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Challenges for critical raw material recovery from WEEE – The case study of gallium

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ABSTRACT

Gallium and gallium compounds are more frequently used in future oriented technologies such as photovoltaics, light diodes and semiconductor technology. In the long term the supply risk is estimated to be critical. Germany is one of the major primary gallium producer, recycler of gallium from new scrap and GaAs wafer producer. Therefore, new concepts for a resource saving handling of gallium and appropriate recycling strategies have to be designed.

This study focus on options for a possible recycling of gallium from waste electric and electronic equipment. To identify first starting points, a substance flow analysis was carried out for gallium applied in integrated circuits applied on printed circuit boards and for LEDs used for background lighting in Germany in 2012. Moreover, integrated circuits (radio amplifier chips) were investigated in detail to deduce first approaches for a recycling of such components. An analysis of recycling barriers was carried out in order to investigate general opportunities and risks for the recycling of gallium from chips and LEDs.

Results show, that significant gallium losses arose in primary production and in waste management. 93 ± 11%, equivalent to 43,000 ± 4700 kg of the total gallium potential was lost over the whole primary production process until applied in electronic goods. The largest share of 14,000 ± 2300 kg gallium was lost in the production process of primary raw materials. The subsequent refining process was related to additional 6900 ± 3700 kg and the chip and wafer production to 21,700 ± 3200 kg lost gallium. Results for the waste management revealed only low collection rates for related end-of-life devices. Not collected devices held 300 ± 200 kg gallium. Due to the fact, that current waste management processes do not recover gallium, further 80 ± 10 kg gallium were lost.

A thermal pre-treatment of the chips, followed by a manual separation allowed an isolation of gallium rich fractions, with gallium mass fractions up to 35%. Here, gallium loads per chip were between 0.9 and 1.3 mg. Copper, gold and arsenic were determined as well. Further treatment options for this gallium rich fraction were assessed. The conventional pyrometallurgical copper route might be feasible. A recovery of gold and gallium in combination with copper is possible due to a compatibility with this base-metal. But, a selective separation prior to this process is necessary. Diluted with other materials, the gallium content would be too low.

The recycling of gallium from chips applied on printed circuit boards and LEDs used for background lighting is technically complex. Recycling barriers exist over the whole recycling chain. A forthcoming commercial implementation is not expected in nearer future. This applies in particular for chips carrying gallium.

1. Introduction

Due to its content of highly functional and strategically important metals Waste Electric and Electronic Equipment (WEEE) has been recently discussed as an upcoming source for raw materials. In the same time "recycling restrictions" are one of the key indicators for classifying metals as critical (European Commission, 2014, 2010). The present economic and legal boundary conditions result

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in recycling technologies that are not optimized for the recovery of all materials, in particular not for minor metals. As a consequence, recovery of critical metals from WEEE is, in opposite to the recovery of industrial base and precious metals, limited in current practice.

The project UPgrade aims at an enhanced recovery of trace metals along the value chain by developing new liberation and separation processes (mechanical, thermal, chemical), considering the technological requirements of final recovery processes. "Upgrading" material flows along the recycling chain does not aim at a 100% recovery of all metals, but is the result of an interdisciplinary decision making and optimization inside recycling networks.

Main drivers for current recycling are the recovery of valuable materials like precious metals (silver, gold), platinum group metals (palladium, platinum) and bulk materials like industrial base metals (copper, steel/iron, aluminium) and plastics. These materials can be used as indicators for measuring the efficiency of current recycling processes and have been defined as "lead metals". Additionally, cadmium and lead are metals of environmental concern which need to be addressed in the recycling chain of WEEE. Approaches developed in the UPgrade project focus on both, lead and target metals in order to establish higher recycling rates of critical elements in combination with economically feasible processes. Fig. 1 shows an overview of all addressed metals investigated in this project.

This article presents selected results for the case of gallium. We want to assess gallium flows in primary production and waste flows related to WEEE with a material flow analysis (MFA). Through this, losses and according recycling potentials related to location and relevance will be identified. In addition, a first approach for the pre-treatment of components carrying gallium will be investigated for its selectivity. Finally, we want to identify potential recycling barriers, which impedes or support the recycling of gallium based on the findings in this study.

