Exploring the Patent Landscape of Sintered Metal Technologies: An Analysis Using LLM-Based AI Patent Search

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Abstract- This study leveraged a proprietary Large Language Model (LLM) via app.amplified.ai, focusing on sintered metal technology patents for die-bonding uses in electronics packaging. This AI platform analyzed patent complexities, particularly examining 11 pre-selected patents with known activities on uses of silver or copper paste formulations as die-attach materials from companies like Infineon Technologies, Siemens, Nihon Superior Tanaka Kikinzoku, Heraeus, Hitachi and Alphametals. Following similarity assessments with these 11 pre-selected patents, 243 core patents were identified from the app.amplified.ai patent databases (of more than 150 million), retrieved and analyzed, resulting in six key clusters: 1) conductive adhesive bonding 2) metal particle bonding 3) porous metal bonding 4) sintered silver bonding, 5) substrate bonding methods 6) terminal management bonding. These clusters match the dominant Cooperative Patent Cooperation codes as follows: H01L24/83, H01L24/29 and H01L2224/8384; all methods related to connecting semiconductor using layer connector, and mainly with sintering technology. Finally, these clusters helped to outline the interconnections among patents, their legal statuses, and assignees from 1994 to 2024, offering valuable insights for patent analytics regarding significant patents and the main technology players for this sintered bonding

Keywords: sintered metal, large language model, patent, die-attach materials

I. INTRODUCTION

Sintered silver bonding is extensively used as a high-temperature die-attach bonding material for high-value power modules in the last few years. The continuing use of wide band-gap semiconductors, such as. silicon carbide and gallium nitride in electric and hybrid vehicles fuelled this demand [1, 2]. Sintered silver offers superior mechanical and thermal properties and is a lead-free solution complying with the current European Union directives. The increasing interest in this technology necessitates an understanding of its patent landscape to leverage its potential and freedom-to-operate as die-attach materials[3-5].

A good understanding of patent landscape requires .patent search and retrieval. Patent and prior art searches serve various objectives, including determining patentability, identifying infringement risks, ensuring freedom to operate, and scanning for technology trends. Each objective necessitates a different focus on specific sections of patent documents, whether it be the claims, patent descriptions, or other relevant parts[6] .

Regardless of approach, patent search and retrieval relies heavily on text-based and classification-based searches in the past. This approach typically involves the use of relevant keywords and their synonyms, proximity, truncation, and patent classification in Boolean logic. Then, the patent engineers iteratively modify the search statements as they refine their understanding of the prior art. These statements may include terms not originally present in the claims, reflecting the complex and evolving nature of patent documentation.

Since domain knowledge is necessary for successful retrieval, there is a compelling need to explore the application of artificial intelligence (AI) to facilitate patent retrieval, especially considering the vast repository of over 150 million patent documents. The patent system is established with the expressed mandate to disseminate knowledge in exchange for a limited monopoly of up to 20 years; thus, inefficient patent retrieval undermines this fundamental purpose.

However, patents are characterized by unique linguistic nuances, with patentees often employing their own lexicon or using abstract terms to maximize their protective scope, not necessary to ease reader's understanding. The evolving nature of technology and patent text genres leads to shifts in terminology over time, where different term is used to represent similar technical concepts across different periods. For example, sintered silver, was also known as low temperature joining technique in the late 1980s to 1990s, before shifting to the current term sintered silver from mid to late 1990s onwards.

Additionally, patents encompass various data artifacts, such as drawings, mathematical formulas, bio-sequence listings, or chemical structures, which necessitate specialized techniques for effective search and analysis. Keywords and synonyms are typically extracted from the claim or technical description fields of patent applications, but selecting relevant search terms is challenging due to the complex technical structure of patents and the prevalence of vague or mismatched terms, often requiring further domain-specific research.

While keyword-based searches offer certain advantages, such as ease of use and the potential to retrieve comprehensive invention details, they also present significant drawbacks. These include issues with synonyms and context (e.g., "plasma" in different fields like biology blood plasma and radio-frequency plasma), chemical search terminology, translation errors, spelling discrepancies, optical characters recognition errors for older patents, and the challenge of searching for numerical data.

Similarly, patent classification searches have their own merits, providing more complete results, being independent of text language and terminology changes, and enabling concept searches. However, they also involve complex classification structures and require a thorough understanding of classification rules [7]. Historically, combining text-based and classification-based searches in traditional Boolean logic was advisable to achieve best results. This approach has yielded valuable insights, particularly in the domain of sintered metal for die-bonding [3-5].

