Alternative leaching methods for gold from PCB

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Printed Circuit Boards (PCBs) contain valuable metals that could be utilized as a secondary raw materials. In this work, different leaching solutions such as aqua regia and thiosulfate were tested in order to dissolve gold from PCBs.

Background and previous studies

Waste Electrical and Electronic Equipment (WEEE) is the world's fastest growing waste stream with an annual growth of 3-5%. In the world, approximately 30-50 million ton of WEEE is formed every year. The recycling of WEEE is important due to the ecological and economic reasons. Gold is in the center of interest in WEEE's metal recycling due to its high value. Printed Circuit Boards (PCBs) are a part of WEEE, and they contain more gold than average WEEE (see Fig. 1), therefore, the gold recovery from PCB is important. (Cucchiella *et al.*, 2015)

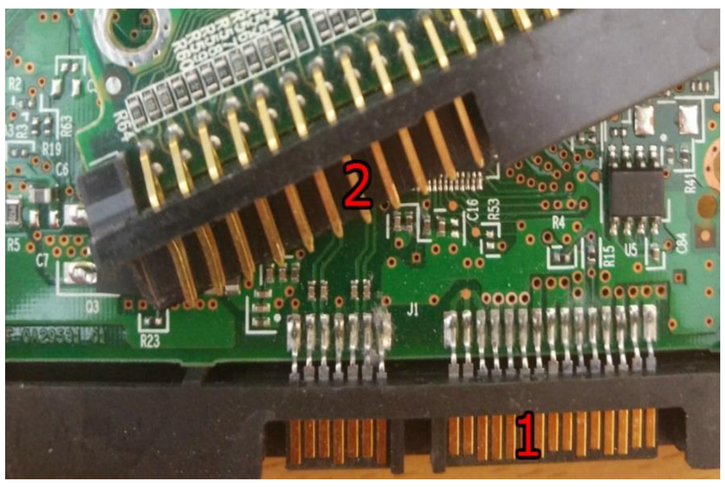

Figure 1. Gold is presented in PCBs as coating in connectors and surfaces.

Currently, gold can be separated from PCBs with pyrometallurgical and/or hydrometallurgical methods. Cyanide is mainly used in hydrometallurgy due to its relatively low price, simple chemistry decent reaction kinetics, easy gold recovery from cyanide solution and because cyanide forms a very stable $Au(CN)_2$-complex with gold. However, cyanide is highly dangerous and toxic to the environment, consequently other leaching solutions are required and researched. (Marsden & House, 2006)

Various methods have been tested in order to dissolve gold from different raw materials (see Table 1), but PCBs as a gold source are not that well investigated since their complex composition. Thiosulfate has been researched as an alternative gold leaching solution, but its complex chemistry and high consumption rate are the main reasons why it's not yet commercially in full use. Additionally, thiourea is one of the most used alternatives for gold leaching, but its high reagent consumption makes it economically unfavorable for commercial use. Bioleaching and electrochemical leaching have been introduced to gold leaching recently and are being constantly researched when searching the optimal leaching solutions and methods. (Syed, 2012)

Table 1. Hydrometallurgical gold leaching methods and their conditions.

Leaching method	Temperature	Time	Additional information	Gold extraction
Cyanide	25 °C	24 h	Toxic	95%
Thiosulfate	25 °C	2 h	Unstable	98%
Thiourea	25 °C	1 h	High consumption	95%
Aqua Regia	20-90 °C	1 h	Corrosive	100%
Bio leaching	25-45 °C	3-7 d	pH important	7-44%
Electrochemical	20-70 °C	1-3 h	Amplitude and HCl important	5-93%

Materials and methods

Gold containing PCBs presented in Fig. 2, were used as raw material in experiments. Some PCBs were grinded to <1 mm, but vast majority of test were conducted with 5 cm x 5 cm PCB pieces. Different solutions were tested in batch leaching tests (see experimental conditions from Table 2, which were conducted in a 800 ml reactor in which the temperature and current (if required) were controlled. Samples were collected from the solution and analyzed with atomic absorption spectroscopy (AAS).

