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Your contact: Dr. Uwe Hamm

Your ref.:
Yours of: 20.04.2018
Our ref.: SPU-EC/Hamm
Date: 01.06.2018

Study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15)

Stakeholder Consultation 20.04. – 15.06.2018

Our Statement concerning the planned restriction on Nickel Sulfate and Nickel Sulfamate

Dear Ms. Baron,

thank you very much for the opportunity to participate and contribute to the stakeholder consultation process in the ongoing review of the list of restricted substances under RoHS2 (2011/65/EC), the pack15 procedure running from 20.04. – 15.06.2018. We understood from the project description dating 01.02.2018 and the accompanying technical specification (http://rohs.exemptions.oeko.info/index.php?id=288) that seven substances are being investigated in this pack15 procedure, amongst them are nickel sulfate and nickel sulfamate.

Please find our statement concerning these two substances as follows for your further consideration in the pack15 procedure. We are happy to answer any further questions you may have in this respect.

Yours sincerely,

i. V.

Mr. Edgar Bader
Senior Director Development and Technical Services

i. V.

Dr. Uwe Hamm
Director Chemistry/Materials and Environmental Officer

Study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15)

1st Stakeholder Consultation – Questionnaire for nickel sulfate (CAS 7786-81-4; EC 232-104-9) and nickel sulfamate (CAS 13770-89-3; EC 237-396-1)

1.
Applications in which nickel sulfate and nickel sulfamate are in use

1a.
Please provide information concerning products and applications in which the sub-stances are in use.

i. In your answer please specify if the applications specified are relevant to EEE products and applications or not.

ii. Please elaborate if substitution of the substance is already underway in some of these applications, and where relevant elaborate, which chemical or technological alternatives may be relevant for this purpose. For example, please specify possible alternatives to the use of these compounds in nickel plating (substance level substitution) or possible alternatives to nickel plating that would eliminate the need to use these compounds (tech-nological level substitution).

Nickel plating (electroless as well as electrolytic (galvanic)) is a common surface treatment technology to modify metallic and non metallic surfaces by deposition of a metallic nickel layer onto such surfaces. Such metallic Ni layers do not contain any residues of either nickel sulfate or nickel sulfamate, since the processes involved in either electroless or electrolytic deposition leads to the formation of a metallic nickel layer without any inclusion of the starting substances in the deposited nickel layers.

In other words: **Nickel sulfate and nickel sulfamate are only intermediate substances used in the production process and are not found in the final EEE product (EEE: electric and electronic equipment).**

Nickel plated surfaces are used in general in a variety of EEE products, in the more business to consumer like product categories 1 – 7 and 10 as well as in the more business to business like product categories 8 and 9 or the new product category 11.

The reasons for applying metallic nickel layers are that such layers:

- show interesting reflective properties which is relevant in EEE applications where optical properties of such metallic layers are important as well,
- Nickel layers build up rather homogeneously,
- Nickel layers have strong adhesive properties to their substrate surfaces,
- Nickel layers can be used as a sealing layer for degassing substrate surfaces underneath the nickel layer,
- Nickel layers can be applied in a wide range of layer thicknesses,
- Nickel layers can be very well treated later on by mechanical finishing (like polishing, turning, milling etc.), of course always under strict consideration of proper health and safety measures to protect the workers from nickel dusts,
- Nickel layers can be magnetic and have some electrical conductivity,
- Nickel layers have a good corrosion resistance and show interesting hardness properties.

There are **<u>no feasible substitution possibilities for nickel layers</u>**, as we have tested for our own EEE application.

One substitution possibility tested for our own application would be to use layers of silver, gold or tantalum on the base uncoated substrate. However from an environmental point of view these substitutes have – to the best of our knowledge – much more negative environmental impacts than a nickel plating has. This can be clearly seen already from the different cumulative raw material demands for nickel, silver, tantalum and gold being several orders of magnitude higher for silver, tantalum and gold in comparison to nickel [1], [2]:

Element	Cumulated Raw Material Demand (t/t)
Nickel	133,1
Silver	6834,8
Tantalum	9179,7
Gold	740317,7

Tab. 1: Cumulated Raw Material Demand (ton of raw materials per ton of product), [1], [2]

Especially gold as a prominent example of the 3TG metals (tin, tantalum, tungsten, gold) is well known to cause severe damage to the environment when being exploited from soil (the processes involved need either mercury and/or cyanides to get the gold metal from the ore) as well as high negative social impacts in these countries, where such 3TG metals are produced at the beginning of the value creation chain.

