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# Recovery of gold from computer circuit board scrap using aqua regia

Computer circuit board scrap was first treated with one part concentrated nitric acid and two parts water at 70°C for 1 h. This step dissolved the base metals, thereby liberating the chips from the boards. After solid–liquid separation, the chips, intermixed with some metallic flakes and tin oxide precipitate, were mechanically crushed to liberate the base and precious metals contained within the protective plastic or ceramic chip cases. The base metals in this crushed product were dissolved by leaching again with the same type of nitric acid–water solution. The remaining solid constituents, crushed chips and resin, plus solid particles of gold, were leached with aqua regia at various times and temperatures. Gold was precipitated from the leachate with ferrous sulphate.

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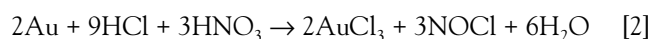
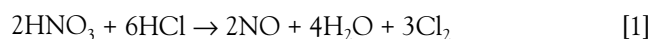
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## Introduction

Electronic scrap, especially printed circuit boards, is recognized as an environmental problem today. In addition, it contains several valuable metals. The metal content in electronic scrap can be as high as 40% by weight (Setchfield 1987, Feldmann & Scheller 1995). Recycling of electronic scrap may provide a substantial source of both ferrous and non-ferrous metals, as well as precious metals. This also recovers non-metallic materials, mainly ceramics and plastics. Although the majority of the metals (about 39% of the scrap weight) are base metals such as copper, iron, nickel, tin, lead, aluminum and zinc, major attention has been on the recovery of the precious metals gold, silver and palladium (Setchfield 1987, Feldmann & Scheller 1995). Of these metals, gold recovery receives the most attention because a considerable quantity has been used in the electronics industry during the past three decades (Zhang & Forsberg 1998). Figure 1 shows some typical computer circuit board components with plated gold and base metals.

The traditional medium for dissolving gold (and the platinum group metals) is aqua regia, a mixture of three parts concentrated hydrochloric to one part concentrated nitric acid. The reactions involved are as follows (Herschlag 1941, Jacobson 1959):



From these reactions, note that nitrosyl chloride forms in reaction [3] between hydrochloric and nitric acid. If the aqua regia solution is diluted with water, then chlorine and nitrosyl chloride recombine to form hydrochloric acid and nitric acid, as shown above by reversing reaction [3].

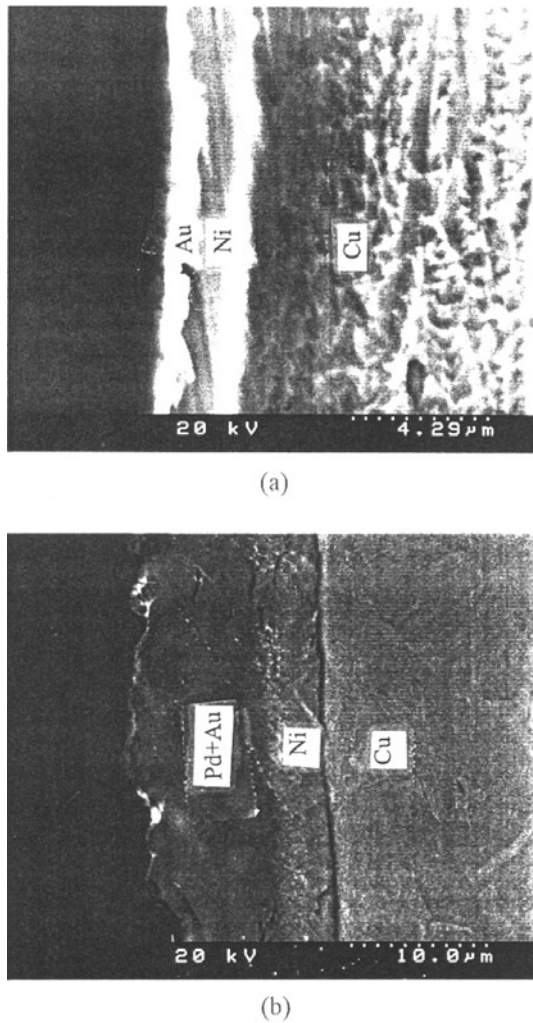


Fig. 1: SEM micrograph of computer circuit board components with metal plating of: (a) Au–Ni–Cu; and (b) (Pd + Au)–Ni–Cu.

