

METHOD FOR RECOVERING METALS FROM SOLUTIONS**Field of the Invention**

This invention concerns a method for recovering metals from solutions.

5 Background of the Invention

The toxicity of metals has been well documented, and releasing effluents containing metals into the environment is now strictly controlled by environmental protection laws. For instance, the effluent limitations on copper are as low as about 0.0017 pounds of copper per 1,000 pounds of effluent (about 1.7 ppm). 40 C.F.R. § 421.52. The electronics industry generates large volumes of used circuit-board etching solution containing high levels of copper ions. This effluent cannot be discharged directly into the environment without first being subjected to expensive procedures to reduce the effluent copper concentration.

Some processes are known for removing metal ions from solution. For instance, Spedden et al.'s U.S. Patent No. 3,634,071 is directed to a process for accelerating the precipitation of copper from solution. According to Spedden's process, a solution containing copper ions must be treated with sulfur dioxide. The purpose of the sulfur dioxide is to produce hydronium ions (H^+) by reacting with water to form sulfurous acid (H_2SO_3). This compensates for the consumption of hydronium ions that occurs during the reduction of copper ions. Spedden teaches that using sulfuric acid as the sole source of hydronium ions is unacceptable in a process for recovering copper ions from solution.

Guess' U.S. Patent No. 5,122,279 also describes a process for removing dissolved metals from water. The process comprises treating solutions containing heavy metals with ferrous dithionate to form a complex which precipitates from solution. Guess attempted a number of copper recovery trials to compare his process to other processes for recovering copper. Example I of Guess discusses treating a feed solution with steel wool.



Guess indicates that some removal of copper was visually evident as the steel-wool mass gradually turned from steel color to copper-colored fibers. Atomic absorption spectrometry of the treated solution indicated that only
5 28% of the copper in the solution was collected on the steel wool.

Example VI of Guess discusses removing copper from solution using iron particles. A litre of a solution having a pH of about 9 and containing copper
10 ions was treated with an equimolar quantity of iron particles. A sample of this solution was withdrawn for filtration after a coating of metallic copper was deposited on the surface of the iron particles. Analysis of the sample determined that approximately 87%
15 of the copper remained in solution. Hence, Example VI of the Guess patent teaches that only about 15% of the copper ions in solution can be recovered as copper metal by treating the solution with iron powders. A 15% conversion is obviously unacceptable when the copper
20 concentration in an effluent can be no greater than about 2 parts-per-million.

Guess also discusses U.K. Patent Application GB 125828 A. This application describes a process involving contacting a solution containing copper ions
25 with steel wool. According to Guess, the problems associated with this method include: (1) an uneconomically low conversion of copper ion to copper metal; (2) a high cost associated with steel wool; and (3) a high labor cost associated with handling the
30 materials.

Despite ongoing investigations, a process for efficiently and inexpensively recovering metals from solutions containing ions of the metal still has not been developed. Although it is known to treat solutions
35 with iron to precipitate low levels of copper, this reaction has not been effectively tailored for recovering copper ions from used circuit-board etching solutions. Moreover, the patents discussed above teach



that simply using iron to recover copper metal is an inefficient and unacceptable method for recovering copper from solutions containing copper ions.

Summary of the Invention

5 The present invention provides a process for recovering metals from aqueous solutions. The method comprises treating aqueous solutions containing ions of a first metal, such as copper (II), with a finely-divided reducing metal within a controlled pH range to
10 precipitate the first metal from solution. The invention addresses the problems identified in the Background of the Invention for prior related processes. A preferred process according to the present invention accomplishes at least two goals: (1) The metal ions in
15 solution are reduced to the zero oxidation state to produce reusable metals. For instance, copper (II) is reduced to copper (0). The recovered copper metal preferably should have a sufficient purity to allow for subsequent use, such as greater than about 60% pure.
20 (2) The concentration of copper (II) ions remaining in solution is reduced to be within applicable environmental regulations, such as from about 2 ppm to about 3 ppm, prior to disposal or discharge into the environment.
25 One embodiment of the method comprises treating an aqueous solution containing metal ions with a sufficient amount of an inorganic acid to obtain a pH of less than about 2.5. Thereafter, a finely-divided metal reducing agent is added to the solution in an amount
30 sufficient to reduce substantially completely the dissolved metal ions to metals (i.e., a metal in the zero oxidation state). The reducing metal added to the solution has an oxidation potential greater than the metal ions in solution. Without limitation, a preferred
35 inorganic acid is sulfuric acid, and a preferred reducing metal is iron.