Other possibilities tested in our own application would be for instance layers of nitrides like titanium or chromium nitride. However the properties of these layers do not match the technical requirements and specifications in such a way as nickel layers do. Additionally such nitride deposits are made with processes involving temperatures of several 100°C. Such rather high temperatures can lead to deformation of parts with tight mechanical specifications.

According to our own experience within our company with electroless as well as electrolytic nickel plating for more than 25 years, nickel layers best match all the required specifications for protective layers on parts and components being later on assembled to EEE.

Anyway, the discussion of any possible substitutes for nickel sulfate and nickel sulfate is adding no additional value in consideration of the final EEE itself, since **nickel sulfate and nickel sulfamate are only used as intermediates in the production process and are not found in the final EEE itself.**

1b.
Please specify if you are aware, if aside from actual use of the substances, it may be reintroduced in to the material cycle through the use of secondary materials.

i. ***Please detail in this case what secondary materials may contain impurities of nickel sulfate and nickel sulfamate and at what concentrations as well as in the production of what components/products such materials are used.***

ii. ***If possible please provide detail as to the changing trends of concentrations of nickel sulfate and nickel sulfamate in such secondary materials as well as the changing trend of use of the respective secondary material in EEE manufacture.***

To the best of our knowledge and ample evidence in literature nickel layers from either electroless or electrolytic nickel plating processes do not contain any residues of either nickel sulfate or nickel sulfamate.

We are not aware either of any secondary materials that may contain impurities of nickel sulfate and nickel sulfamate.

Reaction Mechanism for Electroless Nickel Deposition out of Nickel Sulfate [3]:

The overall reaction equation for electroless nickel deposition is as follows:

$NiSO_4 + 3\ H_2O + 3\ NaH_2PO_2 \rightarrow \mathbf{Ni\ (s)} + 2\ H_2 + H_2SO_4 + 3\ NaH_2PO_3$

Nickel sulfate as the starting material in the solution is reduced by sodium hypophosphite to metallic nickel which precipitates and deposits on the metallic or non-metallic surface which shall be coated by this electroless nickel deposition treatment.

The sodium hypophospite (NaH_2PO_2,, Phosphorus in oxidation state +1) is the reducing agent for the nickel(II) ions and is oxidized to sodium orthophosphit (NaH_2PO_3, with phosphorus in the oxidations state +III).

The sulfate anion from the nickel sulfate ends up as sulfuric acid (H_2SO_4) which dissolves in the plating bath.

The whole process is schematically depicted in fig. 1 showing the deposition of a metallic nickel layer on a substrate by reduction of nickel ions by sodium hypophosphite.

