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Effect of Tantalum Doping on the Surface properties and antibacterial Activity of zinc oxide Thin films prepared by magnetron sputtering

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Abstract :

In this study, tantalum -doped zinc oxide to (ZnO-Ta) thin films were deposited glass substrates on using a direct - Current (DC) magnetron sputtering system operating under aragon atmosphere with a target substrate distance of (5cm) and a room temperature, the films were prepared at sputtering Powers of (70, 80 W) with a deposition time of (5 min) and a pressure (10-5 bar). The FE-SEM images revealed that the tantalum doped ZnO thin films exhibit a well adhered nanostructure composed of nearly spherical grains within the nanoscale range of approximately (17-66 nm) depending on the doping ratio and deposition conditions. The results also showed that increasing the Ta doping concentration leads to a noticeable increase in grain size and surface roughness this observation is further supported by cross-sectional analysis, indicating that higher tantalum doping results in increased surface roughness furthermore, the antibacterial fast revealed that the samples with rougher surfaces the and larger grain sizes exhibited the highest inhibition efficiency against both Gram- Positive (Staphylococcus aureus) and Gram-negative (Escherichia coli) bacteria the results demonstrated that controlling the surface morphology through Ta-doping in the key factor governing the antibacterial Performance. It was found that increasing the tantalum doping ratio leads to higher surface roughness and enhanced bacterial inhibition efficiency which makes these films highly suitable for medical applications as antibacterial materials.

Keywords: Tantalum Doping, Surface Properties, Magnetron Sputtering, Antibacterial Activity .

تأثير تطعيم التنتالوم في الخصائص السطحية والنشاط المضاد للبكتيريا لأغشية أكسيد الزنك الرقيقة المُحضَّرة بتقنية الرشّ المغناطيسي (Magnetron Sputtering)

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مستخلص:

في هذه الدراسة ثم العمل على تحضير أغشية رقيقة من اوكسيد الزنك المطعمة بالتنتالوم على ركيزه من الزجاج باستخدام منظومة الرشرشة المغنترونية بالتيار المستمر. تحت جو من الاركون ومسافة بين الأقطاب (5 cm) وبدرجة حرارة الغرفة جرى تحضير الاغشية لقدرات (70w) (80w) و بزمن ترسيب (5 min) وضغط (〖10〗^(-5) bar) . أظهرت نتائج فحص المجهر الالكتروني الماسح (FESEM) ، إن اغشية أوكسيد الزنك المطعمة بالتنتالوم تمتلك بنية نانوية متماسكة تتكون من حبيبات شبه كروية ضمن المدى النانوي (17- 66nm). اعتماداً على نسبة التطعيم وظروف الترسيب كما أظهرت النتائج إن زيادة تركيز التطعيم بالتنتالوم تؤدي الى زيادة ملحوظة في حجم الحبيبات وخشونة السطح ، وتم دعم هذه النتائج من خلال صور المقاطع العرضية (cross sectional) .أما اختبار النشاط المضاد للبكتيريا وجد إن العينات ذات السطح الأكثر تجانساً والحبيبات الأكبر أظهرت أعلى كفاءة تثبيط ضد البكتيريا موجبة الغرام وسالبة الغرام وتبين إن التحكم في مورفولوجية السطح من خلال التطعيم بالتنتالوم يؤدي الى زيادة خشونة السطح وتعزيز كفاءه النشاط المضاد للبكتيريا مما يجعل هذه الاغشية مناسبة بشكل كبير للتطبيقات الطبية و المواد المضادة للبكتيريا.

Introduction:

Thin film physics is considered one of the most important braced branches of applied physics. The term thin films is used to describe a single layer or multiple layers of atoms of a given material, with thickness that may reach only a few nanometres or up to approximately one micro meter. These layers are deposited on to solid substrate such as glass or silicon [1] a Human kind has increasingly turned toward the extensive use to nanomaterial's across wide range of chemical, physical, and biological in dustiest and applications nanomaterial's can be defined as an engineering approach based on functional systems at the molecular level relying on the integration of physics and engineering, they are considered among the most advanced and rapidly evoling technologies in the modern era [2] these are particles with extremely small dimensions falling within the nanoscale range (1-100 nm) [3].