The size of the metal particles also appears to influence the efficiency of the reaction. When iron is



used as the reducing agent, the iron preferably should have a mesh size smaller than about 350 mesh, and even more preferably should have a mesh size of at least as small as about 400 mesh. The iron powder may be added
5 to the solution batchwise or continuously, and the solution may be agitated during the addition.

A particular embodiment of the invention comprises treating a solution containing copper ions with a sufficient amount of an inorganic acid to obtain
10 a pH of less than about 2.5. A finely-divided metal powder is then added to the solution in an amount sufficient to substantially completely reduce the copper ions to copper metal. The metal preferably has a mesh size of at least as small as about 350 mesh and an
15 oxidation potential greater than copper. The copper metal is then recovered, such as by filtration, with the solution thereafter having a copper ion concentration of less than about 5 ppm, preferably from about 2 ppm to about 3 ppm, and even more preferably less than about 2
20 ppm.

A preferred embodiment of the method comprises first diluting an aqueous solution containing copper ions with water. Without limitation, a preferred dilution is about a five-fold volume dilution. The
25 diluted solution is then treated with a sufficient amount of sulfuric acid to obtain a solution pH of from about 1.0 to less than about 2.5. A sufficient amount of iron powder is then added to the solution to precipitate the copper ions as copper metal. The amount
30 of iron to be added to the solution may be determined empirically, or by measuring the oxidation-reduction potential of the solution using techniques known in the art. The iron powder has a preferred mesh size of at least as small as about 400 mesh. The copper metal that
35 precipitates is recovered using a filter press, and the solution thereafter has a copper ion concentration of less than about 5 ppm, preferably less than about 2 ppm.



The recovered copper metal has a purity of greater than about 60 percent.

An object of the present invention is to provide a process for treating circuit-board etching solutions with iron powder to precipitate dissolved copper ions as copper metal, thereby obtaining an etching solution that is substantially completely free of copper ions.

Still another object of the present invention is to provide a process whereby a substantially pure copper metal can be obtained from used circuit-board etching solutions by treating such solutions with iron powder wherein the copper ion concentration in the treated etching solution is decreased to about 2 parts per million.

Brief Description of the Drawing

FIG. 1 is a flow chart showing certain process steps for a particular embodiment of the present invention.

Detailed Description of the Preferred Embodiments

In accordance with one embodiment of the present invention, finely-divided metal powders are used as reducing agents to precipitate from aqueous solutions metals having a lower oxidation potential. The process steps for one particular embodiment of the invention include: (1) obtaining an etching solution containing dissolved metal ions; (2) diluting the solution with water; (3) acidifying the diluted solution with an inorganic acid to a pH of below about 2.5, and preferably from about 1.0 to about 2.0; (4) adding a reducing metal, having a particle size of 350 mesh or smaller, preferably at least as small as about 400 mesh, to the solution. Without limiting the present invention to one theory of operation, it appears that an oxidation/reduction reaction (redox reaction) occurs upon the addition of the reducing metal to the solution. For instance, iron may be used as a reducing metal if copper ions are dissolved in solution. Iron (0) reduces

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copper (II) to copper (0) metal; and (5) recovering the precipitated metals.

Each of the reagents used to practice this invention, as well as each of the process steps summarized above, will be discussed in more detail below.

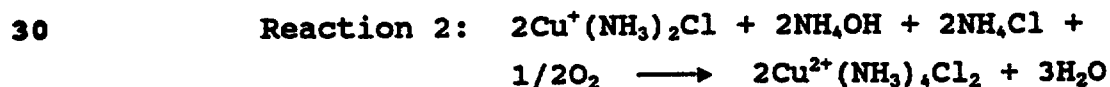
I. REAGENTS

A. Circuit-Board Etching Solution

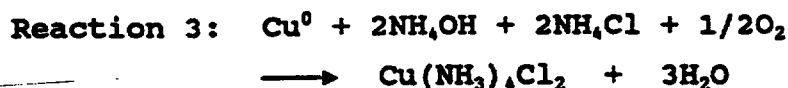
One embodiment of the present invention is particularly useful for treating ammoniacal etching solutions to precipitate copper ions. "Ammoniacal" refers to a solution containing ammonia or ammonium salts. Such solutions also may contain a number of other inorganic species, such as cupric chloride. Ammoniacal etching solutions are basic, having a pH of typically greater than about 9.

