Strategic analysis of innovative laser interference lithography technology using claim-based patent informatics

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Abstract: Patent analysis depicts the innovative directions of research and development (R&D) and technical breakthroughs in given domains, because patents are effective means of intellectual property right (IPR) protection for innovations with viable commercial applications. Patent analysis often helps companies monitor IPs and assess their competitive positions in the marketplace. Patent clustering is one of the crucial analytical approaches in the overall patent analysis procedure for gathering the relevant technologies into coherent and specific clusters. Prediction methods for future technology directions are then utilized to formulate effective R&D strategies and to forecast likely outcomes. Currently available approaches in technology forecasting through clustering are mostly based on general patent text mining to identify key words/terms in the patents and group patents according to similar appearances of keywords. These approaches are not particularly effective at categorizing patent features. A company’s R&D or IP decision makers cannot fully rely on the categorization analysis outcomes to obtain precise insights into emerging technological trends. This paper proposes a new approach to patent claim-based technology clustering to forecast the frontiers of IP protected technologies. The proposed approach is applied for strategic patent analysis of Laser Interference Lithography.
(LIL) innovations. Patentable features are identified from annotated elements within independent claims of patents. These features are then summarized into simplified sentences for the definition of specific clusters. This method establishes a unique clustering principle to improve patent analysis accuracy and credibility of forecasting future R&D trends based on crucial patent claims.

**Subjects:** Intellectual Property Law; Laser & Optical Engineering; Mechanical Engineering; Nanoscience & Nanotechnology; Patents

**Keywords:** patent analysis; laser interference lithography (LIL); claim based technology analysis; patent clustering; independent claim; patent search; innovative design and manufacturing

1. Introduction
Lase interference lithography (LIL) is a branch of various lithography technology segments used in nanoscale structures fabrication, which has been successfully applied experimentally since the 1960s through the use of interference as a useful tool and the use of laser as light source (Wolferen & Abelmann, 2011). Many patents related to LIL technology have been issued for subsequent improvements. Figure 1 shows USPTO application trends related to LIL patents from 1970 to 2014.

Understanding into emerging technical trends can help businesses simultaneously sidestep low-productivity investments and take advantage of new opportunities. Patent analysis techniques are widely used to identify emerging technological developments. Visualizations resulting from patent analysis are called patent maps, and can be used to present complex patent information in ways that can be easily comprehended and interpreted for technical and managerial decision-making. These maps integrate quantitative and qualitative analyses of patent documentation for domain-specific technologies (Liu & Yang, 2008; World Intellectual Property Organization, 2015a). Quantitative analysis is derived from a statistical assessment of patent bibliographical information, e.g. the number of patent applications, assignees, inventors, and applicant names and countries of origin, etc. (Introduction to Patent Map Analysis, 2011; Liu & Yang, 2008). Qualitative analysis refers to the contents of the patents, typically presenting technical information using matrix or tree diagrams. Data relevant to managerial space decision-making include statistics related to patent assignees, countries, application dates, issuance dates, classification codes, citations and other usable bibliographical information. Technology-oriented maps take the form of technology/function matrices or a tree-structured forms illustrating showing the development of the relevant specialities over time (Cheng & Wang, 2013).

Patent maps offer managers easy access to information which can facilitate strategic innovation management, particularly in terms of optimizing technology investments. However, the greatest
difficulty in using patent technology maps for analysis is the efficient and precise categorization of patents, and this remains a significant drawback to traditional clustering approaches (Nazeer & Sebastian, 2009).

This paper proposes an alternative method for analyzing patent-claim based technology that overcomes the disadvantages of traditional patent clustering methods. In the proposed approach, technology analysis is conducted based on claim-based clustering, with a case study based on the LIL technique used as validation. Unlike the traditional k-means clustering algorithm for patent analysis, the proposed approach related to efficiently identifies patentable features from patent documents, especially from independent claims of that, thus allowing for the more precise forecasting of important technology applications and trends. This approach also facilitates the precise identification of emerging market trends for strategic innovation planning.

2. Literature review

2.1. Laser interference lithography (LIL)

In 1801, Young’s double-slit experiment illustrated light interference to establish the wave theory of light (Young, 1802, 1804). In 1834, Lloyd demonstrated light interference with the use of a mirror (Lloyd, 1831). The development of the laser in 1960 made coherent light easily available, thus driving additional research into optical interference, including the development of laser interference lithography (LIL), which is now is widely used to produce periodic nanoscale structures.