Our current research acknowledges the limitations of our previous studies constrained by Cooperative Patent Classifications (CPC) and keywords, and but also aims to address some potential biases introduced by AI-based databases, which rely on learning data to build background knowledge and predict future results.

In short, biases in AI systems for patent searches arise from various sources, impacting result accuracy. One major bias is in training data [8]. Although Amplified.ai is trained in multiple languages, AI systems trained mainly on English-language patents may struggle with patents in other languages, missing relevant documents. Additionally, patents use specialized terminology, and without sufficient context, AI might misinterpret these nuances, leading to inaccurate results. Relevance ranking algorithms can also introduce bias, creating a feedback loop that prioritizes certain results based on past searches. This can filter out diverse or novel information. Moreover, many patents include critical non-text information like diagrams and chemical structures, which text-focused AI may miss. Addressing these biases requires diversifying training data, improving contextual understanding, integrating non-text analysis, and maintaining human oversight to enhance the reliability and effectiveness of AI patent searches.

However, recent publications and implementations, such as European Patent Office's Presearch framework, have explored various AI techniques, including supervised and unsupervised machine learning approaches to address this bias and improve this patent data retrieval [9, 10]. Other AI-initiatives by patent office are also listed herein [11]. In general, patent search methodologies are broadly categorized into traditional Boolean searches (keywords and classification), semantic and citation networks, knowledge graphs and deep learning, and large language models (LLM) and deep learning.

The tool selected for this study, Amplified.ai, falls within the LLM model category. Here, we conducted the preliminary studies of a large language model-based patent search database to revisit patents related to sintered metal pastes as die-attach materials in electronics packaging.

II. Experimental Approach

A. *AI-based patent search engine: amplified.ai*

Amplified.ai utilizes a proprietary transformer-based large-language model (LLM) as the core of its AI development, similar to the technology behind widely known systems like ChatGPT, to search relevant patent or prior art. The choice of different language models lead to different patent search results.

Amplified.ai is a proprietary model specifically tailored for handling long, complex, technical documents such as patents. Amplified's search system learns to understand the nuances of patent similarity by looking at the full text of the patent and examination history. The trained model is then used to convert all global patents into vectors, thereby creating a vector space that aims to accurately represent patent information. This allows for conceptual similarity search based on natural language, simply by providing existing patents, or a combination of both.

Furthermore, Amplified.ai allows users to integrate AI and Boolean tools (e.g. terms, assignees, inventors etc.) within a single platform, which proved to enhance user control and flexibility. Then, the vectors can be clustered and labelled dynamically using generative AI in order to better understand the technology landscape. Later, the selected patents were summarized and categorized by parameters such as problems, solutions, challenges, features, benefits, target use, and potential use for further analysis. This approach allows users to explore information from various perspectives quickly, enabling them to iteratively build a robust understanding and gather extensive training data. In essence, Amplified.ai acts as a research partner to complement human feedback, helping them to overcome biases discussed earlier.

B. *Search strategies*

The Aimplified.ai platform examined eleven pre-selected patents with known activities on uses of silver or copper paste formulations as die-attach materials. These patents were from companies, such as, Infineon Technologies (US8835299B2, US8828804B2, US8253233B2, US7851334B2, US20130203218A), Hitachi Ltd (US7393771B2). Siemenss (US5893511A), Nihon Superior (US20150037197A1), Tanaka Kikinzoku (US7789287B2), Alphametals (US20120114927A1) and Heraeus (US8950652B2). These eleven patents were selected to cater the range of materials suppliers and electronics companies utilising sintered metals as part of their electronic package designs. Following similarity assessments with these 11 pre-selected patents, 243 core patents were identified from the Amplified.ai patent database, retrieved, analysed and labelled as relevant.

III. Results and Discussions

As shown in Figure 1, the similarity assessment analyses the entire documents to reveal six broad clusters of patents focusing on areas such as conductive adhesive bonding, metal particle bonding, sintered silver bonding, substrate bonding methods, and thermal management bonding. These six clusters matched the dominant Cooperative Patent Cooperation codes as follows: H01L24/83, H01L24/29 and H01L2224/8384; all methods related to connecting semiconductor using layer connector, and mainly with sintering technology to dissipate heat from the chip when used as die-attach materials.