Zinc oxide (Zno) is considered one of the most widely used semiconducting oxides in thin film fabrication due to its wide band. Approximately (3.37 eV) high trans patency n the Visible region, and strong absorption capability in the ultraviolet range, these properties provide ZnO with significant potential for optical, biomedical, and anti-bacterial applications [4,5].

It also provides insights into the dynamical Properties of the plasma, which represent an Important parameter for understanding the collision frequency and its effects on the, emission processes that occur during gas breakdown under collapse conditions [6].

Researchers often resort to doping ZnO with transition elements such as (Ta) in order to modify its structural and surface properties [7].

Surface properties play a crucial role in determining the antibacterial activity of thin films. Study have shown that improving surface uniformity and increasing the number of active sites an enhance the ability of ZnO to inhibit the growth of both cram-negative and gram-positive bacteria [8].

There are several techniques for depositing thin films, including both chemical and physical methods among the physical techniques magnetron sputtering is widely used due to its flexibility and simplicity as it allows precise control over the deposition rate and the resulting film thickness [9] the aim of studying the effect of tantalum doping on ZnO thin films prepared by DC magnetron sputtering includes analysing the Surface structure and evaluating the films effectiveness against both Gram-positive and Gram-negative bacteria. This is Carried out in order to establish a correlation between the surface properties of the prepared films and their biological activity, and to assess their suitability for potential biomedical applications.

The experimental Part

Involved the deposition of tantalum doped zinc oxide (ZnO :Ta) thin films using the DC magnetron sputtering technique inside a high-Vacuum chamber with abased pressure of (10^{-5} Torr) and a high voltage Power supply. Glass substrates were used after being thoroughly cleaned in an ultrasonic bath to remove any surface contaminants or impurities that could effect the deposition quality The system was equipped with a cooling unit and electronic controllers for monitoring temperature, voltage and pressure three samples were prepared namely ZnO Ta8, ZnO –Ta9 and Zno-Ta10 using a tantalum-doped zinc oxide target under an argon atmosphere, sample zno-Ta9 was deposition at a sputtering power of (70W), while zno-Ta10 was deposition at (80W) with a fixed target substrate distance of5 (cm).

The deposition was carried out at room temperature for (5 minutes).

After deposition the samples were placed on the surface of an agar medium that had been uniformly inoculated with bacterial cultures of two different strains. *E coli staphylococcus aureus*. The inoculated plates were then incubated in a laboratory incubator for 24 hours at 37C the antibacterial activity was evaluated by observing the presence or absence of inhibition zones around the wells loaded with the deposition thin film samples.