There are various geometrical configurations of interference lithography (IL) systems, the two major systems being the Lloyd’s mirror configuration and the beam splitter based configuration.

In the 1830s, Lloyd developed the mirror interferometer as a simple LIL implementation used to project high-resolution line patterns on almost any surface (Wolferen & Abelmann, 2011). As shown in Figure 2, the apparatus entails a mirror placed perpendicular to the sample holder. The expanded laser beam illuminates both the mirror and the sample. A portion of the laser’s light is reflected on the mirror and thus interferes with the portion of the beam that directly illuminates the sample, thus generating a series of high and low intensity light bands (de Boor, Kim, & Schmidt, 2010; Xie et al., 2008). The Lloyd’s Mirror can be rotated to tune the angle of incidence (θ) and adjust the period of pattern (Xie et al., 2008). The setup of Lloyd’s Mirror interferometer is relatively simple and requires fewer optical components.

Beam splitter-based configuration is needed if a larger area is to be exposed. Two or more amplitude splitting beams can be directed to an intersection area of a resist-coated substrate and then the interference fringes will be generated. In a two-beam setup the laser beam is split into two beams which are individually expanded and then recombined directly over the substrate to form interference patterns. Figure 3 shows a schematic of a typical two beam interferometer with a pair of beam-splitters and two mirrors (Jang et al., 2007; Walsh, 2004). In addition, many studies have developed three-beam LIL system for the fabrication of two dimensional (2D) periodic patterns both directly in the target material and through a photoresist (Divliansky et al., 2001; Hobbs, McLeod, & Kelsey, 1999). Furthermore, the superimposition of four beams can produce 2D or 3D periodic
patterns by varying the arrangement or polarization of four beams (Ullal et al., 2004). The more a laser beam is split, the resulted geometries more complex. For example, a complex nanostructure can be obtained through the exposure of six beams LIL system (Jang et al., 2007). Accordingly, we also call this configuration as a multi-beam LIL system.

Moreover, various types of LIL experimental arrangements based on diffractive optics have been demonstrated such as achromatic holographic lithography (Anderson, Komatsu, & Smith, 1988; Savas, Shah, Schattenburg, Carter, & Smith, 1995) and diffractive phase masks (Gamet et al., 2006; Park, Kim, Constant, & Ho, 2011).

Another method that can be developed to define smaller features is immersion LIL. Immersion configurations as simple as a drop of water or a coupling prism were used to reduce the period of the structures (Hoffnagle, Hinsberg, Sanchez, & Houle, 1999; Raub et al., 2004). Namely, to obtain a smaller linewidth further, requiring to increase refractive index (n) to reduce the period of the interference pattern (Λ) by immersing the target material in the fluid with refractive index (n) or using a prism (de Boor et al., 2010).

Laser interference lithography is an attractive method to reproducibly and efficiently produce large-area periodic patterns with nanometer scale features. LIL has found commercial applications where generation of periodic patterns is desired. Applications that require more complex pattern generation are in the research and development (R&D) stages. Many prior studies have applied this approach to create new patented applications. However, this mode of analysis has not yet been comprehensively applied to LIL techniques in an attempt to forecast emerging technologies or applications, or to identify potential domain-specific competitors. The present paper presents a systematic patent analysis targeting the LIL technology domain.

2.2. Patent analysis

Patents are nation- or region-specific exclusive rights to a novel product or process (World Intellectual Property Organization, 2015b). This exclusivity is provided for a limited period. The process of applying for patent protection requires the full disclosure of information critical for subsequent technological development (World Intellectual Property Organization, 2015b). Previous studies have
extensively analyzed patent statistics to generate indicators of technological and economic trends (Grilliches, 1990).

Given the brevity of modern product life cycles and continuous changes to market requirements (Trappey, Trappey, & Wu, 2010), Granstrand (1999) proposed using patent analysis to help businesses reduce R&D costs and expand market share. R&D engineers and business decision makers use patent analysis to understand current technological developments and future trends (Paci, Sassu, & Usai, 1997), and for maximizing benefits from strategic enterprise planning, mergers and acquisitions, licensing opportunities, R&D, and human resources (Introduction to patent analysis, 2015). To optimize management of strategic innovation, patent analysis enhances management of proprietary technologies, product development and research processes, enabling companies to generate precise competitive analyses, forecast future trends, and plan competitive responses and contingencies (Fleisher & Bensoussan, 2002). Today, patent are critical business assets, and patent analysis has emerged as a crucial component of effective enterprise management (Kim, Suh, & Park, 2008; Lai & Wu, 2005).