A discussion of ammoniacal etching solutions is provided in Lee's U.S. Patent No. 4,915,776, entitled "Process for Etching Copper with Ammoniacal Etchant Solution and Reconditioning the Used Etchant Solution." Lee's patent is incorporated herein by reference. According to Lee's patent, the reactions between copper and the ammoniacal etching solution can be summarized as follows:

1. Reactions of Copper with Ammoniacal Etching Solutions



The overall reaction can be determined by adding reactions 1 and 2. The result is:



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Reaction 3 shows that the reaction involves the reduction of Cu metal [indicated as Cu^0 , i.e., copper in the zero oxidation state] with ammonium hydroxide (NH_4OH), ammonium chloride (NH_4Cl) and oxygen. The product is an oxidized ammonia copper complex with copper oxidized to Cu^{2+} .

An "oxidation reaction" refers to any reaction in which electrons are transferred. "Oxidation" specifically refers to a chemical species which loses electrons. "Reduction" refers to a chemical species that gains electrons. The compound or element which gains electrons is referred to as the "oxidizing reagent"; the agent that loses electrons is referred to as the "reducing agent." By way of example, if copper (II) ions are present in an etching solution, then the oxidation reaction would refer to the transfer of electrons from Fe (0) to copper (II). Iron loses two electrons and becomes positively charged, i.e., is oxidized. Copper (II) gains two electrons and becomes neutral, i.e., is reduced. Copper (II) is referred to as the "oxidizing agent."

The terms "reduction potential" and "oxidation potential" also are used in this application. "Oxidation potential" refers to the potential of a chemical species to lose or donate electrons. "Reduction potential" refers to the potential of a chemical species to gain electrons. A discussion of these concepts can be found in a number of standard chemistry texts, including, for example, Cotton and Wilkinson's "Advanced Inorganic Chemistry," published by John Wiley & Sons.

B. Metal Powder

One aspect of the present invention involves treating an etching solution with a finely-divided metal. "Finely divided" is defined below in terms of mesh size. The metal is selected to have an oxidation potential sufficient to reduce the metal ions in solution to the zero oxidation state. The selection of

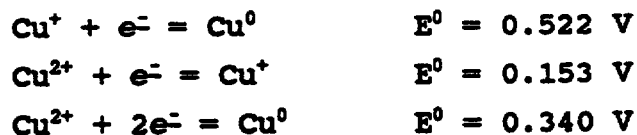
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the metal will depend upon a number of factors, including the oxidation potentials of the metals in question. It will be appreciated by one skilled in the art that a number of metals have a sufficient oxidation potential to reduce a particular ion, such as copper (II). Whether a particular metal has a sufficient oxidation potential can be determined either empirically, or by examining the electrochemical series and calculating the free energy associated with a particular reaction. This procedure is known to those of skill in the art. And, the electrochemical series is published in a number of standard references, including The Handbook of Chemistry and Physics, which is published by CRC Press.

By way of example, if the dissolved ion of interest is copper (II), then a number of metals potentially can be used to reduce the copper (II) to copper (0). This can be determined by knowing the following potential data for copper and comparing such data to the potential of the reducing agent:



25

By way of example and without limitation, metals that can be used to reduce copper (II) to copper (0) include: (1) magnesium ($\text{Mg}^{2+} + 2\text{e}^- = \text{Mg}$; $E^0 = -2.375 \text{ V}$); (2) manganese ($\text{Mn}^{2+} + 2\text{e}^- = \text{Mn}$; $E^0 = -1.029 \text{ V}$); and (3) iron ($\text{Fe}^{2+} + 2\text{e}^- = \text{Fe}$; $E^0 = -.409 \text{ V}$). For the present invention, applicant has determined that iron is a preferred metal useful for reducing copper (II) ions in solution to copper (0). One reason for this, other than the fact that iron has a sufficient oxidation potential, is because iron is readily available and relatively inexpensive.