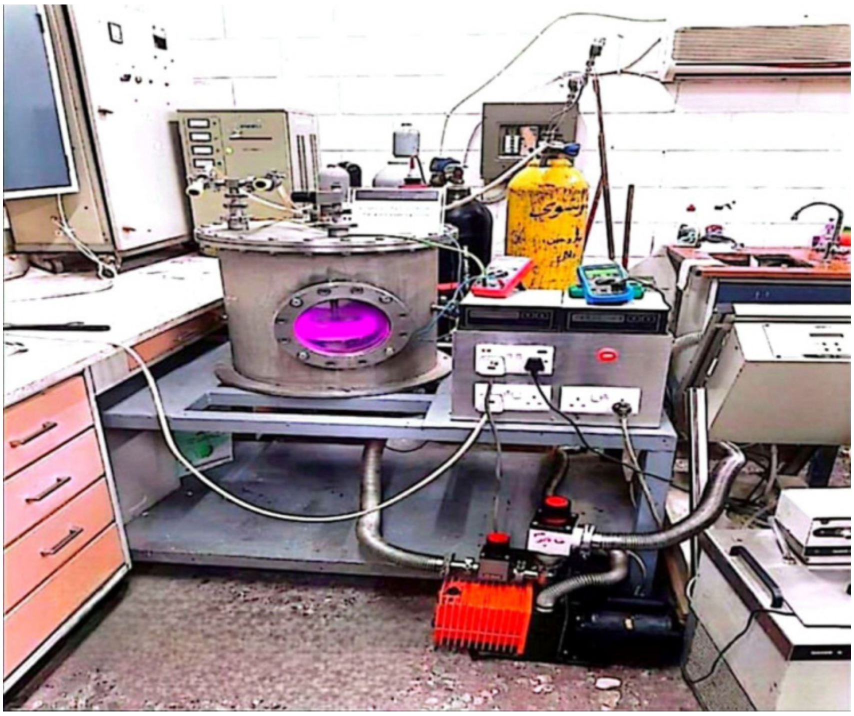

Fig.1 plasma Sputtering system

Results and Discussion

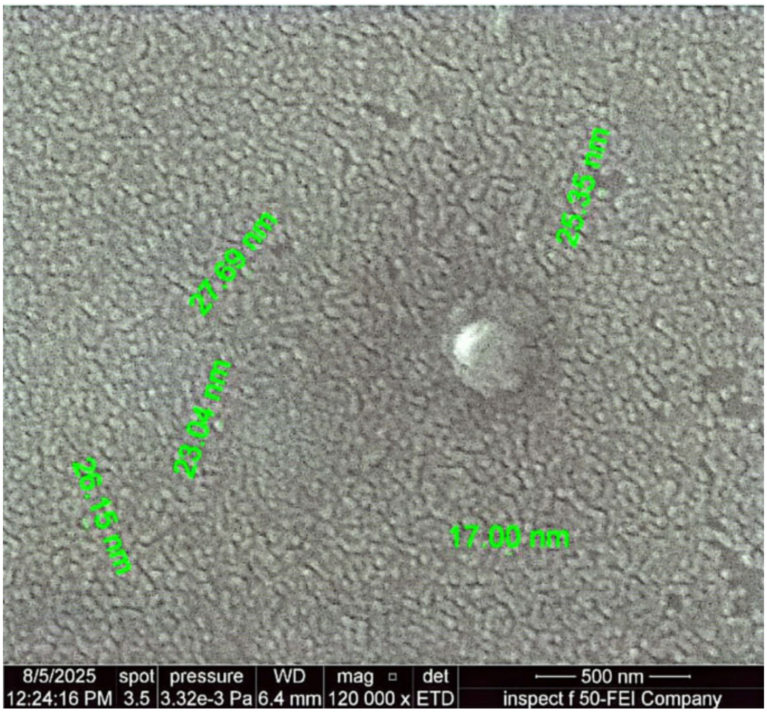

Figure (2) shows the FE-SEM image of the Pure ZnO sample deposited by DC magnetron Sputtering.

- The examination shows the deposition of ZnO thin films before the doping process Nano scale Particles were obtained, where the grain diameters were measured to be aspartame approximately (17-28 nm) the grain distribution appears homogeneous indicating that the Preparation using the Dc magnetron sputtering technique resulted in films with a smooth surface which typically leads to a moderate or weak antibacterial activity.

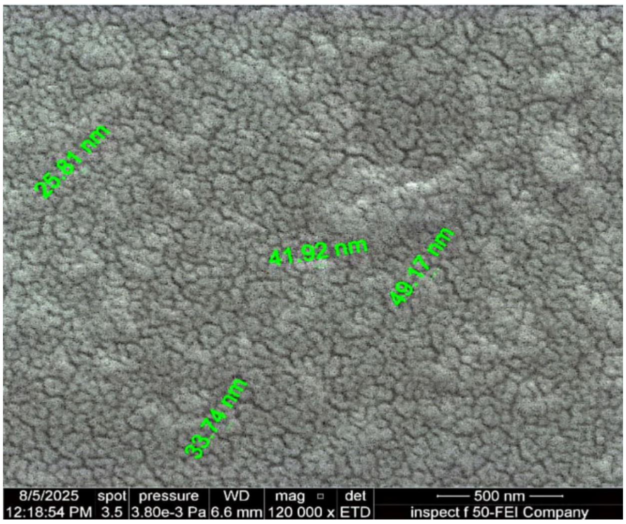

Figure (3) shows the FE-SEM image of the Zno: Ta Sample prepared by DC magnetron sputtering.