Patent analysis integrates quantitative and qualitative elements (Hong, 2009). Qualitative analysis relies on text mining of the patent documents (Trappey et al., 2010), while quantitative analysis uses metadata taken from the patent’s bibliographical information (e.g. inventors, assignees, filing dates, issue dates, citations) using statistical processing approaches (Hong, 2009; Trappey et al., 2010). Past research on patent analysis focused on text mining and visualization techniques (Abbas, Zhang, & Khan, 2014).

Text mining uses analytical techniques to obtain machine-readable data from natural language documents (Ghazinoory, Ameri, & Farnoodi, 2012; Tseng, Lin, & Lin, 2007), utilizing term frequency-inverse document frequency (TF-IDF) to assess the importance of individual terms according to their frequency of appearance in the text (Chen et al., 2005). Ramos (2003) used TF-IDF to assess word relevance in document queries. Tseng et al. (2007) proposed approaches for text mining specifically designed for use in patent analysis tasks, including text segmentation, summary extraction, feature selection, term association, cluster generation, topic identification and information mapping.

Visualization-based approaches are used to create visual representations of patent information and analysis outcomes. Patent maps and patent clustering facilitate the quick and effective identification of technological trends within a particular domain (Abbas et al., 2014). Kim et al. (2008) proposed a visualization approach to cluster related patents together.

2.3. Cluster analysis
Clustering is an unsupervised classification method for grouping data according to similarities in internal characteristics (Trappey et al., 2010), and various clustering methods have been developed to suit different types of data. Once the clusters have been determined, they are interpreted by subject matter experts. The goal of clustering is to maximize the similarity of objects within the cluster, while maximizing differences among clusters (Trappey et al., 2010).

Accurate interpretation requires researchers to process considerable volumes of patent information. K-means clustering is a widely used clustering algorithm, and was used by Kim et al. (2008) to design a visualization approach for clustering patents based on keywords taken from filing documents. But K-means clustering is subject to several disadvantages (Abbas et al., 2014; Chen et al., 2005; Trappey et al., 2010) and is requires a high degree of computational loading, especially for large data sets. The accuracy of the output clusters is also potentially problematic because the initial centroids are chosen at random (Nazeer & Sebastian, 2009).
3. Methodology

The present research utilizes a domain-specific patent analysis technique. Figure 4 outlines the research methodology and structure. The proposed method for patent-claim based technology analysis is designed to improve strategic innovation planning.

This research presents an analysis of U.S. patents related to LIL technologies. The source documents are taken from the Thomson Innovation (TI) commercial patent database, following a patent search strategy described as follows.

3.1. Selecting a technical topic to be analysis and determining data coverage

When targeting a particular technology domain one must first clearly define the subject for patent analysis. U.S. patent data related to LIL technology were obtained from the Thomson Innovation (TI) database for the period spanning 1836 to April of 2016.

3.2. Gathering keywords

Initial keywords were obtained from subject matter experts and from highly-relevant patent documents. These keywords were used to formulate an initial query to search patent documents and generate an initial patent pool.

3.3. Sieving related-patent

An initial screening selects patents from the initial patent pool for inclusion in the specified technology domain. Screening performance is determined by the specificity of patent-related definitions.

3.4. Updating patent search queries to generate an optimal patent pool

The screening procedure uses a comprehensive list of keyword synonyms for the patent cluster, along with patent classification numbers (e.g. IPC or UPC). Searches are conducted iteratively, and the search strategies and criteria are regularly updated. Multiple iterations will generate an optimal patent pool including relevant patent documents.

3.5. Patent clustering in accordance with claim analysis

Application and grant documents for 287 patents were used to generate a patent management map, using the Intellectual Property Defense-based Support System (IPDSS) software package to produce visualizations for longitudinal analysis of patent application trends, assignee activity, assignees’ countries of origin, inventors, citations, and the distribution of patent classification.
numbers. The subsequent technology analysis interprets patent claims selected from the optimal patent pool. The proposed approach provides a claim-based technology analysis to optimize strategic innovation decision-making. The claim-based patent clustering procedure is a crucial analytical step in the overall patent analysis process for gathering the relevant technologies into coherent and specific clusters. Detailed descriptions of that begin by clearly identifying and annotating the various elements in every independent claim for the invention. Ideally, each independent claim should be reviewed if a patent specification is more than one independent claim. Next, individual patentable features are identified from among the different elements in each independent claim. The number of patents which use file wrappers to identify patentable features is relatively few, and patent classification codes (including IPC and UPC) can be used as an additional reference. To simplify the process output, we summarize the patentable features in a single sentence, and these brief feature descriptions are then compared against each other to identify patents characterized by similar features for inclusion in a patent cluster which is then named and defined. The resulting clusters are then utilized to construct technology clusters in a fish-bone figure or technology function matrix will be described as follows.