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As stated in the Background of the Invention, steel wool and iron particles previously have been tried



to precipitate copper ions from solution. These previous processes have proven unsatisfactory. Surprisingly, and contrary to the teachings of the prior art, applicant has determined that a process involving
5 using an iron powder that (1) is at least about 70% pure, and preferably at least about 90% pure, and (2) has a suitably small mesh size, produces an efficient reduction of copper ions to copper metal in acidic aqueous solutions. Currently, a mesh size smaller than
10 about 350 mesh is preferred, and is even more preferably at least as small as about 400 mesh. Thus, as used herein, the phrase "finely-divided metal" describes a metal having a sufficient purity and a sufficiently small mesh size to efficiently carry out the desired
15 reaction, namely the reduction of dissolved metals ions to the zero oxidation state.

One skilled in the art will realize that iron powders meeting the requirements stated herein can be obtained from a number of sources. One source of an
20 iron powder suitable for the present invention is Hoeganaes Company, ~~of Riverman, New Jersey~~.

Etching solutions, particularly ammoniacal etching solutions, are basic and therefore have a pH greater than about 7. More typically, ammoniacal
25 etching solutions have a pH of greater than about 9. A surprising increase in reaction efficiency, in terms of the recovery of copper metal and the decontamination of etching solutions, can be achieved by treating etching solutions with finely-divided iron powders at a pH of
30 less than about 2.5, and even more preferably at a pH of from about 1.0 to about 2.0.

Thus, the process of the present invention includes the step of acidifying the solution prior to treating the solution with the finely-divided metal
35 powder. Acidification typically is accomplished using an inorganic acid. Suitable inorganic acids include, without limitation, hydrochloric acid, nitric acid, sulfuric acid and phosphoric acid. A presently



preferred inorganic acid is sulfuric acid. Sulfuric acid is readily available from a number of commercial sources, and is relatively inexpensive. Furthermore, and again without limiting the invention to one theory
5 of operation, applicant currently believes that the intermediate formation of copper sulfate aids the subsequent reduction of aqueous copper (II) ion to copper (0) metal.

II. Process Steps

10 Using the reagents discussed above, the present invention provides a process whereby metal ions are reduced and precipitated from solution. Certain of the process steps of the invention will now be discussed in more detail.

A. Dilution

15 A used industrial solution, such as ammoniacal etching solution, generally is diluted with water as a first process step. One purpose of this dilution is to decrease the heat of neutralization that occurs upon the
20 addition of an inorganic acid to the etching solution. One skilled in the art will realize that the amount of dilution required for a particular reaction will depend upon the amount of heat of neutralization that is generated. To provide a guideline, the solution should
25 be maintained at a temperature below about 100°C so that the water, and any compounds less volatile than water, is not vaporized during the process. Even more preferably, the dilution should be sufficient so that the heat of neutralization does not increase the
30 temperature of the solution to much greater than about 50°C.

By way of example only, a five-fold volume dilution of ammoniacal etching solution sufficiently controls the temperature increase that results from the
35 evolution of heat during addition of the inorganic acid. One of ordinary skill in the art will realize that there is nothing critical about a five-fold volume dilution. Smaller and larger volume dilutions also may suffice.



-11-

Presently, it is believed that volume dilutions of from about a two-fold volume dilution to about a ten-fold volume dilution, preferably from about a three-fold volume dilution to about a six-fold volume dilution, and even more preferably about a five-fold volume dilution, will suffice for the present invention.

B. Acidification

Following dilution, the solution then is treated with an inorganic acid. pH has a surprising influence on the efficiency of the reaction. The influence of pH on the reaction is considered further in the examples provided below. However, when a solution having a pH of greater than about 3.0 is treated with a finely-divided iron powder, the recovery of copper metal from the solution is unacceptably low. Specifically, when the pH of the solution is greater than about 3, atomic absorption spectrometry shows that the recovery of copper metal from the ammoniacal etching solution is less than about 20%. However, if the pH is less than about 3, then a specific pH need not be achieved in order to provide a satisfactory reaction. In other words, although pH is important, a range of pH values below about a pH of 2.5 still provides satisfactory results.

C. Addition of Finely-Divided Metal Powder

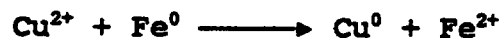
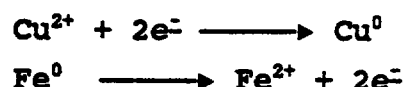
Following the step of acidification, the solution is ready for treatment with a reducing metal. The finely-divided metal powder may be added to the etching solution either batchwise or continuously. Currently, the continuous addition of metal powder is considered preferable to batchwise addition. Presumably, continuous addition prevents agglomeration of the metal powders in solution, thereby providing more surface area for reaction with the metal ions in solution.