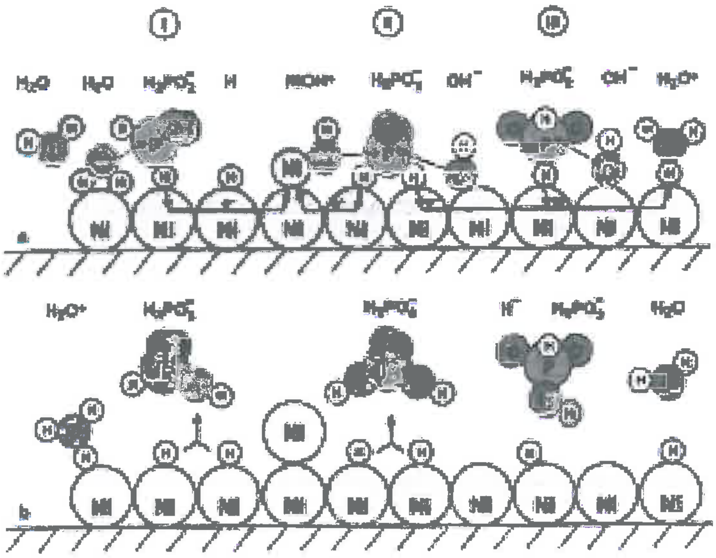


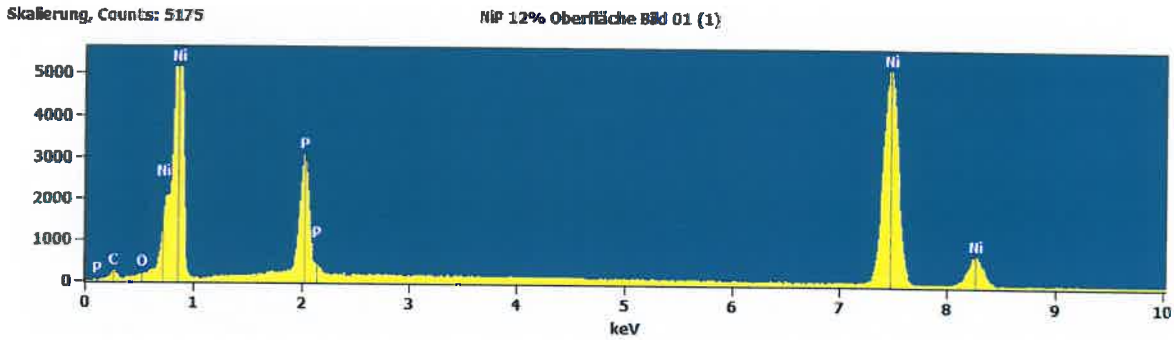
Fig. 1: Reaction scheme for the process of the oxidation of sodium hypophosphite and the reduction of nickel ions (a) process at the beginning, (b) process at its end showing the formation of a metallic nickel layer

In several side reactions which involve rather complex mechanisms elemental phosphorus is included in the metallic nickel layers up to several percent by weight.

The summary reaction equation for this process is as follows [3]:

$4\ H_2PO^- + 2\ H^+ \rightarrow 2\ H_2PO_3^- + 2\ H_2O + H_2\ (g) + 2\ P\ (s)$

The typical elemental composition of an electroless deposited nickel layer is as follows (results from own measurements by energy dispersive x-ray spectroscopy (EDX)):



Quantitative Results NiP 12% Oberflache Bild 01 (1)

Element Linie	Gew.-Konz %	Gew. % Fehler	Atom Konz %	Atom-% Fehler
P K	11.77	± 0.12	20.18	± 0.64
Ni K	88.23	± 0.52	79.82	± 1.40
Total	100.00		100.00	

Fig. 2: EDX spectrum of an electroless plated nickel layer (Layer thickness: 3 µm), **showing no residual nickel sulfate in the deposit**

So in the end there is no remaining nickel sulfate in the electroless deposited metallic nickel layer and there is also no process thinkable how nickel sulfate from whatever secondary sources may enter such metallic nickel deposits.

Reaction Mechanism for Electrolytic Nickel Deposition out of Nickel Sulfate [4, 5, 6, 9]:

The electrolytic (galvanic) deposition of nickel layers out of an aqueous solution of nickel sulfate can be schematically shown as follows:

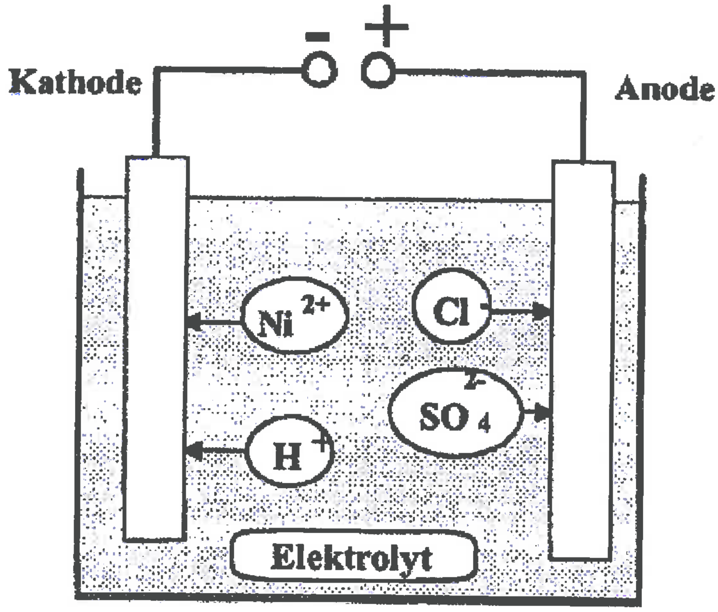


Fig. 3: Basic electric circuit for nickel electroplating [2]