3.6. Predicting technology trends
Accurate predictions of future technology trends can help identify potential applications for specific technology clusters or sub-clusters. Patent technology visualizations reveal trends for developments in specific technology domains, giving companies the opportunity to track potential competitors. Critical patent holders could be a top assignee or a potential competitor, and decision makers can easily discern patent development activity from patent maps.

3.7. R&D strategy and market advantage
Combining patent-claim based technology analysis with our patent analysis approach produces patent maps that offer insight into particular technologies, recent trends for technology distribution, and the development status of technological subfields. Based on this information, decision makers are better able to anticipate future patent developments or R&D trends. The patent maps also facilitate tracking of the patent activity of major industrial firms, thus offering managers a useful vantage point for assessing competitive challenges and allowing them to respond through the strategic allocation of R&D resources. The proposed claim-based technology analysis is a new approach to assist in the creation of effective R&D strategies for targeted patent deployment, thus maximizing potential market opportunities.

4. Case demonstration of the methodology
The proposed method is validated based on a case study of LIL-related U.S. patents in four parts. The first section describes a domain-specific technology patent analysis of the LIL-based technique. Section two illustrates the strategic patent search procedure to create an optimal pool of 287 U.S. patents (including applications and grants). Part three presents an example based on a real case to illustrate the patent management and patent technology mapping processes. The final section discusses the application of patent clustering concepts.

4.1. LIL technique
Laser interference lithography (LIL) is a technique for exposing an interference fringe formed in a light overlap region of two or more coherent beams to a photoresist layer and then developing it. More specific explanation, LIL technique is a method in which at least two coherent beams intersect at a resist-coated substrate to efficiently produce a large-area periodic interference pattern with period \( \Lambda = \frac{\lambda}{2 \sin \theta} \), where \( \lambda \) is the beam wavelength, \( \theta \) is half the angle between the two interfering beams. We chose laser as light source because the laser having a stable wavelength to stabilize the period of periodic interference pattern. The two laser beams interfere constructively and destructively at a resist-coated substrate to create a series of high intensity and low intensity interference fringes thereon. Figure 5 shows a schematic diagram for the interference fringes of two coherent beams based on the theory of constructive interference and destructive interference.
The technique can be used to fabricate one-dimensional gratings through two beams, two-dimensional periodic structures through three beams, and three-dimensional periodic structures through four beams. This technique can also accommodate N beams for more complex periodic structures. However, Complex periodic structures can also be obtained by multiple-exposure instead of using multiple beams. For example, we may also use only one beam combine the rotation angle of exposure stage to produce one dimensional periodic structure. By using multiple exposures, under varying angles, a wealth of periodic patterns can be realized which can find their way into many different applications.

LIL is a maskless and inexpensive interferometric projection technique capable of providing many advantages such as easy processing with simple equipment, fast patterning the smallest possible features at a given exposure wavelength, efficiently and reproducibly producing large-area periodic patterns with nanoscale.

4.2. The result of LIL patent search

The proposed patent analysis methodology focuses on LIL technology. Key phrases for patent searches are collected according to the features of several types of LIL experimental configurations. For example, the phenomenon of interference may be grouped into two categories: division of wavefront and division of amplitude. Lloyd’s mirror is applied in the former, and beam splitter-based configuration is applied in the latter. Key phrases for patent searches are shown in Table 1. Strategically searching and generating an initial patent pool of 287 LIL patents. Subsequent filtering produces an optimal pool of 202 LIL patents.