The FE-SEM analysis shows the Surface morphology of the ZnO:Ta 9 thin film which. Exhibits a homogeneous secondary structure with in the nanoscale range. The measured grain diameters were approximately (25-49nm) with a uniform grain distribution and quasi-spherical particles the surface appears relatively rough which enhances the antibacterial activity by increasing the number of active sites and promoting the release of reactive ions, thereby contributing to the inhibition of bacterial growth.

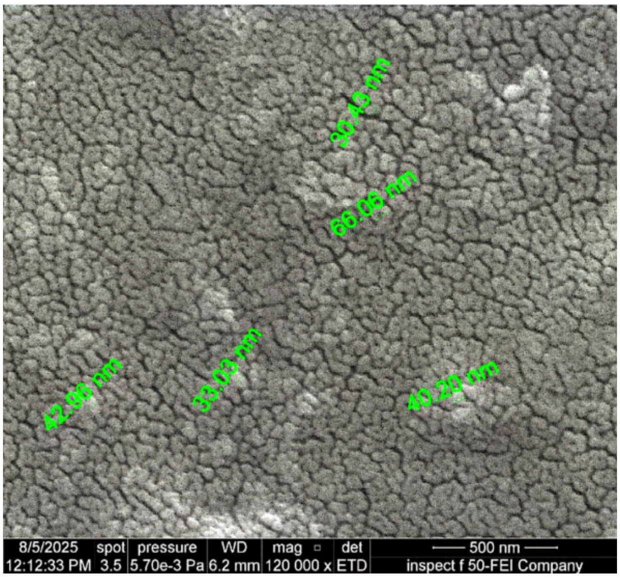

Figure (4) shows the FE-SEM image of the Zno: Ta10 Sample prepared by DC magnetron Sputtering

The FE-SEM examination ill strates the surface morphology of the Zno: Ta10 Sample, which exhibits a compact nanostructure characterized by particles within the nanoscale range, the measured grain diameters were approximately 630-66nm indicating an increase in grain size with the rise in both doping concentration and Sputtering power the growth of larger grains leads to an increase in surface roughness, which subsequent! enhances the antibacterial performance by enlarging the inhibition zones. [10]

As for the cross-section examination

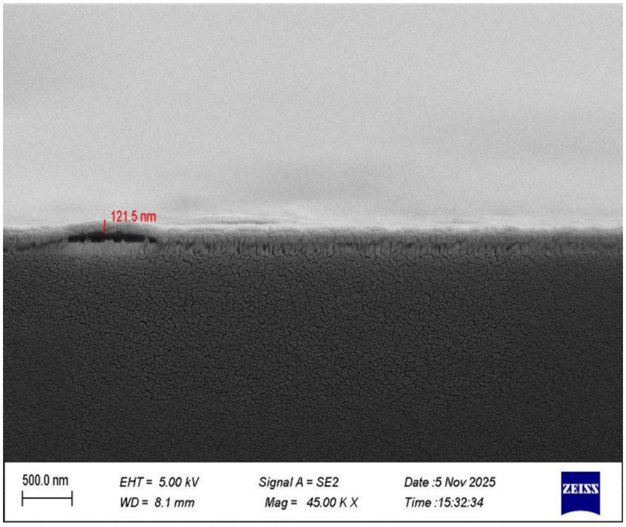

Figure (5) illustrates the cross-sectional analysis of the ZnO thin film before tantalum doping

The figure shows a cross-sectional image of the sample with a thickness of 121.5nm which is considered very low. The incomplete layer formation indicates a poor film growth which negatively effects the antibacterial activity.