The amount of metal powder added to the solution depends on the amount of oxidized metal ions in solution. If the total amount of dissolved ions in



-12-

solution is known, or if the concentration of the metal ions in solution is known, then the amount of iron powder that should be added to the solution also can be determined. For instance, if the metal in solution is copper, then about an equimolar amount of iron should be added to the solution. This is because the reaction appears to involve a 1:1 molar ratio of iron and copper. This can be seen by comparing the half reactions for copper and iron as shown below:



15

This reaction shows that an equimolar amount of iron (0) should be added to reduce the copper (II) ion to copper metal. However, in practice it is generally preferred to add a slight molar excess of the iron powder to the copper-containing solution. Currently, from about a 1.1 to about a 1.5 molar excess of iron is added to the solution to ensure complete reduction of the copper (II) ion to copper metal.

An alternative method for determining the amount of reducing metal that should be added to the solution containing metal ions involves determining the oxidation-reduction potential (ORP) of the solution. ORP involves measuring the voltage capacity of the solution. The method for determining the amount of iron powder to be added to a solution comprises first forming a solution having a known concentration of ions in solution.

For instance, if the solution is an ammoniacal solution containing copper (II) ions, a standard solution can be formed having about the same concentration of copper (II) ions. The potential of the solution is then measured using standard devices known in the art. Thereafter, iron powder is added to the



solution until the supernatant has a copper (II) ion concentration of about 2 ppm. The potential of the solution is again measured. The value of the potential is then used as a reference point for determining how much iron should be added to larger, industrial quantities of etching solution.

The reaction also is facilitated by agitating the reaction during, and perhaps subsequent to, the addition of the finely-divided iron powder. Agitation can be accomplished in a number of ways. For instance, the etching solution can be continuously stirred with devices known in the art, such as mechanical stirrers. It will be apparent that magnetic stirrers are not preferred because if magnetic metals, such as iron particles, are added to the solution such particles will be attracted to the magnetic stir bar. Moreover, one skilled in the art also will understand that agitation methods other than mechanical stirring can be employed. One example would be to sonically agitate the solution.

D. Recover of Reduced Metals

The finely-divided metal apparently reduces metal ions in the solution that have a lower oxidation potential than does iron. Once the etchant solution is treated with a reducing metal, the dissolved metal ions having a lower oxidation potential are reduced and may precipitate from solution. Sometimes the pH of the solution may require adjustment upwards in order to cause the reduced metals to precipitate. The composition containing the precipitated metal is then passed to a press filter to reduce the amount of water present in the precipitated solids. Although press filters are known in the art, a presently useful press filter is a J-press filter by JWI Inc., having a 630 mm plate size. Once the water content of the precipitated solids is reduced, the dehydrated solids are recovered.

When the metal in solution is copper ion, the product from the press filter is both copper metal and an etching solution that has had the copper ions



substantially completely stripped therefrom. As used herein, the phrase "substantially completely" means a solution that has a metal-ion concentration of less than about 5 parts-per-million (ppm), preferably less than about 3 ppm, and even more preferably from about 1 ppm to about 2 ppm.

The purity of the copper metal and the level of copper ion in the treated etchant solution was determined using atomic absorption. Atomic absorption is an analytic process known to those of ordinary skill in the art. For the present invention, a Perkin/Elmer Atomic Absorption Spectrometer, Model No. 2280, was used to determine both the purity of the copper metal obtained using the process and the level of copper ions still remaining in solution once the etching solution is treated according to the present invention.

An atomic absorption spectra of a copper sample obtained according to the process of the present invention showed that a copper purity of greater than about 70% can be obtained. Perhaps more important, and in contrast to the teachings of the prior art, the concentration of copper ions in solution following treatment according to the present invention is less than about 3 ppm.

25

III. Examples

The following examples are provided for illustrative purposes only. These examples are in no way intended to limit the scope of the invention to the particular aspects illustrated by such examples.

30

Example 1

This example describes treating a solution containing copper ion with iron powder without acidifying the solution prior to the addition of iron powder. A 250 ml aliquot of an etchant was obtained having a copper concentration of about 135 g/l. Thus, the 250 ml aliquot had a total copper content of about 33.75 grams, or about 0.53 moles. To this aliquot was added 33.75 grams (0.60 mole) of iron having a mesh size



-15-

of about 400. Thus, about a 1.12 molar excess of iron was added to the solution. Upon the addition of iron, the solution remained unchanged in appearance, indicating that the amount of copper in solution remained relatively unchanged. Thus, treating a solution with iron powder without first acidifying the solution is an unacceptable method of recovering copper metal.