2. Background

2.1. Primary production of gallium

Approximately 90% of produced primary gallium is extracted as a by-product of the aluminium production (Zhao et al., 2012). Most important primary resource is the mineral bauxite, which is used for both, the aluminium and gallium production (Angerer et al., 2009). The Ga content in bauxite ranges from 0.0025 to 0.01% (Schreiter, 1960). Therefore, even refined aluminium can contain between 0.017% and 0.02% of gallium. With current processing strategies, approximately 70% of the gallium potential can be extracted; 30% remain in the red sludge (Zhao et al., 2012).

Other potential gallium resources are zinc sulfides, respectively by-products of zinc smelting processes. Gallium in low thermal native zinc sulfides can be present with mass fractions up to 0.002% (Schreiter, 1960). Up to 3% of the globally available gallium originates from this source (Løvik et al., 2016). Moreover, minor concentrations of gallium can be measured in some coal deposits. But, processes for an extraction from coal or fly ashes with reasonable expenses are not developed yet (Løvik et al., 2016; Wittmer et al., 2011).

In 2014, 444 Mg gallium have been extracted worldwide (U.S. Geological Survey, 2015). Regarding the refining process, China and Germany had a share of 54% and 13.5%, respectively (Drobe and Killiches, 2014). But, the production and demand is rapidly increasing. Between 2009 and 2011, the production of extracted and refined gallium doubled (Dehnavi, 2013). This was most probably based on the growing market of general wireless communication and mobile technologies using gallium based power amplifiers. This is intensified by higher sales of light emitting diodes (LEDs) used as background lighting and in lighting industry in general. Estimations reaching till 2050, forecast a demand 12 times higher for gallium (Løvik et al., 2016).

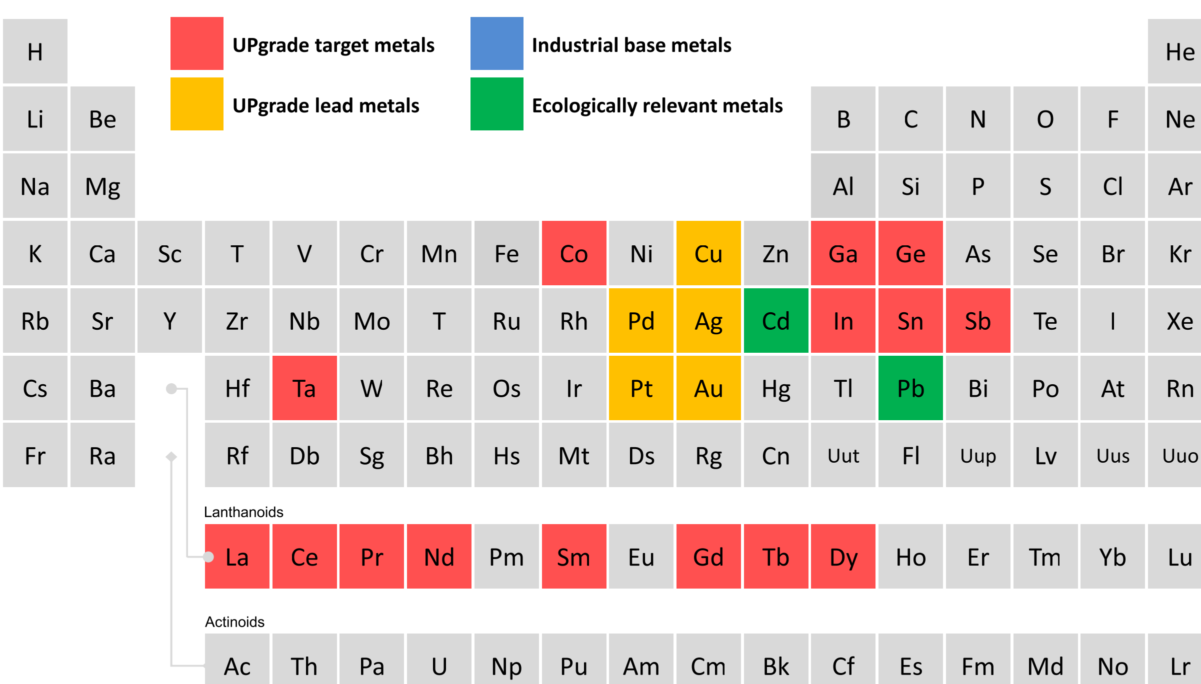

Fig. 1. Defined target, lead and other investigated metals within the UPgrade project.

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