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State of the Art and Challenges in Development of Electrical Contact Materials in the Light of the RoHS Directive

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Abstract:
The article surveys current state of the art and challenges in the development of the electrical contact materials in the light of the EU Directive on Restriction of Hazardous Substances (RoHS). The focus was placed on widely used silver-cadmium alloys. According to this directive, as of July 1, 2006, use of six hazardous materials, including cadmium, are restricted for applicable electrical and electronic products intended for the EU market. In contrast, traditionally preferred material for production of electrical contacts is Ag-CdO, due to its outstanding functional properties. These conflicting interests result in present state where RoHS directive has not yet been implemented in its original form and has undergone numerous amendments and exceptions regarding the use of cadmium. Main reason for this seems to be the unrealistic time frame imposed by legislation. Although, significant effort has been put into research and development of alternative materials, there are still cases where adequate replacement materials had not been found. Therefore, importance of synchronicity between legislation and technological progress i.e. communication between legislative administration and industry and academia is brought to light as well as some common issues that may arise with an introduction of new replacement materials or product modification.
Keywords: *Electrical contacts, RoHS, Ag-CdO,*

1. Introduction

Recent directives approved by the European Union aim to reduce potentially hazardous substances contained in electrical and electronic equipment thus minimizing risks to health and the environment, and guaranteeing the safe reuse, recycling or ultimate disposal of equipment. One of the core documents is the EU Directive 2002/95/EC also known as Restriction of Hazardous Substances (RoHS). The directive restricts the use of six hazardous materials including cadmium found in electrical and electronic products and imposes that all applicable products in the EU market after July 1, 2006 must pass RoHS compliance [1].

Given that RoHS impacts the entire electronics industry and many electrical products as well as any business that sells applicable electrical or electronic products, sub-assemblies or components directly to RoHS countries, the implemented legislation creates a significant pull for the research and development of new electrical contact materials with less harmful

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impact on the environment. It also imposes fundamental challenges in material development and ongoing research in these areas that can lead to better understanding of these materials as well as aid in making them commercially viable.

On the other hand, for many years silver cadmium oxide (Ag-CdO) has been the preferred material for electrical contacts used in different low-tension devices of contactors type, due to its outstanding functional properties [2-4]. Thus, finding the adequate replacement material is by no means an easy task. The main properties required for such contact materials are high hardness, to avoid erosion, and excellent electric conductivity. Physical properties that favor extinction of the electrical arc when switching off contact [5,6], good processing capabilities [3] and RoHS compliance are desirable as well. Powder metallurgy process which includes mixing, pressing and sintering stages is usually the method of choice for production of electrical contacts since it provides uniform microstructures, high electrical conductivity and gives possibility for quick and easy production of contacts in a variety of sizes, shapes and chemical compositions. Moreover, it offers unique possibility of production of contacts containing two or more metal oxides. Over the years significant research efforts have been put into replacement of CdO with non toxic oxide dispersed in silver matrix, nevertheless currently available alternative materials, do not always offer the same performance as Ag-CdO.

As a direct consequence, the RoHS directive in its original form has not yet been implemented and has undergone numerous amendments and exceptions regarding the use of cadmium, among which the latest one from September 24, 2010 extends the use of cadmium in electrical contacts without set expiry date!

The presented article stresses the importance of synchronicity between legislation and technological progress and points out to some of the key development and testing issues concerning the real-world implementation of the RoHS directive on electrical contact materials.

2. Background - motivation

The European Union with its 27 member countries and around 495 million inhabitants represents significant market for electronics and electrical industry. In 2009, it was estimated that about 10.3 million tons of electrical and electronic equipment is placed in the EU-27 market annually. Electronic waste generation was estimated to 9 million tons per year with a predicted increase up to 12.3 million by year 2020 [7].

By the end of ’90s, due to technological innovation and market expansion electronic waste was the fastest growing waste stream, with an annual growth of 3-5%. More than 90% of waste was being landfilled, incinerated or recovered without any pretreatment, thus representing considerable environmental problem and also loss of valuable resources.

For that reason RoHS directive was adopted by EU countries and similar legislations were adopted by China, Korea, Japan and some U.S. states. Objectives of RoHS are to avoid leakage of hazardous substances from waste to the environment and to prevent contamination with these substances when recycling materials.