Example 2

This example considers what affect acidifying the solution has on the efficiency of the reaction. An etchant solution having the concentration discussed in Example 1 was obtained. Sulfuric acid was added to this solution. The pH target value was about 2.5. However, as the addition of sulfuric acid continued, the viscosity of the solution slowly increased. At a pH of about 7.6, the solution turned unmanageably viscous. This may be the result of the formation of copper hydroxide. This experiment was discontinued when the solution no longer could be stirred.

Example 3

This example illustrates what affect diluting and acidifying the solution has on the efficiency of the reaction. A 250 ml aliquot of an etching solution was obtained as described in Example 1. The aliquot was then diluted with water in a 1:5 volume ratio, i.e., a five-fold volume excess of water was added to the solution. The addition of sulfuric acid was then begun. As the pH approached 7.5, the solution became increasingly turbid. As the pH continued to decrease as more sulfuric acid was added, the solution remained turbid until a pH of about 2.5 was obtained. At this pH, the turbidity disappeared and the solution became blue, apparently indicating the formation of aqueous copper sulfate. 33.75 grams of iron powder, having a particle size of about 400 mesh, were then added to the solution. An immediate reaction occurred, and metallic copper began to precipitate. The solution was then



-16-

filtered to remove the precipitated copper metal. An aliquot of the filtered supernatant was submitted for atomic absorption analysis. The results of the atomic absorption showed that the copper concentration in the supernatant was about 2.67 ppm.

Example 4

This example further considers the affects of pH on the reaction efficiency. An etching sample was formed having a copper (II) ion concentration of about 180 g/l copper. The etching first was diluted with a five-fold volume of water. The pH of the solution was then adjusted to be about 3.2. A 250 ml aliquot of the etching solution (containing about 45 grams, .71 moles of copper) was then treated with about 45 grams (0.805 moles; a 1.1 molar excess) of iron powder having a mesh size of about 400. A reaction was observed and the solution turned a lighter shade of green. Copper metal also was seen to precipitate. However, the reaction did not continue to completion. It was clear that acidifying the solution to a pH of only about 3.2 did not achieve the desired result. As a result, acidifying to a pH of at least as low as about 2.5 as stated above in Example 3 is preferred and results in a much more efficient reduction of copper ion to copper metal.

Example 5

This example describes the treatment of a cupric chloride solution with iron powder according to the present invention. The solution was diluted as described above in Example 4, and then sulfuric acid was added until a pH of about 2.5 was obtained. A slight excess (about 1.1 molar excess) of iron powder was then added to the solution. The solution turned clear, with metallic copper particles settling to the bottom of the container. Thereafter, the filtrate was analyzed by atomic absorption spectrometry, which indicated that the filtrate contained about 100 ppm of copper.

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-17-

Example 6

This example also evaluated what affect pH has on the reaction efficiency. The experiment was conducted exactly as in Example 5, except that the initial pH was adjusted to about 1.5, instead of 2.5. The filtrate was then analyzed using atomic absorption spectrometry. The copper concentration of this sample was less than 1.0 ppm. Thus, the examples discussed herein show that the pH should be less than about 3, preferably less than about 2.5, and even more preferably from about 1.5 to about 2.5, in order to obtain a supernatant that is substantially completely free of copper ion.

Example 7

The procedure of Example 5 was repeated with the addition of a final pH adjustment step. This was done in order to obtain a solution having a pH acceptable for introduction into the sewer system. The final pH of the solution was raised to 5.5 with the addition of 50% aqueous sodium hydroxide. The production of iron hydroxide was observed, in addition to the metallic copper produced after the earlier process steps. Thereafter, the filtrate was analyzed by atomic absorption spectrometry, which indicated that the filtrate contained less than 1 ppm copper. Additionally, the precipitated material was analyzed by atomic absorption spectrometry for metallic composition. This indicated that the composition of the product as approximately 50% copper and 50% iron.

Example 8

The procedure of Example 7 was repeated. However, a 50% aqueous solution of magnesium hydroxide was used instead of sodium hydroxide for the final pH adjustment step. A greatly lessened formation of iron hydroxide was observed, possibly due to the slower rate of neutralization that occurs when using magnesium hydroxide. The precipitated material was then analyzed by atomic absorption spectrometry for metallic



composition. This analysis indicated that the composition of the product was greater than 70% copper, and less than 30% iron.