The problems that hinder the leaching of scrap computer circuit boards using aqua regia are quite minor provided precautionary measures are undertaken. First, the purity of the precipitated gold is decreased by the presence of silver chloride in the residue, but a chemical wash with nitric acid before aqua regia leaching minimizes silver contamination in the gold precipitate. Second, metastannic acid hinders the dissolution of gold (Uhlrig 1948). This acid is produced by the dissolution of tin from solder. Production of metastannic acid is also limited by an initial leach with nitric acid. In nitric acid, lead dissolves, tin cracks and flakes, and gold remains inert. Third, aqua regia is ineffective for dissolving the secondary platinum group metals – iridium, ruthenium, rhodium and osmium (Ammen 1984). This is not a concern since only minimal amounts of these metals are present in computer chips. Despite these potential problems, aqua regia leaching was selected for the recovery of gold from computer chips because of its flexibility, ease and low capital requirement (Ammen 1984).

## Experimental

Gold leaching from computer circuit boards involved three stages. During stage I, computer chips were separated from the circuit boards by leaching. Stage I leaching was conducted in nitric acid systems, in which the effects of acid concentration, temperature, pulp density and retention time were studied. Solution agitation occurred naturally through the emission of nitrogen oxide vapours. These gases cause bubbling and frothing of the solution. Computer circuit boards were added to the solution in small increments to minimize excessive heating due to the exothermic reaction and to prevent excessive frothing due to the release of nitrous oxide fumes. On completion of the test, the charge was cooled, filtered and washed with distilled water. The various products were then weighed and analysed.

After stage I leaching, the computer chips and coagulated epoxy resin were mechanically crushed. This crushing changed the structure of the computer chip–coagulated epoxy resin mixture from that of a plastic or ceramic case to a fine particulate. Along with liberation of the encased metals, this reduction in particle size naturally aids in the further leaching of silver and base metals. Stage II leaching used the optimized parameters from stage I.

The third stage leach dissolved metallic gold with aqua regia from the second stage leach computer chip residue. The parameters investigated for the third leach stage were: (1) temperature, (2) pulp density and (3) retention time. Experiments were undertaken in a 200 mL Pyrex beaker which was initially charged with 50 or 100 mL of aqua regia. After charging, the solution was allowed to stabilize at the predetermined temperatures of 23, 50, 70 or 90°C. Elevated temperatures were achieved by using a hot plate. Upon temperature stabilization, a total of 25 g of crushed computer chips from the second stage leach was added to the solution in small increments to control the reaction rate and minimize temperature change due to the exothermic reaction. This overall weight was selected to provide a solid/liquid ratio of 1 g solid to either 2 or 4 mL aqua regia. A vigorous reaction was maintained throughout dissolution by gas evolution (reactions [1] to [3]). Upon completion of the test, the charge was cooled, filtered and washed with distilled water. The various products were then analysed with atomic absorption spectrophotometry (AAS).

## Results and discussion

Through extensive investigation, optimized leaching parameters were obtained for stage I: acid concentration, one part nitric acid to two parts water; temperature, 70°C; pulp density, 3 mL of solution per gram of solid; and retention time,

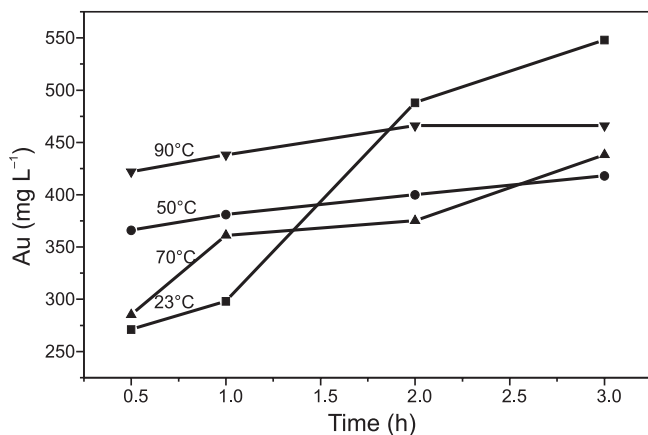


Fig. 2: Effect of temperature and time on the third stage leaching of gold from computer circuit boards.

1 h. Under these conditions, the computer chips readily separated from the fibreglass boards. These leaching conditions maximized metal dissolution, but minimized fibreglass decomposition and nitric acid usage.

For the third stage leaching, the computer chip residue was digested at 23, 50, 70 and 90°C in aqua regia to determine the effect of temperature on the dissolution of gold. The results for the four temperatures at various leaching times are shown in Figure 2. The differences in the rates of leaching among the four solution temperatures were probably mainly due to the more rapid formation of chlorine and nitrous oxide at higher temperatures, providing more effective solution agitation. Inconsistencies (e.g., between 50 and 70°C at short times and at 23°C for longer times) are more probable when agitation rather than kinetics is controlling the rate of gold oxidation. Furthermore, the temperature effect is generally less dramatic.

