A Scientometric Comparative Study of Single-walled and Multi-walled Carbon Nanotubes Research

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ABSTRACT

In the present study, we aim to quantitatively investigate and compare the intellectual landscapes of single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs) research between 2000 and 2014. The overall intellectual structure of these fields is illustrated by emerging trends of bursting keywords and thematic concentrations of co-cited references. This study is based on two sets of bibliographic records retrieved from the Web of Science database. The SWCNTs dataset contains 18,700 original research and review articles. The MWCNTs dataset, consisting of 23,584 records, is also collected from the database. We find that both domains have scrutinized chemical concepts which underlie the properties of the materials. Recent thematic trends show that MWCNTs research focuses on the improvement of the material while SWCNTs research lays more emphasis on their applications. In conclusion, it is argued that SWCNTs and MWCNTs have co-evolved. At the same time, both fields are distinctively diverging with their own scientific concerns.

Keywords
Carbon nanotubes, visual analytics, emerging trends, recent developments, scientometrics, data science

BACKGROUND

Carbon nanotubes (CNTs), discovered in 1991 by Iijima (1991), is recognized as the ideal building block for nanotechnology. These materials consist of one or more concentric cylinders. CNTs have many unique properties such as high aspect ratio structure, high thermal conductivity, high electrical conductivity, super hardness, chemical inertness, bio-compatibility, and so on. A quest for unique properties of CNTs has been causing a number of CNT-related journal publications to grow exponentially. Such properties enable many application potentials in the areas of electronics, composites, biotechnology, sporting goods, energy, etc.

In the present study, we aim to understand the similarities and differences between SWCNTs and MWCNTs research in a systematic and quantitative manner. Toward that end, we explore and compare the intellectual landscapes of the domains. Thematic patterns, emerging trends, and recent developments of the domains are scientometrically investigated. In particular, our study is guided by a computational approach implemented in CiteSpace, a visual analytic system for illustrating emerging trends and critical changes in scientific literature (Chen, 2006; Chen et al., 2012; Chen et al., 2014). In what follows, two questions guide us through our research:

- What are the scientometrically shared contexts of SWCNTs and MWCNTs research?
- How do emerging trends and new developments in SWCNTs and MWCNTs research differ from each other?

METHODOLOGY

Data Collection

To investigate and compare the intellectual landscapes in SWCNTs and MWCNTs research, we collected two datasets of bibliographic records from the Web of Science. A data collection method proposed by preceding literature (Chen et al., 2012; Kim & Chen, 2015) is employed as follows. We retrieve each dataset between 2000 and 2014 by a topic search in the Web of Science. Each search query consists of 6 phrases -- 1) for SWCNTs: “single wall* carbon nanotube*”, OR “singlewall* carbon nanotube*” OR “single wall* carbon nano-tube*” OR “singlewall* carbon nano-tube*” OR “SWCNT*” OR “SWNT*,” and 2) for
MWCNTs: “multi wall* carbon nanotube*” OR “multiwall* carbon nanotube*” OR “multi wall* carbon nano-tube*” OR “multiwall* carbon nano-tube*” OR “MWCNT*” OR “MWNT*.” The wildcard “*” captures relevant variations of a word such as “single wall” and “single walled”. A record is considered relevant to the queries if any of these terms is found in the title, abstract or keyword fields of the record. The queries resulted in 18,700 original research articles, proceeding papers, and reviews for SWCNTs research and 23,584 records for MWCNTs research as of May 31 2015. Table 1 describes the brief statistics of the datasets.

Table 1. Brief statistics of the datasets

<table>
<thead>
<tr>
<th>Data</th>
<th>Duration</th>
<th>Records</th>
<th>Authors</th>
<th>Refs</th>
<th>Keywords</th>
</tr>
</thead>
<tbody>
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<td>625,236</td>
<td>187,746</td>
</tr>
<tr>
<td>MWCNTs</td>
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<td>23,584</td>
<td>112,336</td>
<td>762,547</td>
<td>273,286</td>
</tr>
</tbody>
</table>

Scientometric exploration of emerging trends

Scientometrics is the quantitative study of science. Specifically, we employ scientific literature for this scientometric investigation and comparison of SWCNTs and MWCNTs research. To this end, we use CiteSpace, a scientometric tool to generate and visualize networks of co-cited references based on bibliographic records (Chen, 2006). The intellectual landscape of a scientific field can be depicted by a network of a variety of entities such as cited references and bursting keywords (Chen et al., 2014). We focus on document co-citation networks and networks of co-occurring keywords to explore the shared contexts and divergent themes in SWCNTs and MWCNTs research.

RESULTS

Bursting keywords in SWCNTs and MWCNTs research

In order to capture intensive attention to specific topics at a particular span of time, we investigate bursting keywords.

Table 2. Top 20 bursting keywords in SWCNTs research

Table 2 lists the 20 keywords with the strongest bursts, showing a bipartite temporal trend, for the case of SWCNTs.