| Key phrase                     | Synonyms             | Interpretation                                                                 |
|--------------------------------|----------------------|-------------------------------------------------------------------------------|
| Interference lithography       | Interfer* lithograph*| Interference lithography                                                      |
|                                | Interferometric lithography |                                                      |
|                                | Interferometric lithographic |                                                      |
| Holograph* lithograph*         | Holographic lithography |                                                      |
|                                | Holography lithography  |                                                      |
|                                | Holographic lithographic |                                                      |
|                                | G03F000770408          | Definition of cooperative patent classification (CPC) is relate to interference lithography |
| Amplitude                      | Division of amplitude  | The amplitude of the incident beam is divided into two or more parts either by partial reflection or refraction. These beams travel different paths and are finally brought together to produce interference. The effects resulting from the superposition of two beams or more than two beams are referred to as beam splitter-based configuration or multiple beam interference |
| Wavefront                      | Division of wavefront  | The coherent sources are obtained by dividing the wavefront, originating from a common source, by employing mirrors, biprisms or lenses. Lloyd’s mirror is one of the instruments used to obtain interference by division of wavefront |
| Lloyd’s mirror, split*, grating, Achromatic, ... | | Keywords for the features of several types of LIL experimental configurations |

*Keyword to search term that begin with a certain string.
4.3. Visualization of patent analytical map

The IPDSS patent management system is applied to produce a statistical analysis of the patent pool to create graphical representations of important patent information. A patent management map offers additional information related to patent numbers, nation of origin, potential competitors, citation ratios and patent classification codes (e.g. IPC and UPC) to illustrate current competitive trends, market participation, and human resource utilization, which provide adequate information for managerial decision-making.

Figures 1 present patent trend for LIL-based technology patent applications drawn in application year, indicating that from 2006 to 2008 such application had reached its peak and from 2009 to 2011 the trend curve was going down. Reasons for the reduction of applications will be discussed in Section 4.4.

Analysis result relating to statistics for LIL patent holders as shown in Table 2, ASML Holding N.V (NL) as well as MIT (US) and University of New Mexico (US) have been expanding their great patents held related to LIL technology. ASML is specialized in designing, manufacturing and integrating wafer lithography equipment and is the largest supplier with the top ten semiconductor plants as its major clients. Tables 3 and 4, on the other hand, illustrates respectively the statistics for top 5 IPCs and UPCs based on LIL technologies, of which the classification is defined in the last column.

4.4. Technology trend analysis

Patent technology maps are applied to explain in great detail technical contents and systemically decompose claims for each patent so that R&D directors and executives can thus easily better understand relevant technology language and various hierarchical technology classes. From the maps the R&D persons may further realize density of the patented technology with which they can design around or make it a source for innovative inspiration.

| Table 2. Statistics for major LIL patent holders |
|-----------------------------------------------|
| **Assignees** | **Patent counts** | **Inventor counts** | **Patent age** |
| ASML | 13 | 16 | 10.30 |
| MIT | 9 | 15 | 14 |
| UNM | 8 | 9 | 16.43 |
| Optical Switch Corp. | 5 | 5 | 17 |
| Applied Mertials | 4 | 27 | 6.83 |
| Seiko Epson Corp. | 3 | 5 | 12 |
| Intel | 3 | 3 | 13.2 |
| Carl Zeiss | 3 | 6 | 9.5 |
| LG | 3 | 16 | 9.75 |

| Table 3. Statistics for the top 5 LIL-based IPCs |
|-----------------------------------------------|
| **IPC** | **Patent counts** | **Context** |
| G03F7/20 | 36 | Exposure |
| G03B27/54 | 10 | Lamp housings |
| G01B9/02 | 5 | Interferometers |
| G03H1/04 | 5 | Processes or apparatus for producing holograms |
| G02B5/18 | 5 | Diffracting gratings |
The methodology proposed for performing technology clustering on 287 selects patents via claim construction during which tedious claim-related syntax is deciphered and every element of each independent claim is systematically disintegrated, not only efficiently identifying patentable features but also highlighting these features in a single descriptive sentence which facilitates precise and efficient categorization. An illustration of using claim interpretation to perform hierarchical technology classes based on our claim-based technology analysis is shown in Table 5. It shows evidence that the logical hierarchical technology classes are similar to the description of Cooperative Patent Classification (CPC). For example, G02B26/0816 is a major CPC of US8681315 and the hierarchical description of that is relating to by means of one or more optical reflecting elements to control the direction of light. This is similar to our hierarchical technology classes based on our claim-based technology analysis, which is logical defined with hierarchy by using two rotatable mirrors of mirror based arrangement to have well-reflection control and further achieve an optical correction. Thus, the patentable features cited in the claim of patent application must be discerned, contributing precise categorization based on the aforementioned clustering principle. The proposed patent analysis methodology is for the purpose of addressing this need.

