with a 50-gpm and a 100-gpm installation.

Table 4 shows a summary of the savings estimates. The Totals* include materials, labor, and net gain for a 50-gpm installation; Totals** shows this for a 100-gpm installation. The 100-gpm figure assumes the original UPW operation needed twice the pumping, chemicals, etc. of the 50-gpm system. In summary, the first year savings from an EDI installation at the 50 gpm rate would be \$74K; in subsequent years, \$174K. For a 100-gpm unit, first year savings would be \$223K, and subsequent years would be \$373K.

Summary

We can fill in some of the TBD's from Table 1 now. The feedwater conductivity can be elevated and variable, and the EDI will still produce high resistivity water for injection into the main UPW system at the RO product tank. There's no evidence of scaling or other chemistry-related

performance degradation. The waste stream pH, monitored by sampling during high conductivity events, has shown no problems. Testing for metal contamination shows little or no structural component dissolution, and excellent rejection of some historically difficult elements. Hydrogen peroxide has not been detected. Finally, the brief look at economics has shown a very positive result. There has been no maintenance required, no regenerations, and it operates with strong or weak feed streams with no technician involvement.

Electrodeionization has proven to be of significant value as a recycle system component. Just prior to fab shut down, the recycle system was treating an estimated 95% of the collected water, including every rinse from most (including SPM) process baths. The loss due to the reject stream from the EDI left system recovery still over 90%. The installation has met every desired metric, and more. In fact, the EDI technology has made available numerous opportunities for water reuse heretofore felt prohibitive due to cost or unknown water quality.

Acknowledgements

This work was made possible by the generous donation of unending engineering support from Ionics, Incorporated, of Watertown, MA. Not that the unit malfunctioned in any way: they responded to my strange requests and potential threats to the EDI unit with professionalism and much patience.

Biography

Russ Parker, Ph.D.

Dr. Parker is a member of BioScience Products at Agilent Technologies in Palo Alto, CA. He has been a member of the Sematech S116 Water Use Optimization/Conservation project, and has been involved in various research projects with the ERC⁵, Stanford University, and Sematech. Dr. Parker has a Ph.D. in Analytical Chemistry from Purdue University.

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