The amount of solution required for complete immersion of the computer chips was approximately 2 mL per gram of computer chips. Gold dissolution in aqua regia at a temperature of 90°C was almost complete within 30 min as long as the computer boards were crushed to a particle size of 425  $\mu\text{m}$ , thereby ensuring the liberation of precious metals from the ceramic and plastic components. For a lower pulp density of approximately 4 mL per gram of computer chips, the rate of precious metal solubilization was unchanged. Therefore, increasing the amount of acid used per gram of computer chips did not measurably increase the leaching rate. This would not have been the case without the previous nitric acid leaching which solubilized the base metals (Stage II). Otherwise the base metals would have acted as an acid consumer thereby increasing the amount required for total gold dissolution.

The effect of agitation on the dissolution of gold in aqua regia was monitored at 90°C. At this temperature, the agitated and non-agitated solution dissolved the gold at approximately

the same rate; dissolution was complete in both solutions within 1 h. The behaviour of the non-agitated solution closely resembled that of the agitated solution because of the self-induced agitation brought about by the release of nitrous oxide and chlorine vapours causing bubbling and frothing of the solution. Fresh reagent from the bulk of the solution was constantly brought to the gold surfaces in the non-agitated case. At the same time, the gold chloride was constantly removed from the surface of gold. This solution transfer occurred in both cases and allowed for complete dissolution of the gold.

As for gold deposition from the leachate, it can be easily done through traditional methods such as a ferrous sulphate precipitation procedure (Jacobson 1959, Ammen 1984). The gold flakes obtained were impure with some other elements and sulphate. Purer gold was obtained by repeating the aqua regia digestion–ferrous sulphate precipitation cycle on the gold flakes.

## Conclusions

The results obtained from the study of leaching base metals, and leaching and recovering gold from scrap computer circuit boards allow the following conclusions to be drawn.

1. An effective method to recover gold from as-received scrap computer circuit boards involves the following steps: (1) leaching in a nitric acid–water system; (2) mechanical crushing of computer chips and coagulated resin; (3) further leaching in a nitric acid–water system; (4) leaching of solid residue in an aqua regia system; and (5) precipitation of gold with ferrous sulphate.
2. Mechanical crushing liberated base and precious metals that were once contained within the protective plastic or ceramic computer chip cases. A 1 : 2 nitric acid : water leach readily strips the crushed computer chip-coagulated resin product of base metals, which would contaminate the gold precipitate.
3. Higher temperatures tend to give faster leaching rates of gold, possibly due to the fact that more rapid formation of chlorine at higher temperatures allows the gold to be more readily oxidized.
4. The amount of aqua regia required for complete immersion of the computer chips was approximately 2 mL per gram of computer chips. Increasing aqua regia beyond this ratio did not increase the leaching rate of gold.
5. Agitation was unnecessary for gold leaching in the aqua regia solution. The self-induced agitation brought about by the release of nitrous oxide and chlorine vapours caused bubbling and frothing of the aqua regia solution.
6. Ferrous sulphate precipitation can be used to recover gold from the leachate.

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## References

- Ammen, C.W. (1984) *Recovery and Refining of Precious Metals*. Van Nostrand Reinhold, Toronto, Canada.
- Feldmann, K. & Scheller, H. (1995) *Printed Circuit Board – a Challenge for Automated Disassembly and for the Design of Recyclable Interconnect Devices*, IEEE Conference-Publication No. 416, pp. 186–190. IEEE, Stevenage, UK.
- Herschlag, V.E. (1941) A procedure for volumetric determination of gold by means of potassium iodide and arsenious acid. *Industrial and Engineering Chemistry*, **13**, 561–563.
- Jacobson, C.A. (1959) *Encyclopedia of Chemical Reactions*. Reinhold Publishing Co., New York.
- Setchfield, J.H. (1987) Electronic scrap treatment at Engelhard. In: Vermeulen, G. & Verbeeck, R., (eds.) *Precious Metals 1987*, pp. 147–164. Pergamon Press, Toronto, Canada.
- Uhlig, H.H. (1948) *Corrosion Handbook*. John Wiley and Sons Inc., Toronto, Canada.
- Zhang, S. & Forsberg, E. (1998) Mechanical recycling of electronic scrap – the current status and prospects. *Waste Management & Research* **16**, 119–128.