Having illustrated and described the principles
5 of the present invention in many preferred embodiments,
it should be apparent to those skilled in the art that
the invention can be modified in arrangement and detail
without departing from such principles. I claim all
modifications coming within the spirit and scope of the
10 following claims.

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Claims

1. A method for recovering copper metal from an aqueous solution containing copper ions, comprising the steps of:

5 adding to the solution a sufficient amount of an inorganic acid to obtain a solution pH of less than about 2.5; and

adding a finely-divided reducing metal to the solution in an amount sufficient to reduce substantially
10 completely the copper ions in solution, the reducing metal having an oxidation potential greater than copper.

2. The method according to claim 1 wherein the inorganic acid is sulfuric acid.

3. The method according to claim 2 wherein the
15 pH of the solution after the addition of sulfuric acid is from about 1.5 to about 2.0.

4. The method according to claim 1 wherein the reducing metal is iron.

5. The method according to claim 4 wherein the
20 iron has a mesh size smaller than about 350 mesh.

6. The method according to claim 5 wherein the iron has a mesh size at least as small as about 400 mesh.

7. The method according to claim 1 wherein the
25 step of adding metal to the solution comprises adding the metal continuously.

8. A method for recovering copper metal from an aqueous solution containing copper ions, comprising:
treating the solution with a sufficient amount
30 of an inorganic acid to obtain a pH of less than about 2.5;

adding to the solution a sufficient amount of a reducing metal to substantially completely reduce the copper ions in solution, thereby forming precipitated
35 copper metal, the reducing metal having a mesh size of at least as small as about 350 mesh, the metal also having an oxidation potential greater than copper; and





recovering the precipitated copper metal from the solution, the solution thereafter having a copper ion concentration of less than about 5.

9. The method according to claim 8 wherein the
5 inorganic acid is sulfuric acid.

10. The method according to claim 8 wherein the reducing metal is iron.

11. The method according to claim 10 wherein the iron has a mesh size at least as small as about 400
10 mesh.

12. The method according to claim 8 wherein the the solution has a copper ion concentration of less than about 2 ppm following the step of recovering the copper metal.

13. A method for recovering copper metal from an aqueous solution containing copper ions, comprising:
adding to the solution a sufficient amount of sulfuric acid to obtain a solution pH of from about 1.0 to about 2.0;

20 adding a sufficient amount of iron powder to the solution to precipitate the copper ions as copper metal, the iron powder having a mesh size of at least as small as about 400;

recovering the precipitated copper metal from
25 the solution, the solution thereafter having a copper ion concentration of less than about 5 parts per million, the recovered copper metal having a purity of greater than about 70 percent.

14. The method according to claim 13 wherein
30 the solution is an ammoniacal circuit-board etching solution.

15. The method according to claim 13 and including the step of diluting the solution prior to the step of treating the solution with sulfuric acid.

35 16. The method according to claim 13 wherein the iron powder is added to the solution continuously.

17. The method according to claim 16 and further including the step of agitating the solution





during the continuous addition of iron powder to the solution.

18. A method for recovering copper metal from a circuit-board etching solution containing copper ions, comprising:

diluting the solution with at least about a two-fold volume excess of water;

treating the solution with a sufficient amount of sulfuric acid to obtain a solution pH of from about 1.5 to about 2.5;

adding a sufficient amount of an iron powder to the solution to precipitate substantially completely the copper ions in solution as copper metal, the iron powder having a mesh size of at least as small as about 400 mesh; and

recovering the precipitated copper metal, the solution thereafter having a copper ion concentration of less than about 3 parts per million, the recovered copper metal having a purity of greater than about 60 percent.

19. The method according to claim 18 wherein the step of treating the solution with sulfuric acid includes adding a sufficient amount of sulfuric acid to obtain a pH of less than about 2.0, the solution having a copper ion concentration of about 2 ppm following the step of recovering the precipitated copper metal.

20. The method according to claim 18 and further including the steps of:

increasing the pH to greater than about 5.5 after the step of recovering the metal; and discharging the solution into the environment.

21. The method according to claim 18 and including the step of measuring changes in solution potential during the step of adding a sufficient amount of an iron powder to the solution.

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