Nickel is deposited on the cathode by the electrochemical laws of electrolytic metal deposition by reducing nickel ions out of the electrolyte solution by electrons:

$Ni^{2+} + 2e^{-} \rightarrow Ni(s)$

The deposition of nickel at the cathode is thermodynamically more feasible than the evolution of hydrogen out of protons (H^+), because the latter process would need a high overpotential (i.e. significantly more electrical energy) due to polarization effects of hydrogen at the cathode material.

The electroneutrality of the process is obtained by oxidizing water at the anode to oxygen.

$H_2O \rightarrow \frac{1}{2} O_2 (g) + 2 H^+ + 2 e^-$

Anions like sulfate or chloride in the aqueous solution are not anodized because this reaction is thermodynamically less favorable than the oxidation of water at the anode.

The anions like sulfate thus stay in the electrolytic bath and react with protons (H^+) further to sulfuric acid, which dissolves in the aqueous solution:

$2H^+ + SO_4^{2-} \rightarrow H_2SO_4$

So in the end there is also no remaining nickel sulfate in the electrolytically deposited metallic nickel layer and there is also no process thinkable how nickel sulfate from whatever secondary sources may enter such metallic nickel deposits.

Reaction Mechanism for Electrolytic Nickel Deposition out of Nickel Sulfamate [4, 5, 6, 9]:

For galvanic nickel deposition out of nickel sulfamate the supplier material for nickel is the nickel salt of the amido sulfuric acid ($H_2N\text{-}SO_3H$).

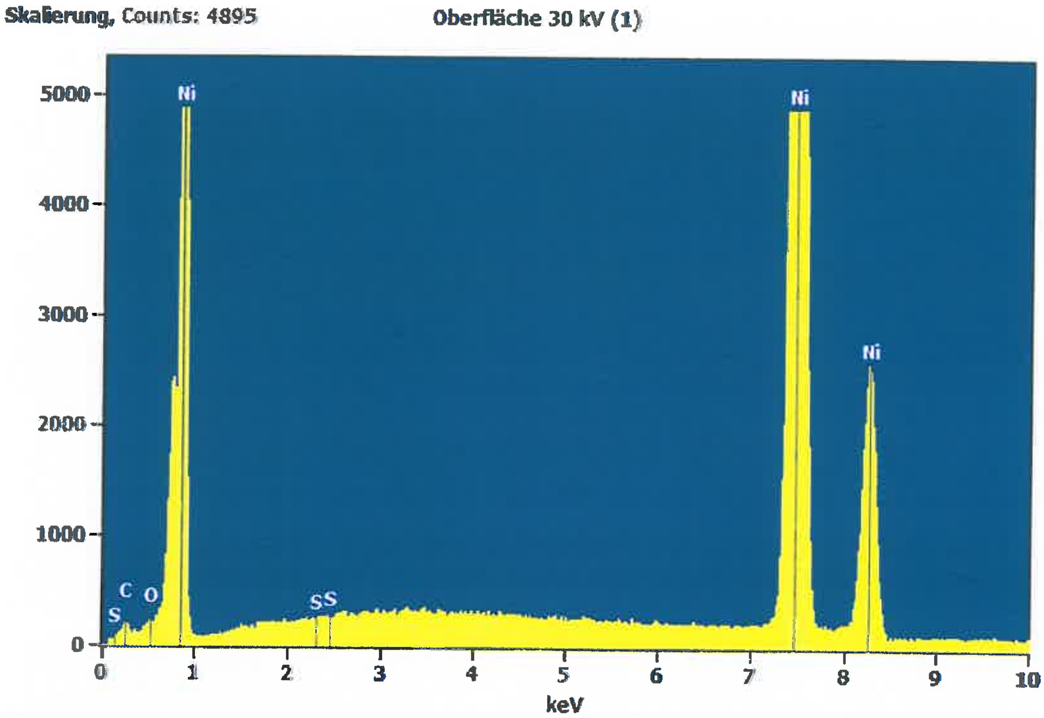
The reaction mechanisms are very similar to the reaction mechanisms for electrolytic nickel deposition out of nickel sulfate:

$Ni(SO_3\text{-}NH_2)_2 + 2\ H^+ + 2e^- \rightarrow Ni(s) + 2\ H_2N\text{-}SO_3H$

A metallic deposit of nickel is formed and the sulfamate anion is dissolved in the aqueous solution as amido sulfuric acid.

