THIN FILMS SCIENTIFIC STATE OF THE ART TRENDS

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Abstract: In the following text there are exposed a statistical analysis of the main "*thin films*" research topics from the past four years. After a short introduction, those topics are explained and compared with the statistics of Spain and Portugal publications to recognize the main differences between them. The more extended part is centered on *solar thin films cells*, comparing which are the most studied layers to absorb solar energy.

Key words: thin films, statistic analysis, solar cells, PVD.

1. - INTRODUCTION

Thin film technology includes all material layers with thickness going from few nanometers (usually called a monolayer) to several micrometers. These thin films are obtained by a process called deposition or growth, usually performed in vacuum or high vacuum (up to 10^{-8} Torr).

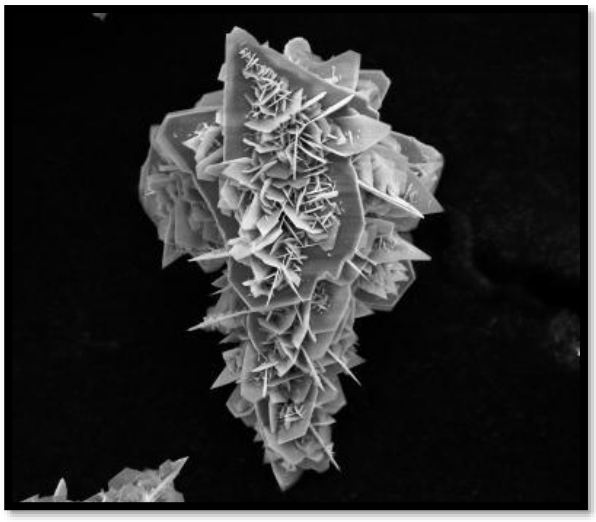

Figure 1. [1] Nanostructures of ZnS in doped ZnS, obtained by physical vapor deposition.

During the 20th century advance in deposition techniques have lead to a high technological development in multiple areas, such as optical coatings, magnetic recording media, semiconductor devices, energy generation and storage… It's been even applied in pharmaceutics and biomedicine via thin-film drug delivery.

The main deposition techniques for thin films are Chemical deposition, Physical deposition (the most known is physical vapor deposition performed in vacuum), growth modes such as layer by layer, "joint islands" and epitaxial (molecular beam epitaxial and pulsed laser deposition). PhotonExport core business is thin films, in particular consumables for Physical Vapor Deposition and Pulsed Laser Deposition (PLD) like sputtering targets and vacuum evaporation materials. It's ISO9001 certified process allows PhotonExport to served custom made needs of high purity materials (up to 5N: 99,999% purity) for High technology or scientific Research and Development applications, to higher quantities for industrial applications needs.

2. - WORLD MAIN TOPICS

From 2014 to 2018 the number of "thin films" scientific publications have raised by almost 75%. More than 140.200 publications related to thin films from the main scientific journals (Nature, Elsevier, Springer, Taylor & Francis, and Wiley) have been examined to deem its main study topics.

In the following figure, it can be observed the main thin film research topics with its respective impact on the number of publications.

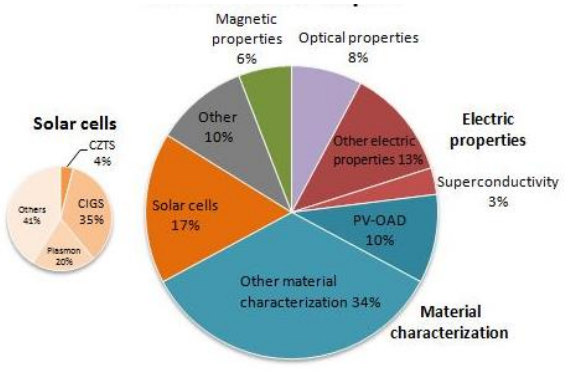

Figure 2. A circular graph with the main research topics and its publication percentages. It's a statistical study based on the keywords of the articles

2.1 Material Characterization.

"*New material characterization and manufacturing*" is the principal research topic representing 44% of the

scientific literature analyzed related to "*thin films*". This topic includes changes in thin film properties relative to electronics, optics, magnetism, and mechanics. An essential part of material characterization is related to the study of the deposition angle. Depending on that angle, the deposited layer can achieve distinct properties.

For this analysis, they use physical vapor oblique angle deposition (OAD) techniques to create the different layers. The increasing interest shown by the scientific community in these films has been a direct consequence of their unique morphology, promoting the development of new applications and devices with specific functionalities; such as photonic sensors. This technique emits particles at a certain angle, obtaining porous layers or zig-zag columns. The most common technique is glancing angle deposition (GLAD).

As it can be seen in the following *figure* [2], those are the first stage of growth during an OAD deposition.