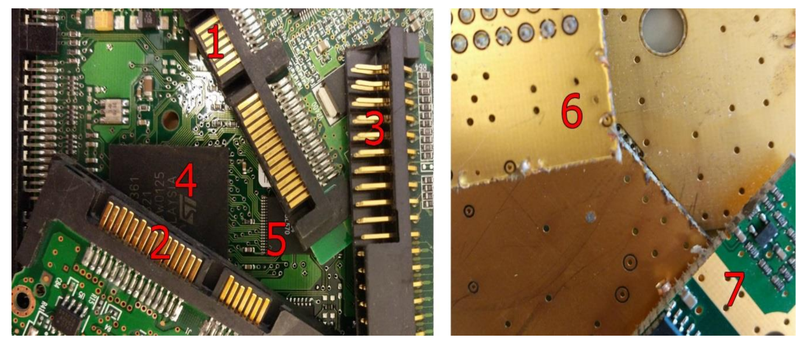

Figure 2. Gold coated PCBs were used as raw material in experiments.

Table 2. Solutions and their conditions in experiments.

Leaching method	Solution concentration	Time	Temp	Current	PCB particle size	Oxidation
Aqua Regia	30 vol-%	0-5 h	70 °C	N/A	<1 mm	2 l/min
Thiosulfate	0.2 M ammonium thiosulfate, 0.05 M $CuCl_2 \cdot 2H_2O$, 0.07 M Na_2SO_4, 14.82 g $Ca(OH)_2$	0-3 h	50 °C	N/A	<1 mm	2 l/min
Copper chloride	0.01 g/l; 0.31 g/l or 10 g/l Cu^{2+}	0-3 h	60 °C; 75 °C or 90 °C	N/A	3 cm	2 l/min
Anodic leaching	1 M; 1.5 M or 2 M NaCl	0.5 h; 0.75 h or 1 h	25 °C; 37.5 °C or 50 °C	30 mA, 45 mA or 60 mA	3 cm	N/A

Results

The best leaching results of the experimental part are summarized in Table 3. Solutions used for the best gold extraction rates were as follows: Aqua regia: 30 vol-% aqua regia. Thiosulfate: 0.2 M ammonium thiosulfate, 0.05 M copper chloride and 0.07 M sodium sulfate with pH >9. Copper chloride: 0.005 M Cu^{2+} and 3 M sodium chloride with pH <1. Anodic leaching: 1 M sodium chloride with a current of 60 mA. Glycine solutions were also used but copper chloride precipitated from the solution before the experiments could be started. Glycine remains a interesting possibility in gold leaching but further studies need to be conducted to reveal its full potential.

Table 3. Results of the gold leaching experiments.

Leaching method	Gold extraction	Leaching time	Temp
Aqua Regia	11%	5 h	70 °C
Thiosulfate	30%	0.5 h	50 °C
Copper chloride	23%	3 h	75 °C
Anodic leaching	varies	1 h	50 °C

Conclusions

Thiosulfate appears to be most efficient after 0.5 h leaching time after which the gold extraction begins to decline due to precipitation. Copper chloride offers a decent gold extraction rate with a cheap price even though it requires a long leaching time. Electrochemical experiments (anodic leaching) were particularly interesting as they allow gold leaching with a low current when only sodium chloride is used in the solutions. Therefore, anodic leaching seems like a cheap and promising way to leach gold from PCB, though more research is required to fully understand its capabilities.

References

Cucchiella, F., D'Adamo, I., Lenny Koh, S. C. & Rosa, P. (2015). Recycling of WEEEs: An economic assessment of present and future e-waste streams. Renewable and Sustainable Energy Reviews, Vol. 51, s. 263-272.

Marsden, J. O., & House, I. C. (2006). The Chemistry of Gold Extraction. Littleton, Colorado, United States of America: the Society for Mining, Metallurgy and Exploration, Inc.

Syed, S. (2012). Recovery of gold from secondary sources—A review. Hydrometallurgy, Vol. 115-116, s. 30-51.

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