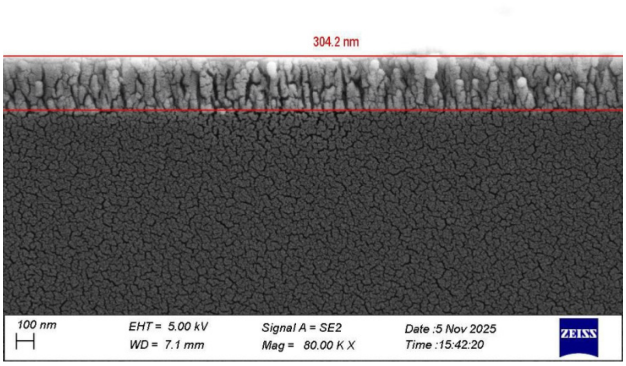

Figure (6) illustrates the cross-sectional analysis of the ZnO: Tag thin film after tantalum doping

The cross-sectional image reveals a film thickness of 304.2nm with noticeably larger grain structure and improved film growth. The increase in thickness provided better surface coverage and more active sites, which consequently enhanced the antibacterial Performance.

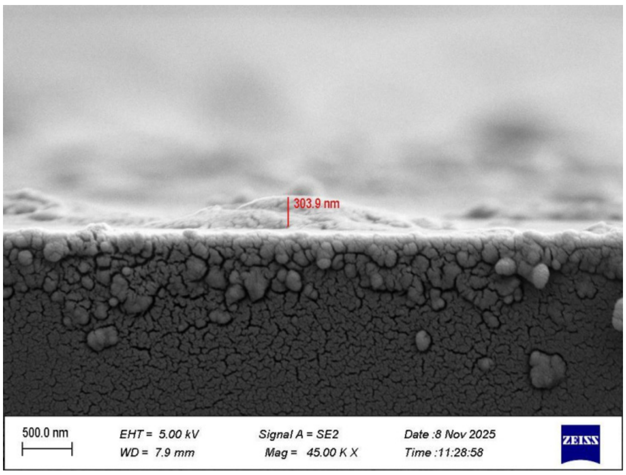

Figure (7) illustrates the cross-sectional analysis of the ZnO: Ta10 thin film after tantalum doping

The figure shows cross-sectional image of the sample with a thickness of 303.9nm indicating an increase in the film thickness as well as higher surface roughness and porosity this implies the presence of more active sites that enhance the antibacterial activity, making the film suitable for biomedical applications [11].

Figure (8) shows the antibacterial

Inhibition

Regarding the antibacterial activity as shown in the figure the antibacterial performance of the 2008, Zno: Ta9, zno:Ta10 thin films was evaluated against both Gram-negative *Escherichia (coli)* and Gram-Positive *Staphylococcus aureus* bacteria it was observed that sample number (to) exhibited the highest inhibition efficiency against both types of bacterial, with inhibition zone diameter of (21mm and 22mm) respectively. This enhance enhancement is attributed to the increased tantalum doping ratio, which resulted in larger grain sizes and higher surface roughness, thereby promo on thereby promoting more active sites the surface. This observation is consistent with previous studies and support proposed mechanism (12] .

As Show in the table

Sample code	The local effect of the film on bacterial growth	
	S aureus	E - coli
8	13mm	22mm
9	21mm	13mm
10	22mm	21mm

The table present on the antibacterial activity of the compounds measured in millimeters. Against Gram - Positive and Gram-negative bacteria.

In addition oxygen gas was used as a reactive gas to interact with zinc and form Zinc oxide. It was observed was that the oxygen-to-aragon ratio has a significant influence on the film Structure and its properties Furthermore, the oxidation process does not Leave any chemical residues, which makes it safer during plasma oxidation oxygen plays a crucial role by generating reactive radicals Such (H, O,OH) through interactions with electrons and molecules these radicals reacts with bacteria, leading to the destruction of the bacterial cell membrane and inhibiting their activity. Moreover, the plasma oxidation process is characterized by high efficiency in deactivating or inactivating bacteria and viruses.

Conclusions

1. The FE-SEM results revealed that the Zno: Ta thin films exhibit a dense and homogeneous secondary structure composed of quasi-spherical grains with size ranging from (17-66nm) depending on the tantalum doping ratio it was observed that increasing The Ta doping concentration led to an enlargement in grain size and a noticeable rise in Surface roughness [13]

2. The antibacterial activity test confirmed that the grain size Plays a crucial role in enhancing the bacterial inhibition efficiency It was found that increasing the tantalum doping significantly improves the functional properties of the films and makes them more suitable for biomedical and biological applications primarily due to the increased surface roughness. [14] .

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