For electrolytically deposited Nickel layers (out of a nickel sulfamate bath) no remaining sulfur could be detected in the metallic layer by EDX spectroscopy as well.

In an in-house EDX study performed by using differnet accelerating voltages of the electron beam between 5 kV and 30 kV giving access to information depths in the metallic nickel layer between 0,1 – 3,0 µm no remaining sulfur (as an indicator element of nickel sulfamate) could be detected.



Quantitative Results Oberfläche 30 kV (1)

Element Linie	Gew.- Konz %	Gew. % Fehler	Atom Konz %	Atom- % Fehler
C K	7.47	± 0.37	28.15	± 4.16
O K	0.24	± 0.12	0.67	± 1.03
S K	0.00	—	0.00	± 0.00
Ni K	92.29	± 0.29	71.17	± 0.67
Total	100.00		100.00	

Fig. 4: EDX spectrum of an electrolytically plated nickel layer out of nickel sulfamate (layer thickness: 3 µm), **showing no residual nickel sulfamate in the deposit**

So in the end there is also no remaining nickel sulfamate in the electrolytically deposited metallic nickel layer and there is also no process thinkable how nickel sulfamate from whatever secondary sources may enter such metallic nickel deposits.

1c.

Please specify in which applications nickel sulfate and nickel sulfamate are used as a material constituent, as an additive or as an intermediate and what concentration of nickel sulfate and nickel sulfamate remains in the final product in each of these cases (on the homogenous material level).

As already described in detail in section 1b, **nickel sulfate and nickel sulfamate are used only as intermediates** in either electroless or electrolytic Nickel deposition.

There remains no nickel sulfate or nickel sulfamate in the deposited metallic nickel layer and thus also not in the final EEE product containing parts or components with such metallic nickel layers.

1d.

If nickel sulfate and nickel sulfamate are considered to be intermediates, please explain the reaction processes and which substances remain in the final product / material?

Please find the answer to this question in the detailed explanations in section 1b.

2. Quantities and ranges in which nickel sulfate and nickel sulfamate are in use

2a.

Please detail in what applications your company/sector applies nickel sulfate and nickel sulfamate and give detail as to the annual amounts of use (please specify which data is relevant for which compound). If an exact volume cannot be specified, please provide a range of use (for example – 50-100 tonnes per annum).

Nickel sulfate and nickel sulfamate is used by our company in annual amounts of less than 1 metric ton for both chemical substances.

2b.

Please provide information as to the ranges of quantities in which you estimate that the substance is applied in general and in the EEE sector.

This information cannot be provided by our company as we are only a downstream user of these two intermediate substances having no knowledge about the ranges of quantities where the substances are otherwise applied in general and the EEE sector in particular.

2c.

If substitution has begun or is expected to begin shortly, please estimate how the trend of use is expected to change over the coming years.

As already explained in detail in section 1a, metallic nickel layers have a wide range of interesting properties which cannot be replaced by substitutes resulting in the same properties.

3.
Potential emissions in the waste stream

3a.
Please provide information on how EEE applications containing nickel sulfate and nickel sulfamate are managed in the waste phase (with which waste is such EEE collected and what treatment routes are applied)? For example, how are nickel plated components managed in the waste phase?

Waste of electrical and electronic equipment (WEEE) is regulated under the WEEE directive 2012/19/EC. This directive is aimed to yield high recycling rates for materials contained in WEEE and to protect workers in the WEEE industry from risks associated with hazardous materials which might be contained in WEEE.