Table 4. Statistics for the top 5 LIL-based UPCs

| UPC | Patent counts | Context |
|-----|---------------|---------|
| 355/67 | 11 | Photocopying/projection printing and copying cameras/Lumination systems or details |
| 355/71 | 6 | Photocopying/projection printing and copying cameras/Lumination systems or details/ Including shutter, diaphragm, polarizer or filter |
| 430/001 | 6 | Radiation imagery chemistry: Process, composition, or product thereof/Holographic process, composition, or product |
| 430/321 | 5 | Radiation imagery chemistry: Process, composition, or product thereof/Imaging affecting physical property of radiation sensitive material, or producing nonplanar or printing surface—Process, composition, or product/Making named article/ Optical device |
| 359/035 | 3 | Optical: Systems and elements/Holographic system or element/Hardware for producing a hologram |
| 430/322 | 3 | Radiation imagery chemistry: Process, composition, or product thereof/Imaging affecting physical property of radiation sensitive material, or producing nonplanar or printing surface—Process, composition, or product/Making named article/Forming Nonplanar Surface |
| 430/005 | 3 | Radiation imagery chemistry: Process, composition, or product thereof/Imaging affecting physical property of radiation sensitive material, or producing nonplanar or printing surface—Process, composition, or product/Making named article/Radiation mask |

Figure 6. Fish-bone diagrams of LIL technology clustering for both method and equipment.
Patent technology maps are generated through clustering the related patents and then showing the results in graphic representations. For example, Figure 6 illustrates fish-bone diagrams of LIL technology clustering with the patent clusters distributed hierarchically for both LIL method and LIL equipment. LIL method is divided into six clusters: beam splitter, Lloyd’s mirror, diffractive phase mask, achromatic, holography and others. LIL equipment, on the other hand, is divided into four clusters: stage correction/actuation, optical correction, equipment improvement and system planning. Then, integrate together to constitute an entire technical landscape in proportion as shown in Figure 7.

As shown in Figure 6, some of LIL related patents can be regarded as hybrid arrangement such as at least combining beam splitter-based configuration and immersion configuration to which all ASML’s LIL-based patents belong. For example, the patented invention (US7492442) achieves variable resolution of an interferometric lithographic system through the use of a multifaceted pyramidal prism and a movable beam splitter, in which, the lithographic system comprises a liquid between a substrate and a prism and at least a portion of the substrate can be covered by an “immersion liquid” having a relatively high refractive index, e.g. water. The use of an immersion liquid enables the exposure of lines with a smaller pitch and thus the resolution is also increase.

### Table 5. Illustration of claim interpretation based on claim-based technology clustering

| Patent No | Cooperative Patent classification (CPC) | Claim | Hierarchical technology classes |
|-----------|----------------------------------------|-------|---------------------------------|
| US8681315 | G02B26/0816 (by means of one or more reflecting elements) G03F7/70408 (Interferometric lithography; Holographic lithography) | 1. A tunable interference lithographic system, comprising: a. first and second rotatable mirrors defining a first axis extending from said first rotatable mirror to said second rotatable mirror; b. means for providing first and second expanded beams of laser light of a selected frequency so that the ...; c. a track defining a second axis that is longitudinal in relation to said track and that intersects the first axis at a point between said first and second rotatable mirrors; and d. a substrate support for supporting a substrate, ..., and wherein rotation of one or both of said first and second mirrors and translation of said substrate support along said track are sufficient to control the period and coverage area of the interference pattern at the substrate support. | 1. The hierarchical technology clustering like below: a. Optical correction b. Reflection Control c. Mirror based arrangement d. Two rotatable mirrors |

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Figure 7. Overall technological landscape based on LIL technology cluster.
Theoretically, for the purpose of further improvement of the resolution, immersion media with a higher index of refraction needs to be used, or a laser beam with a smaller wavelength, or far better off to have both. The resolution clearly improves with the decrease of the wavelength of light used in a lithographic system. Thus, some lithographic systems are implemented using light in the extreme ultraviolet (EUV) range just like ASML’s patent (US8623588) with EUV radiation, which has a wavelength of approximately 13 nm for creating fine patterns. It is justifiable to surmise that EUV technology prevailed over LIL in terms of resolution and this can be the reason for the drop of trend curve from 2009 to 2011 as shown in Figure 1. Figure 8 shows the application trends of ASML’s LIL-based patents. ASML has become the pioneer of semiconductor lithography equipment industry, with its peak of LIL patent applications in 2006. After that, the quantity of applications declined and new technology (like EUV) was coming up. EUV is regarded as the lithography technology for next generation and is commercialized only by ASML as of today. TSMC, the leading wafer foundry in Taiwan, has purchased a USD 100,000,000 EUV (Extreme Ultraviolet) immersion machine from ASML with a view to obtaining a process below 10 nm, and is now aiming to purchase another new lithography equipment, most likely the new DUV (Deep Ultraviolet) immersion machine. Obviously, due to high price of the equipment, low deprecated rate, and market saturation, it is not easy for smaller companies to survive in the market. Therefore, the advanced lithography market is dominated by limited large companies among which ASML has attained near 90% of the market share. Furthermore,
ASML spent about NT$ 100,000,000,000 to acquire Hermes Microvision, Inc. (HMI), a semiconductor equipment manufacturer based in Taiwan in 2016, and largely expanded its scale in the market of semiconductor equipment, while the situation was increasingly hard for the smaller companies. ASML has effectively dominated over the lithography equipment market for its strong character in technology.