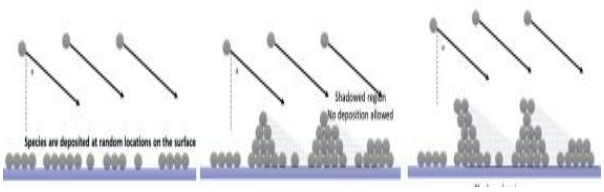

Figure 3. [2] Graph that shows the first QAD deposition stages. 1- Individual particles arrive at random locations with a given angle. 2- Deposited particles accumulate in certain regions then they cast shadows over other zones. 3- Taller surface features are more likely to grow, so its shadow zones are larger, forming titled columnar structures

2.2- Solar Cells

The next research topic with high presence is "*solar cells characterization*", representing 17% of all literature analyzed. For those characterizations, they analyze layers or multilayer of different films deposited by PVD sputtering techniques, like perovskite-CIGS (multilayer film made of copper, indium, gallium, and selenide), layers doped with plasmons, and CZTS (multilayer film made of copper, zinc, tin, and sulfur). The two most studied layers are a perovskite-CIGS tandem and plasmon doped layers.

With the 35% of the research articles related to "*solar cells*", perovskite-CIGS tandem configuration research is emerging due to the attractive and viable approach to achieving ultra-high efficiency and cost-effective thin film solar cells. For example, some researchers from Australian National University [3] have developed a tandem configuration with an 18.1% efficiency perovskite layer combined with a 16.5% efficiency CIGS cell, achieving a total efficiency of 23.9%. Optical simulations are predicting perovskite-CIGS tandems with efficiency over 30%. Other researchers are trying to achieve flexible tandem cells using low-temperature vapor deposition. These cells will be low weight, can be manufactured with a roll-to-roll depositing process and represents a potential way to reduce energy payback time. Even more, this solar cells can be used in new applications due to its mechanical properties.

Doped solar cells with plasmons represent the 20% of all research articles related to "*solar cells*". These cells absorb and convert the light with the assistance of plasmon. Its thickness goes from 2 μm to a theoretical 100 nm. This cell can be manufactured on cheaper substrates such as glass, plastic, and steel. Plasmonic cells improve the absorption by scattering light with metal nanoparticles excited at their surface plasmon resonance. With this procedure, the sunlight can be trapped and propagated into the absorbing region. Different size, shape and material nanoparticles are key factors determining the scattering and coupling effect. Plasmon resonance peaks always correspond to the best harvesting effect, and it can be modulated by the refractive index of the surrounding material.

2.3 – Electronic Properties

The third research topic is the use of *"electronic and conductivity properties"* to achieve faster and reliable electric devices, with the 16% of the articles. It's important to remark the fact that almost 20% of those studies are about superconductive layers.

3. - SPAIN AND PORTUGAL MAIN TOPICS

Using the same procedure with Spanish and Portuguese publications 600 thin film articles have been analyzed from the same journals and CSIC (Spanish *Consejo Superior de Investivaciones Científicas*) publications to compare the principal topics and research lines with the global average, within the same period. The principal ranking topics remain the same, but there are some differences inside some of the topics, as can be seen in the following figure.

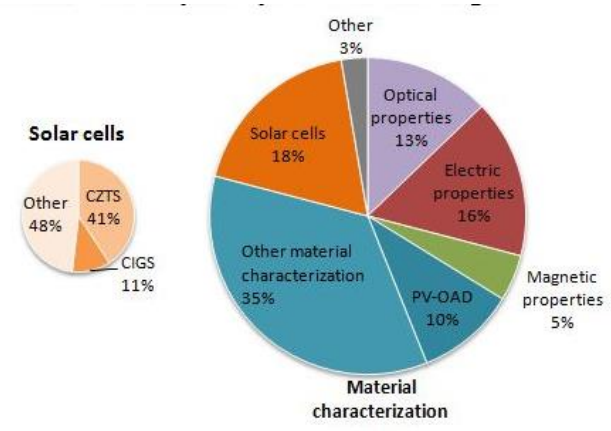

Figure 4. Circular graph with the main Spanish and Portuguese research topics and its publication percentages.

4. – MAIN TOPIC COMPARATION

4.1 – Solar Cells

The main differences appear in solar cells characterization. The principal cell layers studied in Spain and Portugal are CZTS layers, representing the 41% of the total research articles related to "*solar cells*". Pure-sulphide Cu2ZnSnS4 thin film solar cells are manufactured with low-cost (common elements) and non-toxic materials. The main lines of research are new environmentally friendly ways for manufacturing these layers, more efficient cells and different mechanical properties of the substrate. These layers are in primary research phases, as it can be seen in the NREL graph of *Best research cell efficiency* [4]. Researchers started studying these layers in 2010. Furthermore, it seems that in Spain and Portugal it's taking more and more strength.

4.2 – Electronic Properties

Another interesting fact is that superconductivity research in the Peninsula does not reach the 2% of all "*electronic and conductivity properties*" articles when in the worldwide publication it represents more than 15% of the articles.

5. - REFERENCES.

[1] Belen Sotillo, Corazón laminado, nanostructures ZnS In doped ZnS, opbtain by physical vapor depostion ZnS / In2S3 powders. Photo courtesy of SOCIEMAT.

[2] Source: "*Perspectives on oblique angle deposition of thin films: From fundamentals to devices*", Progress in Materials Science, Volume 76, March 2016, Pages 59-153

[3] "Mechanically-stacked perovskite/CIGS tandem solar cells with efficiency of 23.9% and reduced oxygen sensitivity", Energy Environ. Sci., 2018,11, 394-406

[4] You can find this graph on https://www.nrel.gov/pv/assets/images/efficiency-chart.png