Metallic parts in WEEE, whether they are nickel plated or not, are collected due to their inherent value and recycled in metallurgical processes aimed to regain the various metals. This replaces the need for primary metal sources entering the materials life cycle at the very beginning and thus is a contribution to better resource efficiency and reduced resource consumption.

The small amounts of nickel contained in the nickel plating itself (which is a very thin layer of a few µm thickness), is used in recycled metals which – for instance for certain corrosive-resistant steel alloys – contain metallic nickel anyway as a constituent of the alloy composition.

3b.
Please detail potentials for emissions in the relevant treatment processes.

The process of nickel plating is already strongly regulated in the European Union, mostly via the Industry Emissions Directive (IED) 2010/75/EC and the BREF document on surface treatment of metals and plastics by the European Commission [10].

The IED directive and the BREF document impose strong regulations on operators of nickel plating baths, like mandatory allowances and permits for the facilities, regular inspections of the facilities by authorities, low threshold values for contaminants in waste water and emissions into air, just to name the most important obligations for operators of nickel plating baths.

Waste water out of nickel plating processes undergoes a so-called chemical-physical treatment. After addition of sulfides to the aqueous solution with its dissolved metal ions, a precipitate of metal sulfides forms due to the low solubility products of these sulfides. The solubility product for nickel sulfide for instance is as low as $1 * 10^{-26}$ mol^2/l^2 [11].

This means a remaining solubility for Ni ions after sulfide precipitation of a nickel sulfate or nickel sulfamate containing plating bath of only $1 * 10^{-13}$ mol/l which equals a remaining nickel concentration in the aqueous solution above the precipitate of only $5{,}87 * 10^{-3}$ ng / l.

The resulting precipitate is then dewatered in a filter press. The remaining dry sludge is being recycled by metallurgical processes in order to regain the valuable metal content which is present in the sludge.

In order to minimize the consumption of nickel sulfate and/or nickel sulfamate in nickel plating, the nickel baths in a galvanic shop are regularly monitored (at least on a daily basis) to evaluate the actual nickel concentration in the baths and thus to avoid unnecessary additions of chemical intermediate raw materials like nickel sulfate or nickel sulfamate.

Cleaning and rinsing processes of nickel plated parts are done normally in such a way to reduce the amount of necessary cleaning and rinsing water by using techniques like cascade cleaning/rinsing or using recycled water from a closed loop water treatment process.

Such cleaning and rinsing techniques reduce the amount of remaining waste water containing nickel residues for chemical-physical treatment to a minimum.

4.
Substitution

4a.
For which applications is substitution underway?

i. ***Please provide information in relation to specific applications on the substance level (for example substitutes for the nickel compounds in the nickel plating process) as well as for alternatives on the technological level (for example alternatives to the nickel plating process).***
ii. ***For which applications is substitution scientifically or technically not practicable or reliable and why.***
iii. ***Do certain constraints exist (provide details on costs, reliability, availability, roadmap for substitution, etc.) for the application of substitutes?***
iv. ***Please specify in this respect which alternatives are available on the substance level (substitution) and which are understood to be available on the technological level (elimination).***

There are **no feasible substitution possibilities for nickel layers**, as we have tested for our own EEE application.

One substitution possibility tested for our own application would be to use layers of silver, gold or tantalum on the base uncoated substrate. However from an environmental point of view these substitutes have – to the best of our knowledge – much more negative environmental impacts than a nickel plating has. This can be clearly seen already from the different cumulative raw material demands for nickel, silver, tantalum and gold being several orders of magnitude higher for silver, tantalum and gold in comparison to nickel [1], [2]:

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Especially gold as a prominent example of the 3TG metals (tin, tantalum, tungsten, gold) is well known to cause severe damage to the environment when being exploited from soil (the processes involved need either mercury and/or cyanides to get the gold metal from the ore) as well as high negative social impacts in these countries, where such 3TG metals are produced at the beginning of the value creation chain.

Other possibilities tested in our own application would be for instance layers of nitrides like titanium or chromium nitride. However the properties of these layers do not match the technical requirements and specifications in such a way as nickel layers do. Additionally such nitride deposits are made with processes involving temperatures of several 100°C. Such rather high temperatures can lead to deformation of parts with tight mechanical specifications.