A database, which is built from various technical means and functions shown in a technology-function matrix figure, is conducive to subsequent design around, innovative design, patent portfolio creation & planning, and IP entrepreneurship assessment, and thus is useful in constructing a patent network or developing a new patent. The technology-function matrix follows the patent clustering principle by categorizing the relevant patents according to function. Accordingly, LIL technologies are particularly clustered according to their associated functions as shown in Figure 9.

Citation maps are applied to analyze “references cited” in bibliographical information for patents so as to systematically locate targets of potential licensees through sequence of developing patented technology. In the event of numerous patents, a citation map provides a quick way for key patents to be chosen conclusively, allows patent infringement litigants to gain insight into what weapons (patents) are available to opposing parties, and enables patentees to evaluate the licensing of the key patents identified by the citation map. Licensors may design around the licensed patents to create their own patent portfolios which function as bargaining chips for use by the licensors to renew the licenses. Source-style key patents are often cited and thus prove influential, as is US6185019 which was cited by 173 patents. Analyzing claim of key patent is trying to systemically decompose every element of the patent claim so that technical character and technology clusters can be distinctive enough to identify. Claim analysis of this key patent (US6185019) is demonstrated in Table 6. The patent invention relates to a high throughput holographic lithography system for generating interferometric patterns suitable for selectively exposing a photosensitive material and, more particularly, to an easily reconfigurable lithographic patterning tool employing a fiber optic beam delivery system and a prism optically coupled to the photosensitive material. Besides, the concept of immersion lithography was also disclosed in this patent specification, e.g. an index matching fluid placed in a gap between the wafer and the base of prism makes a liquid optical contact between the photoresist layer and the prism. And the index matching fluid can be an immersion oil or water.

In the event of numerous patents, a citation map can be divided into multiple citation maps according to technical features to locate the key patents for every distinguishing technical feature. Marked self-reference indicates intensive patent planning and definite, well-focused targets of R&D. Figure 10 shows ASML’s self-reference citation map from one of source-driven key LIL-based patents. The key patents must be compared for their respective claims and legal statuses. Such information provides an insight for the R&D directors or decision makers and especially the executives who are responsible for the decision-making related to technology investment. It also contributes valuable intelligence for targets of license and thus enables the company tremendous competitive advantage.
Table 6. Illustration of claim analysis for LIL key patent (US 6185019)

| Patent No. | Independent claim                                                                                                                                                                                                 | Interpretation                                                                 |
|-----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| US6185019 | 1. A holographic lithography system for generating an interference pattern suitable for selectively exposing a photosensitive material, comprising:  
   a. a platform for mounting a workpiece having a photosensitive surface;  
   b. a beam delivery system configured to direct a plurality of illuminating beams toward said platform in an overlapping manner to form an optical interference pattern in the vicinity of the workpiece, said beam delivery system including:  
   i. a plurality of optical fibers having transmissive ends from which the illuminating beams respectively emanate divergently; and  
   ii. a support structure on which the transmissive ends of the optical fibers are adjustable mounted, such that positions and angles of the illuminating beams relative to said platform can be adjusted by moving the transmissive ends of the optical fibers to different points on the support structure; and  
   c. a prism in optical contact with the photosensitive surface, said prism refracting the illuminating beams incident on said prism and transmitting the refracted illuminating beams toward the workpiece, such that the photosensitive surface of the workpiece is selectively exposed by the illuminating beams refracted by said prism | a. Platform  
   b. Optical interference phenomenon  
   i. Employing a fiber optic beam delivery system  
   ii. Position control  
   c. Employing a prism optically coupled to the photosensitive material |
|           | 2. A method of performing holographic lithography for generating an interference pattern suitable for selectively exposing a photosensitive material, the method comprising the steps of:  
   a. generating three divergent illuminating beams that are directed through an ambient environment having a known index of refraction;  
   b. passing the illuminating beams through a medium having a higher index of refraction than the known index of refraction, the illuminating beams refracted by the medium overlapping to form an optical interference pattern; and  
   c. exposing the photosensitive material with the light interference pattern formed by the refracted illuminating beams | a. The concept of immersion lithography was also disclosed, e.g. an index matching fluid placed in a gap between the wafer and the base of prism makes a liquid optical contact between the photoresist layer and the prism. The index matching fluid can be an immersion oil or water |
5. Conclusions

