

Towards a Closed-Loop Alchemy — A Vision for the Cyclical Reclamation of Gold from Integrated Circuits

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The extraction of gold (Au) is expected to become increasingly complex in the coming years due to the growing scarcity of this metal. Compounding this issue are the relentless advancements in technology, which, in turn, require Au to ensure greater efficiency and performance. Since halting technological development is neither feasible nor desirable, attention must turn to strategies that enable the recovery of this precious metal from waste streams, such as integrated circuits (ICs). These components, essential to virtually all electronic devices, are composed largely of silica (SiO₂, 62% wt), brominated epoxy resin (14% wt), and a mixture of metals including copper (Cu, 22%wt), iron (Fe, 1%wt), silver (Ag, 0.7%wt), and gold (Au, 0.3%wt) (Niu, 2023).

In this work, a hybrid approach integrating physical, mechanical, and chemical processes was implemented with the primary objective of recovering Au from ICs. For this purpose, firstly, a two-stage physical pre-treatment was implemented to expose the metallic fraction enriched in Au. This pre-treatment consisted on the fragmentation of the IC samples using a hydraulic press at a closed environment, followed by magnetic separation. The non-magnetic fraction, which retains the majority of the Au content, was then subjected to a hydrometallurgical leaching process conducted at 40 °C for 3 hours, using 2.5 M hydrochloric acid (HCl) and 0.34 M sodium hypochlorite (NaClO), as leaching agent, with a liquid-to-solid ratio of 40 mL/g. This process resulted in the extraction of 88.6 wt.% of the total Au present in the initial sample. A multi-metal solution containing not only Au but also Ag, chromium (Cr), Cu, Fe, aluminum (Al), nickel (Ni), lead (Pb), tin (Sn), and zinc (Zn) was achieved. Subsequent purification of Au from this solution was operated in continuous mode using a strong anion exchange resin—Purogold™ A194—a polystyrene matrix crosslinked with divinylbenzene, functionalized with mixed tertiary amine and quaternary ammonium groups. Purogold™ A194 resin was selected since it demonstrated a high total exchange capacity and a high amount of Au is adsorbed in a short period of time when compared to other resins described in the literature (Neto, 2021). Elution of Au from the resin was performed using a solution of 0.5 M sulfuric acid (H₂SO₄) and 0.25 M thiourea (CSN₂H₄) for 120 minutes. After elution, 91% of Au was eluted from the resin with a purity grade of 85%, being Sn (7.5% wt) and Pb (4.3% wt) the major contaminants, which is explained by the formation of anionic chloride complexes (SnCl₅⁻/SnCl₆²⁻, PbCl₃⁻/PbCl₄²⁻ (95,3%), and ZnCl₃⁻/ZnCl₄²⁻ (96,6%), respectively) that were partially adsorbed in the beginning of the experiment being progressively displaced from the resin. The resin was reused in seven consecutive cycles to evaluate its performance and stability.

Other authors have conducted similar studies (also involving ores with high silica content, 54% wt), yet reported considerably less favourable conditions. For instance, Baghalha, 2007 achieved only 69% Au leaching after four hours of treatment. The major drawback of the leaching method is its limited selectivity for Au but when combined with a suitable purification technique, such as is the case of involving the use of ion exchange resin, allows the treatment of larger volumes of effluent due to their high adsorption capacity with high selectivity.

In conclusion, this work suggests a new approach to recycle Au from ICs that proven to be simple and easily scalable that combines conventional methodologies with the practical treatment of e-waste.

References

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