According to our own experience within our company with electroless as well as electrolytic nickel plating for more than 25 years, nickel layers best match all the required specifications for protective layers on parts and components being later on assembled to EEE.

For our own proprietary application of a nickel layer we could show that the metallic nickel layer had the best properties with respect to reflective behavior and reduction of degassing rates from the underlying substrate material underneath the protective nickel layer. For this a detailed in-house study has been performed, where electroless plated nickel has been compared to alternative layers made of silver (Ag), gold (Au), tantalum (Ta), titanium nitride (TiN) and chromium nitride (CrN) [12].

Anyway, the discussion of any possible substitutes for nickel sulfate and nickel sulfate is adding no additional value in consideration of the final EEE, since **nickel sulfate and nickel sulfamate are only used as intermediates in the production process and are not found in the final EEE itself.**

5.
Socio economic impact of a possible restriction

Please provide information as to the socio-economic impacts of a scenario in which nickel sulfate and sulfamate restricted under RoHS. Please specify your answers in relation to specific applications in which the substances are used and/or in relation to the phase-in of specific alternatives in related application areas. Please refer in your answer to possible costs and benefits of various sectors, users, the environment, etc. where possible; please support statements with quantified estimations.

There are studies on socio economic impact of nickel in general [13], which will not be repeated here in every detail. The most important statements are summarized here:

A socio-economic study of nickel in the European Union (EU) carried out by the Weinberg Group in 2008 drew the following conclusions:

- Nickel is an 'enabling technology', not simply an industry sector processing primary materials. Its particular properties, such as strength at high temperatures, corrosion resistance, and ductility, have helped users create new products and industries, to develop new user benefits, and to deliver enhanced performance in a wide range of advanced manufacturing sectors.
- Whilst the EU direct nickel industry itself is relatively small, it has a significant impact on the EU economy through its value chain.
- Using the widest definition of the impact of nickel on the EU economy, the total value added by the nickel industry and its value chain is estimated to be in excess of €80-100 billion, of which around €50 billion is estimated to be generated by industries and applications that are critically dependent on nickel.
- The nickel value chain also supports large numbers of jobs in the EU, estimated to be in the order of 1.25-1.50 million. Of this, an estimated 690,000 jobs in the EU are critically dependent on nickel. Many of these jobs are high skill manufacturing jobs.
- Indeed, the EU is a global leader in the production of nickel-containing alloys, such as stainless steel and super alloys. Moreover, a number of important, high-skill 'end use' manufacturing sectors in the EU are critically dependent on nickel*. These include the

manufacture of jet engines and gas turbines, the production of process plant equipment used in important industries such as food and drink, oil, chemicals, and pharmaceutical production, and the pressing of CDs and DVDs.

- However, the socio-economic contribution of nickel and nickel-based platform technologies to the EU and its citizens also include additional benefits to the EU and its citizens that are often not apparent to policy-makers and the general public.
- Nickel compounds, for instance, play an important role in underpinning the competitiveness of major industrial and service sectors in the EU (such as aerospace, automotive, oil refining, and optical media), in supporting economic efficiency and innovation across large parts of the EU's economy, and in helping the EU achieve its environmental goals.

* Sectors were identified as "critically dependent on nickel" when substitution of the nickel-containing material is not possible without serious degradation in performance or major increase in cost.

For the applications in our company where we use nickel plated parts produced out of nickel sulfate and nickel sulfamate (both chemicals are intermediates) this would mean:

- A substitution by other metal or non-metal layers is not possible, since a combination of layer properties is required which can only be achieved by using nickel plated parts.
- Since substitution is not possible a loss of business will occur in case nickel sulfate and nickel sulfate should become restricted.
- A RoHS restriction on nickel sulfate and nickel sulfate would cause additional administrative burden for first and repeated exemption requests for EEE applications (note: nickel sulfate and nickel sulfamate are **not contained in the final EEE product**) with no additional benefit for human health and safety or the environment.

6. Further information, comments and summary

Both nickel salts, nickel sulfate and nickel sulfamate, are already classified under the CLP regulation (Regulation (EC) No 1272/2008 on Classification, Labelling and Packaging). Additionally the substance restrictions under the REACH ordinance 1907/2006/EC, Appendix XVII, Nr. 28 and 30 apply as well to nickel sulfate and nickel sulfamate.