One of the six restricted hazardous materials is Cadmium. It is a bluish-white, soft metal widely used by the electrical and electronics industry in the form of Cadmium Oxide (CdO) for production of high quality Ag-CdO power switching contacts. The downside of using cadmium is related to health concerns mainly because, if ingested, it causes very slow degradation of kidney function. The majority of human exposure to cadmium results from drinking of untreated water directly from rivers and streams where cadmium dust has been dumped, industrial exposure to cadmium fumes and dust during smelting and processing or by inhaling cadmium fumes created by incinerating garbage. The fact that the majority of Ag-CdO contacts are made by means of powder metallurgy where mixing of cadmium oxide with silver powder is followed by pressing and sintering, only further increases concerns regarding the industrial exposure.

For the past 50 years, a lot of work has been done on research and development of separable electrical contacts [8]. The challenges that were traditionally met in development of electrical contact materials have been to overcome the drawbacks of the available contact materials and fulfill the growing interest for increasing reliability and energy efficiency in electrical and electronic systems. Nowadays, concepts like “green” chemistry and “sustainable technology” are forcing development in this area of industry as well. Concept of “green” chemistry aims at minimization of chemical hazards to health and the environment, waste reduction, and pollution prevention, through the adoption of 12 fundamental principles [9]. These principles apart from use of safer reaction media, material and energy efficiency include design of products for end of life. Thus effectively create additional challenges that need to be considered. As a result, the need for alternative, more environmentally friendly contact materials has been highlighted and considerable effort has been put forward in research of cadmium free electrical contact materials.

3. State of the art

Ongoing worldwide research into new contact materials is enabled by both industry and academia. Hence, process and product development of electrical contact materials is conducted by contact, electrical equipment and electronics manufacturers, private research firms as well as leading academic institutions. The issue that arises here comes from the fact that requirements and motives of legislative administration, manufacturers and academia are quite different. Businesses view their investments in technology in terms of the estimated return on investment, i.e. the gain in profits or market leverage to which the acquired technology will contribute. This is based on a traditional view of investment that is deeply embedded in the concepts of capitalism – you invest capital to create profit. Adopting of new technology before the old one has been paid off is not a popular course of action that is why most businesses plan their activities well ahead. Given that RoHS directive limits access to the EU market, most of the companies were eager to adjust their products to the legislation and for the most of Europe based companies it comes down to ‘‘evolve or die out’’. However, in reality replacement of the contact material in some cases may require changing of the construction of contactor, switch, etc., which could be time and money consuming, problems with patents or licenses may arise, thus making the replacement impractical or economically unfavorable. Development and production of new products (devices) engineered to accommodate substitute materials makes sense, however it can arise all above-mentioned issues as well. Therefore, majority of businesses support continuing and accelerating research into contact materials that could be direct drop-in replacements for Ag-CdO, with the goal of reducing the use of cadmium in electrical contacts as quickly as it is technologically feasible [8].

Whereas research in industry is primarily focused on process and product development in response to market requirements and profit generation, research in academia is less governed by commercial yield and more oriented towards exploration of concepts and phenomena and accumulation of knowledge. To bridge this gap (overcome this issue) some countries have introduced specific acts e.g. the Bayh-Dole Act in the United States, which facilitate academic involvement in product development [10], thus increasing the contribution of academia [11].

In order to illustrate scientific efforts and contribution in the field of electrical contact materials, the bibliometric approach was used. This elegant tool not only allows the statistical analysis of contribution but also the analysis of trends in knowledge dissemination and commercialization [12,13].

The source of the data for peer-reviewed journal publications and citations was the ISI Web of Science database with multidisciplinary coverage of over 11.000 of the highest impact journals worldwide (11.261 journals - September 5, 2009), including Open Access journals and over 110.000 conference proceedings and 727.549.189 cited references (July 2009) with about 12.000 conferences and 65 million cited references being attributed to its contents, per year. In order to emphasize the pull generated by the RoHS directive, data used for this study were retrieved for the publications from January 2001, until May 2011.

Presented graphs in Fig. 1 illustrate major increase in the number of publications and almost exponential growth of citations since 2003, demonstrating the scientific contribution in the field of electrical contact materials.