The development of large-area periodic patterns with nanometer scale features through LIL technique serves as an example to develop a claim-based clustering method based on the methodology proposed in this paper for patent technology analysis. Based on the research findings, this paper provides the following suggestions and sufficient reference for managerial decision-making with strategic innovations.

Firstly, all valuable patents should have high detectability and verifiability for infringements. That is to say, valuable patents are better protected while infringements are easily revealed and verified with evidence. Generally, structural patents are easier to protect than method patents as they are verifiable from external structure and, thus, the infringing objects are clear and difficult to design around. Even if infringement happens in the internal structure, it can easily be tested and validated by the analytical approach of reverse engineering.

Secondly, with a view of discovering infringement from competitors, we suggest that patent applicants expand their patentable scope for more comprehensive protection to shield off possibilities of infringers. The ideal patentable scope should adopt “multiple sets of independent claims” as a strategic deployment including system claim, product claim, device claim, apparatus claim aside from method claim, so as to strengthen the patent right protection. Obviously, mere method claim, as opposed to product/device claim, is often too troublesome to enforce patent protection. ASML’s patent application (US20090208878A1) is a quintessential example for being comprehensive for shielded protection.

Thirdly, a novel approach for patent-claim based technology analysis is presented in this research. In the case of LIL equipment, LIL focused on optical correction, equipment improvement and system planning. In terms of functions, on the other hand, high resolution, large interference coverage area, and high accuracy are the most important functional requirements. Development of LIL technology has long been led by ASML and LIL experimental configuration is focusing on beam splitter based configuration. Besides, for the further improvement of the resolution, immersion media with a higher index of refraction needs to be used to integrate various types of experimental configurations used for LIL systems become basic requirement. Consequently, ASML’s LIL-based patents are all with hybrid arrangement.

Fourthly, patent citation map can systematically position the R&D trends and locate potential targets for licensees, allows patent infringement litigants to gain insight into what weapons (patents) are available to opposing parties, and enabling patentees to evaluate the licensing of the key patents identified by the citation map. Licensors may design around on the basis of the licensed patents to develop their own patent portfolios to function as bargaining chips to renew the licenses. The obvious self-citation relations can also mean that layout of technology is well intensified, targeted and focused, just like the ASML’s case.

Fifthly, applications of LIL technology are broad enough to include most optoelectronics and semiconductor industries such as forming grating, flat-panel displays, liquid-crystal displays (LCDs), thin film solar cell, photonic crystal, magnetic storage device, micro-electromechanical devices (MEMS) and light emitting diodes (LEDs). It can also be used for making security labels with which tiny fine patterns are printed on. In light of its wide application LIL technology possesses great potentiality for technical development, if it continues to enhance process quality and resolution, and stabilize light source and shorten the wavelength, and track down the method for large area and high efficiency manufacturing, LIL technology may provide a major breakthrough for lithography manufacturing industry.

Sixthly, the major reason for the monopolistic market of lithography equipment is that deprecated rate for semiconductor equipment is very low for its validation characteristics, besides its towering price and dominant technology characteristics involved. If a new company intends to enter the
market, for their better chance, their capacity will have to meet with requirements of the wafer foundries. The latecomers will have to provide with ultra-high resolution lithography equipment beyond the existing level, hopefully, aiming to produce 7~5 nm process lithography equipment as the product for the next generation. In addition to reach the requirement of linewidth, the cost is also a key concern. Thus, LIL with mask-less technology meets the cost constraint for market advantage in the high-cost lithography equipment market in the semiconductor industry.

Accordingly, the claim-based technology analysis proposed in this research allows us to understand the landscape of specific-domain technologies and forecast their future development tendency.

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