Having knowledge about these pieces of chemical legislation and the classification of the two substances a downstream user can take appropriate and effective measures in the course of the hazard assessment of his processes when dealing with these two substances in order to achieve the best protection for the environment and to minimize health and safety risks for its employees.

Additionally, nickel and its compounds are already subject to a large number of legal restrictions which provide a very high degree of environmental protection as well as protection of people from a health and safety perspective within the value creation chain of these substances:

- Nickel and its compounds are subject to the restriction entry 27 of REACH Annex XVII, which restricts the use in post assemblies and articles coming into direct and prolonged contact with the skin.
- The IED Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control) sets emission limit values for nickel and its compounds at industrial sites.
- In the Water Framework Directive 2006/11/EC on pollution caused by certain dangerous substances discharged into the aquatic environment of the Community, nickel is listed as a substance for which water pollution has to be reduced. Member states are required to establish environmental quality standards for this purpose.
- A maximum level for nickel is set for water intended for human consumption by the Council Directive 98/83/EC on the quality of water for human consumption.
- Any compound of nickel (including the metals in metallic form, as far as these are classified as dangerous substances) is categorized as “heavy metal” and leads to the classification of hazardous waste according to the Commission Decision 2000/532/EC establishing a list of hazardous waste pursuant to Article 1(4) of Council Directive 91/689/EEC on hazardous waste.
- Limit values are specified for nickel by Council Decision establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 of and Annex II to Directive 1999/31/EC (2003/33/EC).
- Maximum air emission limit values for the incineration of waste are established in the Directive 2000/76/EEC on the incineration of waste.

This shows that the use of nickel and its compounds is already highly regulated and there will be no additional benefit if these substances would be additionally regulated under the RoHS-Directive 2011/65/EC.

This argument is strongly supported by the fact **that the two substances in question (nickel sulfate and nickel sulfamate) are only used as intermediates in electroless or electrolytic nickel plating and do not show up in the final EEE products.** So there is also no exposure of consumers of EEE to these two substances.

So there is no need to impose additional regulations in the framework of the RoHS directive with respect to these two substances, since they are already highly regulated by the chemical and environmental legislation itself.

7. Literature

The information provided in this stakeholder consultation from our company is derived from own experience with electroless and electrolytic (galvanic) nickel plating and the following literature:

[1] VDI 4800 Part 2; Ressource Efficiency – Evaluation of Raw Material Demand, 03/2018
[2] UBA-FB 001563, Indikatoren / Kennzahlen für den Rohstoffverbrauch im Rahmen der Nachhaltigkeitsdiskussion, Januar 2012
[3] Chemische Vernickelung, Nasser Kanani, Leuze-Verlag, 2007
[4] Technologie der Galvanotechnik, Bernhard Gaida, Kurt Aßmann, Leuze-Verlag, 1996
[5] Electroforming – A unique metal fabrication process; Ron Parkinson, Nickel Development Institute, NiDI Technical Series 10084
[6] Nickel Plating and Electroforming – Essential Industries for today and the Future; Ron Parkinson, Nickel Development Institute, NiDI Technical Series 10088
[7] Properties and Applications of Electroless Nickel; Ron Parkinson, Nickel Development Institute, NiDI Technical Series 10081
[8] Avoid Nickel Plating Losses; Bryan Fisher, Nickel Development Institute, NiDI Technical Series 10089
[9] Nickel Plating Handbook, The Nickel Institute, 2014
[10] Reference Document on Best Available Techniques for the Surface Treatment of Metals and Plastics, European Commission, August 2006
[11] Handbuch der Abwasser- und Recyclingtechnik für die metallverarbeitende Industrie; Ludwig Hartinger; Hanser Verlag, 2. Auflage, 1991
[12] Optisches Strahlführungssystem und Verfahren zur Kontaminationsverhinderung optischer Komponenten hiervon, DE 10109031 A1 (05.09.2002), EP1235110A2, EP1235110A3, US6824277, US20020145808
[13] www.nickelinstitute.org (https://www.nickelinstitute.org/NickelUseInSociety/Socio-EconomicBenefits), page visited at 30.04.2018