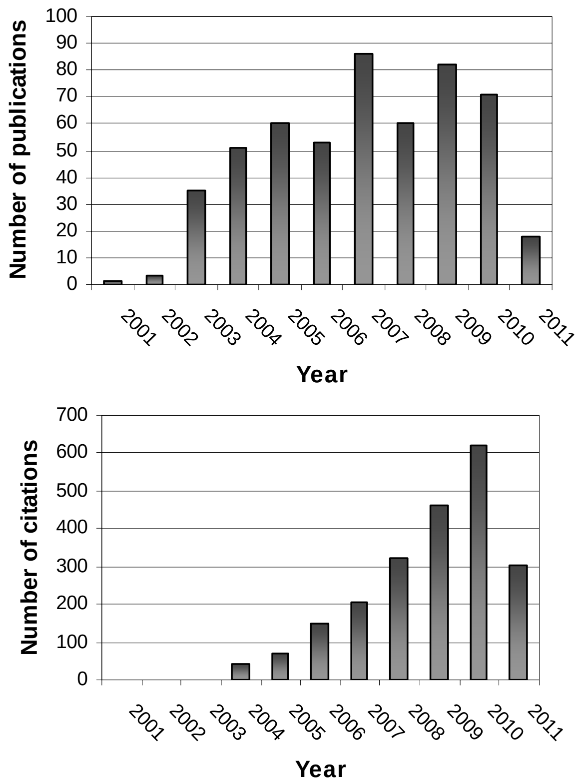

Fig. 1. Peer-reviewed journal disclosures and citations

Contributions and trends in research and development can also be seen through patent applications, since they reveal the invention for the first time, prior to any publication or commercial use. As a source for the patent disclosures database of the European Patent Office (EPO) was used.

Patent, as a form of intellectual property, for a limited period of time, provides protection and gives the exclusive right to the owner for exploitation of the technical invention in the countries for which it has been granted. Considering that EPO grants the European patent for several or all of the 38 Contracting States [14] (almost whole Europe), it is to be expected that reviewed patent applications refer to the products intended for European market.

Search was carried out through "Espacenet" service of the EPO, which gives an access to more than 70 million patent documents from all over the world, most of them being patent applications. Data was obtained using smart search and key words "electric contact material" for selected time period (2000-2011). Comparing the number of patent applications per country where the application was filed, it can be seen that the majority of applications, some 86%, in field of electric contact materials come from China, Japan and Korea (Fig. 2).

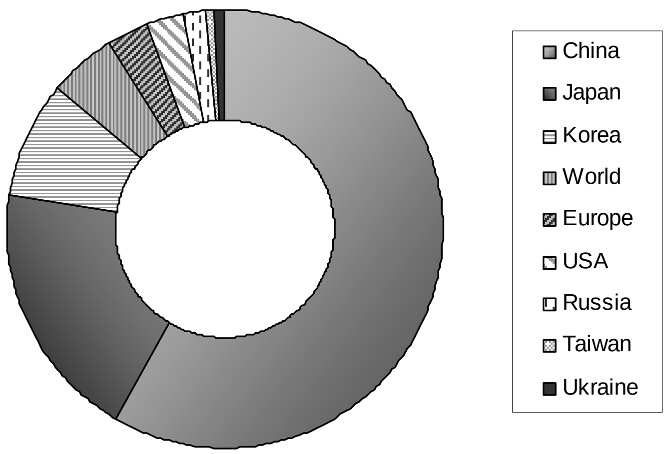

Fig. 2. Patent application according to the country of origin

Analyzing the number of patent applications per year, during the analyzed period, steep increase can be observed from 2000 to 2003 (Fig. 3). However, from 2005 and onwards number of patents varies and could refer to the fact that carried research have shown limited success.