Figure 1 also shows the top nine assignees identified in this analysis as: Hitachi, Infineon Technologies, IBM, Mitsubishi Electric Corp, Mitsubishi Materials Corp, Nitto Denko, NXP, Resonac, and Semiconductor Components (Onsemi). Notably, IBM and Resonac were unexpected top assignees. Further analysis revealed that IBM's filings in this area relate to similar concepts of thermal dissipation and bonding, but not specifically related to sintered technology as bonding materials in electronics packaging. In the case of Resonac Corp, this entity emerged as the amalgamation of Showa

Table 1: Top ten clusters of the retrieved patents based on target use and potential use

No	Target Use (Current use)	Potential Use (Future or possible use)
1	Ceramic substrate bonding	Advanced packaging
2	Chip bonding	Electronic interconnects
3	Compact semiconductor	Heat dissipation
4	Electronic interconnection	High-temperature bonding
5	High-temperature connections	Low-pressure bonding
6	Power module bonding	Power electronics
7	Power semiconductor management	Power module cooling
8	Semiconductor manufacturing	Semiconductor components
9	SiC power packaging	Semiconductor connections
10	Solderless device connection	Thermal management

Denko and Showa Denko Materials (Hitachi Chemicals), which held several patents related to sintered materials. For example, Resonac's patent (JP2023127071A) included a laminate film containing a silver layer, though not necessarily based on sintered technology, while another patent, i.e., JP7468358B2, dealt with sintered laminate applications.

Another notable result of this current AI-based approach not found in earlier studies using CPC-keywords approach was the retrieval of several Japan-only patents, including one by Showa Denko (JP2022088924A) advocating the use of nickel particles (15-50 wt%) in copper paste to promote adhesion to silver or gold-metallized substrates. Technical and patentability can be debated on the merits of this approach, but this finding suggested the complementary nature of using AI-based approach in retrieving patent data.

Based on Figure 2, the patent search also revealed the primary problems addressed by these "sintered metals" patents, as follows: 1) advanced packaging techniques 2) cost-effective manufacturing. 3) heat-dissipation solutions 4) high temperature bonding 5) low-temperature interconnection. 6) sintered joint reliability 7) sintering process challenges 8)Substrate metallization issues 9) thermal expansion mismatch (10) thermal stress management. These ten patent clusters encompassed the general strategies to address these problems using package design with related metallization schemes, process engineering, equipment improvement and materials paste formulation to produce sintered metal joints with long term reliability. For instance, one Osram patent (US10147696B2) suggested the use of iridium and/or rhodium metallization to reduce oxidation and electromigration, and promote interfacial bonding to enhance the long term reliability of these package.

Another approach, as shown in Table 1, listed the "target use" and "potential use" of the retrieved patents. This comparison did not yield any unexpected results. because the clusters were derived from the eleven pre-selected patents, which served as the basis for similarity matching. The potential uses aligned with the current needs for sintered silver in power modules. Further analysis of these patent clusters, based on individual patents, was currently undertaken to look for other insights.

Based on "potential use" in Table, 1, thermal management and heat dissipation related to semiconductor connections or interconnects are prominent on the current wish-lists. However, the "low-pressure bonding" cluster highlighted only one patent, Tanaka's US9561952B2, which pertained to hermetic sealing. This patent suggested the use of stencil-printed silver metal paste with defined topography to act as sealants for MEMS packaging. Additionally, the patent also suggested this sinter-based applications in wafer-level packaging, as part of its technical descriptions.

In the "high-temperature bonding" cluster (Table 1), two patents were particularly noteworthy. Rohm's patent, US11626352B2, addressed the sintering challenges faced in the discrete power MOSFET packaging. This patent proposed designing the electrode pad and offset alignment to enhance coverage and reduce stress concentration, to ensure robust sinter-bonding. Another significant patent in this cluster is from Senju Metal Industry, (US20220347745A1). This patent explored high-temperature bonding techniques using laminate Ag films produced from Ag particles with hybrid particle sizes ranging from 50 to 1000 nm and 1 to 20 μm, The patent also specified a preferred average roughness (Ra) of the faying surfaces between 1.06 μm and 3.3 μm to produce robust joint. This extensive patent claim scope suggested big coverage, which was likely to receive pushback during patent examination.

IV. Conclusions

In conclusion, this LLM-based amplified.ai successfully provided patent analysis related to sintered silver in power modules and semiconductor applications, highlighting current trends and innovations. The six clusters derived from the eleven pre-selected patents included strategies addressing the problems with advanced packaging techniques, cost-effective manufacturing, heat dissipation, and high-temperature bonding. These patents emphasized the importance of optimized sintered material properties and bonding processes. Further investigation of individual patents within these six clusters were expected to provide deeper insights into their potential uses and would be detailed in future publications. Alternative approach of using other-pre-selected patents would also be explored to look at patent landscape of sintered silver and predict future trend in this area.

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