During the first phase, most of the literature seem to focus on investigating structures of SWCNTs (“ropes,” “bundles,” “microtubules”) and their properties (“electronic structure,” “electronic properties”). In order to characterize their optical properties, characterization techniques (“Raman scattering”, “vibrational-modes”) are used. Catalytic growth appears to be the common synthesis technique. Hydrogen storage is found to be one of the major applications in this phase. Recently, the application of SWCNTs in the field of biomedicine (“drug-delivery,” “mice”) is receiving increasing attention of the researchers. Graphene/SWCNT hybrid material is also becoming popular due to its application in energy storage and nanoelectronics technologies.

Table 3. Top 20 bursting keywords in MWCNTs research

Table 3 describes bursting keywords for the case of MWCNTs. During phase-1, apart from investigating structures (“ropes,” “bundles,” “arrays,” “junctions”) and their properties (“field emission,” “transport,” “electronic-structure,” “emitters,”) via characterization techniques (“transmission electron microscopy”), the literature has also focused on the synthesis techniques and their related issues (“growth,” “chemical vapor deposition,” “pyrolysis”). Compared to SWCNTs, in the second phase, the literature seems not to focus on a variety of domains.

The investigation into the bursting keywords gives following findings. First, both domains focus on investigating underlying properties and characteristics of the materials in their early years. At the same time, MWCNTs research covers more diverse topics in terms of structure, synthesis, characterization, and applications. Recently, the literature on SWCNTs is investigating potential applications to other sciences such as biomedicine.

Document co-citation networks

Figures 1 and 3 illustrate the document co-citation networks for SWCNTs and MWCNTs research. Each network is generated from 80 highly cited articles per year. The
minimum spanning tree prunes the networks. An individual node represents a cited reference and the size of it is proportional to its cumulative cited frequency. References with citation bursts are depicted with rings in red, and nodes with high betweenness centrality have a purple ring. We label articles cited more than or equal to 800 times.

In order to identify thematic trends in SWCNTs studies, we cluster these networks by a community detection technique called smart local moving (Waltman & Van Eck, 2013) and depict each node on a time line considering its cluster membership (See Figure 2 and Figure 4). Clusters are labeled in such a way that higher rankings are given to the clusters containing more number of references. Considering both the size of node and citation burst, it is obvious that clusters 0, 1, 6 and 7 have a high concentration of relatively recent attention from the community in the case of SWCNTs. Table 4 summarizes these clusters. In order to label the clusters, two labelling techniques are used – term frequency inverse document frequency (TFIDF) and log-likelihood ratio (LLR). As described in this table, emerging clusters of research have focused on the functionalization and characterization of SWCNTs ("sidewall functionalization," "radial breathing mode," "diazonium," "rayleigh") and promising applications of the material ("thin film", "light absorption"). These are consistent with the findings from the investigation of the bursting keywords.
Overall, the investigation into the document co-citation networks gives following understanding of emerging trends and recent developments in SWCNTs and MWCNTs. First, both domains have tried to enhance the underlying properties of the materials. In doing that, SWCNTs and MWCNTs have had different concerns. Finally, SWCNTs lay more emphasis on the application than MWCNTs.

**DISCUSSION**

**Shared context of SWCNTs and MWCNTs research**

The present study reveals scientometrically shared contexts of SWCNTs and MWCNTs as follows: First, both domains have scrutinized the underlying properties and characteristics of the materials. It is also obvious that the improvement of the materials to make their more and more applications possible is among the leading research themes in both fields as represented by a set of bursting keywords and emerging clusters. Next, there are a few emerging clusters in the domains. We argue that this is because these domains are still emerging, and developing. Based on these observations, we contend that SWCNTs and MWCNTs have co-evolved.

**Divergent themes, trends and developments**

The investigation of bursting keywords indicates that SWCNTs and MWCNTs have diverged from each other despite the fact that they focused on enhancing the properties and characteristics of the materials. In addition, SWCNTs research has put more emphasis on the promising applications such as drug-delivery, thin films, and solar cell (light absorption). The emerging clusters in SWCNTs research are consistent with this observation. To sum up, SWCNTs and MWCNTs are developing with distinct concerns.

**CONCLUSION**

In the present study, we aim to address the guiding question, “How is SWCNTs research similar with or different from MWCNTs research?” Toward that end, we investigated and compared the bursting keywords, intellectual landscapes, and thematic patterns of the literature. Based on the findings, we articulate that both domains have co-evolved and they are developing with distinctive interests.

There are several challenges faced during the present study despite the fact that we adopt a systematic process of domain analysis and comparison. First, it is likely that the topic search do not include thematically relevant literature if a set of terms used for the topic search do not appear in the titles, abstracts or keywords. Second, the scientific database we employed in the present study selectively index publications. Thus, we might partially investigate the intellectual landscapes, emerging trends, and recent developments of the domains. We plan to apply this approach to a broader context through a citation expansion and cover a various type of publication materials.

**REFERENCES**