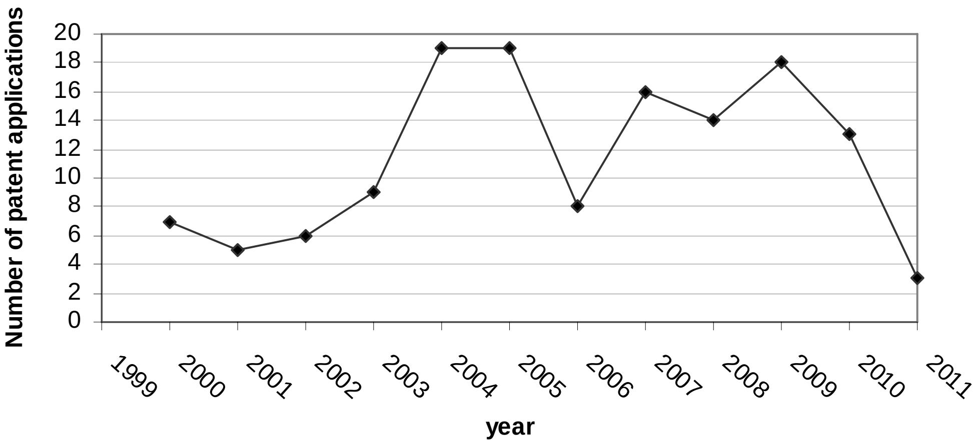

Fig. 3. Patent disclosures

Furthermore, the observed downturns in the number of patents in the periods 2005-2006, 2007-2008 and 2009-2010 coincide with the years in which the Commission decisions on amending for the purpose of adapting to the technological progress regarding the exemptions for applications of cadmium were adopted.

According to the category of assignee, results show that companies dominate with almost 60% of contributions, followed by universities and institutes with 26% and individual inventors with 14%, as illustrated on Fig. 4.

When patents are concerned, without a doubt all three parties are driven by commercialization. Although universities and institutes (academia) made significant contribution in this field of research, companies proved to be much more eager, partially because they could potentially benefit or loose the most.

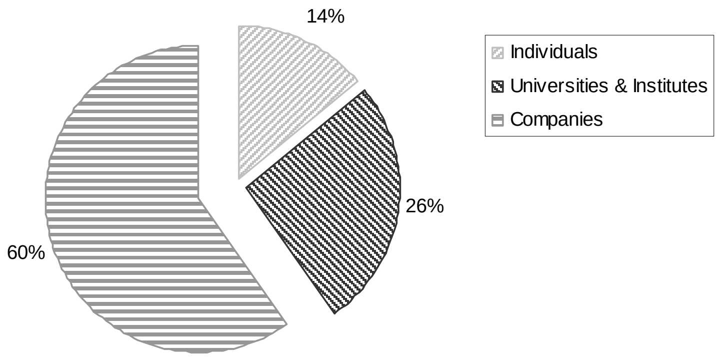

Fig. 4. Patent disclosures according to assignees

As a result of research efforts today we have about 35 major categories of commercially available metal alloys, with numerous formulations within each category, used for production of separable electrical contacts [9]. Considering the abundance of available formulations it would seem that it would be easy to find the adequate replacement for Ag-CdO. Nevertheless, there are still a number of applications and load conditions for which R&D has not provided satisfactory solutions and for which Ag-CdO contacts are irreplaceable. This is particularly true for high current applications and continuous operation or cycling [15].

4. Challenges in contact materials development

The task of finding environmentally friendly alternative is made complex by the fact that material that needs to be replaced possesses quite unique set of properties that makes it ideal for numerous applications. The major advantages of Ag-CdO contacts over any common alternatives are their ability to quench electrical arc and resist welding, high electrical and thermal conductivity and superior erosion resistance. Consequently, Ag-CdO contacts have longer electrical life and they are smaller which reduces the total number of replacements and material and energy requirements for production and ultimately reduces the total volume of product disposed in the environment. Furthermore, due to the fact that Ag-CdO contact performs so well, in some cases it is possible to replace the opposite Ag-CdO contact with a fine silver contact. Considering the possible damage costs in case of contact failure, superior performance of Ag-CdO contacts makes them the obvious choice for any safety-related applications where high reliability is required.

In an expert study R.L. Ekowicki [15] points to just some of the many important issues and challenges that need to be overcome in development of contact materials apart from research and material design issues. The study implies that besides the type of material the type of tests that were performed in determining whether potential replacements can actually function as replacements for Ag-CdO electrical contacts are very important as well. It is suggested that in the past most research on contacts was performed in a lab and not in the actual applications which is significant since in that case contacts do not operate under same conditions. In an actual operation there is a possibility of reaching the conditions that would facilitate the formation of an electrical arc, which could cause the contacts to weld together. The matter is further complicated by the fact that each component manufacturer has its own method of production resulting in many shapes and sizes of components. Hence, type of contact that might work for one manufacturer might not work for the other in a same end product. In some areas of application technological push determines the type of contact to be used. The majority of thermo devices used in automotive DC applications over the years did not have contacts that contained cadmium, however as the electrical motors used in automobiles became more sophisticated traditional contacts could no longer protect them. Again, Ag-CdO contacts proved to be very successful. On the positive side, with the advances in technology over the years, silver thickness and percent of cadmium in the silver were reduced.

According to study [15] in some cases standards and legislation are lagging behind the technological progress, resulting in outdated norms and requirements for different devices containing contacts that could potentially allow substandard devices to be placed on the market.

Another important issue that should be considered when introducing or preferably even in a research stage of the replacement material for Ag-CdO contacts is bonding of the material to the contact holder. Considering that bonding materials (solders) are also subject to RoHS directive, extensive research is undertaken in this area as well [16,17]. This is significant for the reason that if the bonding material or process to bond the new contacts to holder is already patented it could potentially create the supply problem given that resolving of patent issues may take some time, perhaps even years [15].

Even with all mentioned issues successfully resolved the introduction of a replacement for Ag-CdO contact would also require quite time demanding, thorough and extensive testing carried both by certified test agencies and manufacturers.

The issues mentioned so far are only some of the real-world challenges and problems that are encountered in development of a reliable contact material. Majority of these issues are reflected in the criteria for granting exemptions from RoHS directive, which include cases when elimination or substitution is technically or scientifically impracticable, or where the negative environmental, health and/or consumer safety impacts caused by substitution are likely to outweigh the environmental, health and/or consumer safety benefits. Availability and reliability of substitutes and socio-economic impacts are taken into a count as well.

5. Conclusions

With all being said, complexity of the task of finding an acceptable replacement of Ag-CdO contacts becomes evident. It seems that problem mostly lays in the fact that even though RoHS creates significant pull for R&D, in a given time frame, science was not able to provide adequate replacement materials. Hence, the currently available alternative materials do not always offer the same exploitation life and level of performance under same conditions as Ag-CdO.

Given that the goal is to replace the material with by far superior properties than any currently available substitute and which, due to its outstanding properties, has numerous safety related applications, development of new materials requires much more time than originally given by RoHS directive. Elaborate task of finding the adequate replacement materials is made even more complex by the different requirements and motives of companies, academia and legislative administration. Therefore, apart from research and material design issues, there are quite a lot of practical, economical, legal, essentially real-world issues that should be considered. Experts estimate that it may take anywhere between 5 to 10 years in order to find acceptable replacement and even more before final approval for production of new devices.

Common belief of many experts is that hasty introduction of substitute materials could do a great harm to the electrical and electronics industry that requires the use of reliable electrical contacts in their products. So far, the general course of action is to support the existing EU RoHS exemptions permitting the use of cadmium in electrical contacts until contact materials, that are at least as good as Ag-CdO, are developed.

Acknowledgement

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Садржај: *У раду је дат преглед тренутног стања и изазова у развоју електроконтактних материјала у светлу директиве Европске Уније о рестрикцији употребе опасних супстанци (RoHS) са акцентом на сребро-кадмијум легуре као базне легуре за производњу Ag-CdO електроконтакних материјала, најшире заступљених у електро индустрији. према донетој директиви ЕУ, од 1 јула 2006. године забрањује се употреба шест опасних супстанци, између осталих и кадмијума, у производима нсмењеним за тржиште ЕУ. Ово је управо у супротности са чињеницом да је с обзиром на изузетна функционална својства, сребро-кадмијум оксид (Ag-CdO) дуги низ година један од најчешће и најшире коришћених електроконтакних материјала.*

Имајући у виду да се директивом утиче на целокупну електронску индустрију, она ствара знацајан подстицај истраживањима и развоју нових еколошки прихватљивих електроконтактних материјала, који је у раду илустрован преко библиометријских показатеља. У пракси, директива у својој изворној форми још увек није у потпуности имплементирана и у међувремену је допуњена са бројним амандманима, нарочито у вези са употребом кадмијума у електричним контактима. Може се рећи да проблем у многоме лежу у нереалним роковима постављемин од стране законодаваца као и у чињеници да и поред значајног подстицаја који РоХС директива стрвара, у предвиђеном временском периоду, наука није успела да нађе адекватну замену за Ag-CdO. Истакнут је значај усклађивања законодавства са степеном технолошког развоја, као и на значај комуникације између законодавних тела и научно-истраживачких организација. Указано је и на неке од проблема који се могу јавити приликом увођења нових електроконтакних материјала у примену или модификације постојећих производа.
Кључне речи: *електроконтактни материјали, РоХС директива, Ag-CdO*