Sonochemical Coating of Antibacterial Nanoparticles on Flat and Curved Surfaces and Fighting Resistant Bacteria

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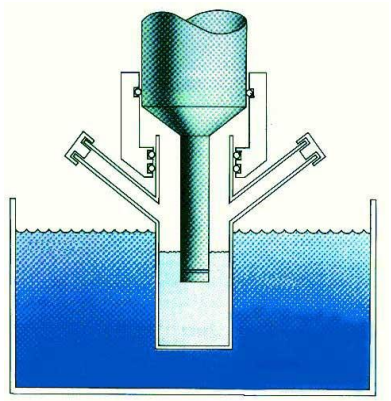
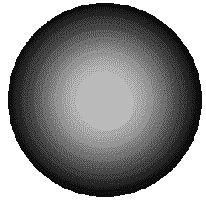
What is Sonochemistry?

The use of sound energy to produce chemical or physical changes in a medium through

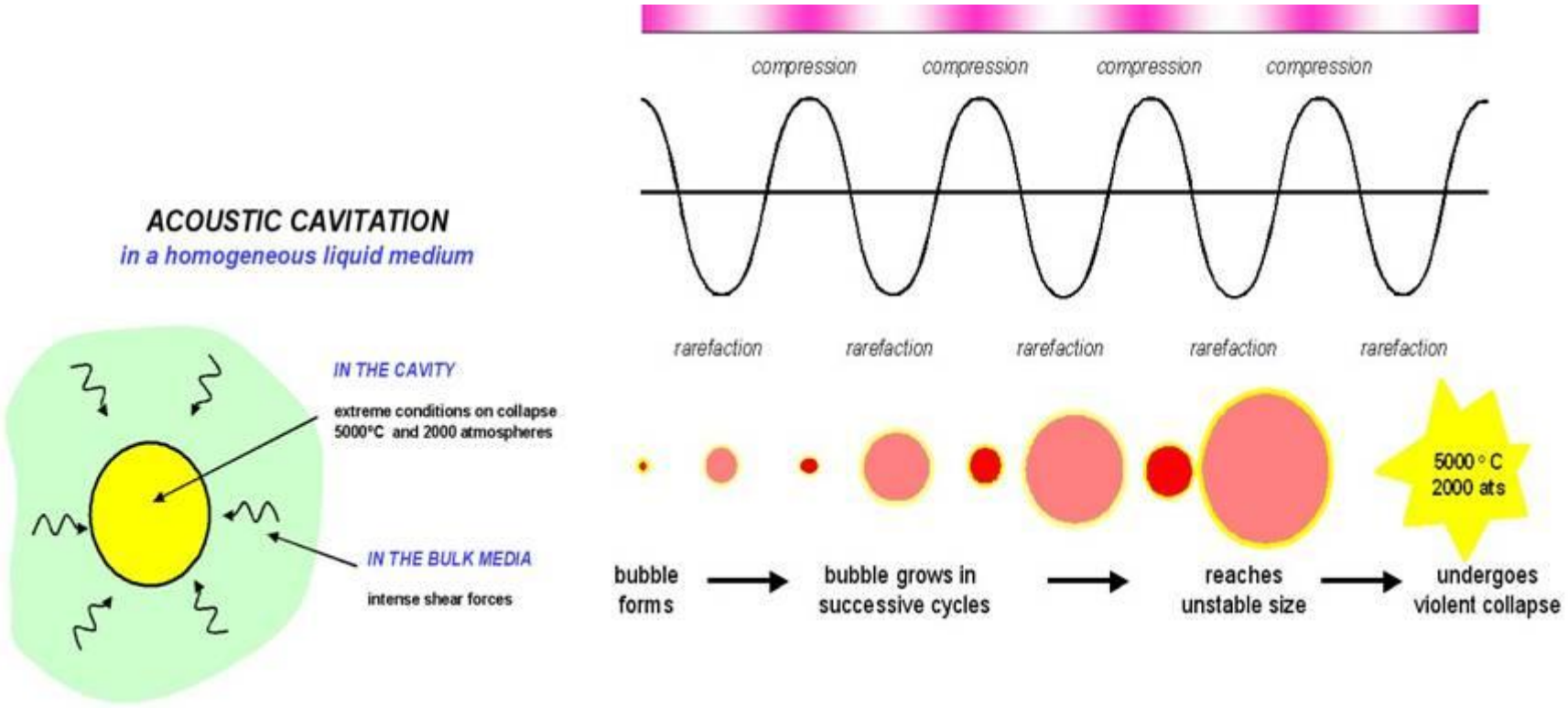
ACOUSTIC CAVITATION



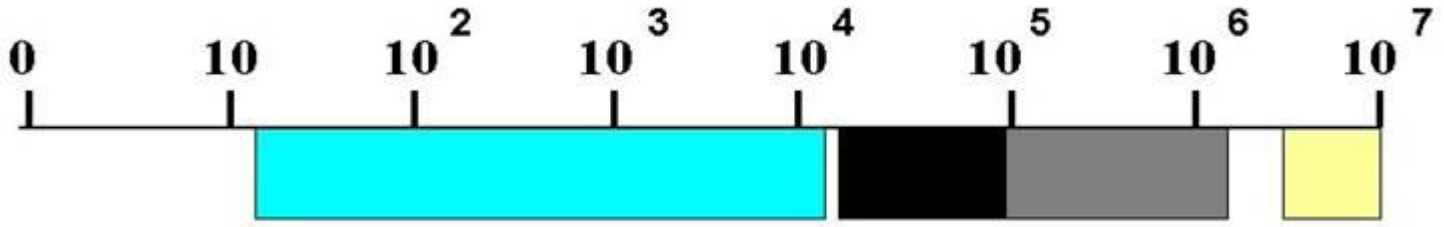
Typical sonochemical apparatus



ACOUSTIC CAVITATION
generation of the bubble:



Frequency ranges of sound



Human hearing		16Hz - 18kHz
Conventional power ultrasound		20kHz - 100kHz
Extended range for sonochemistry		20kHz - 2MHz
Diagnostic ultrasound		5MHz - 10MHz

“Anything you can do I can do better”

What can be done better with Sonochemistry?

1. Prepare Amorphous Nanoparticles.

2. Deposit Nanoparticles on Flat and Curved Surfaces

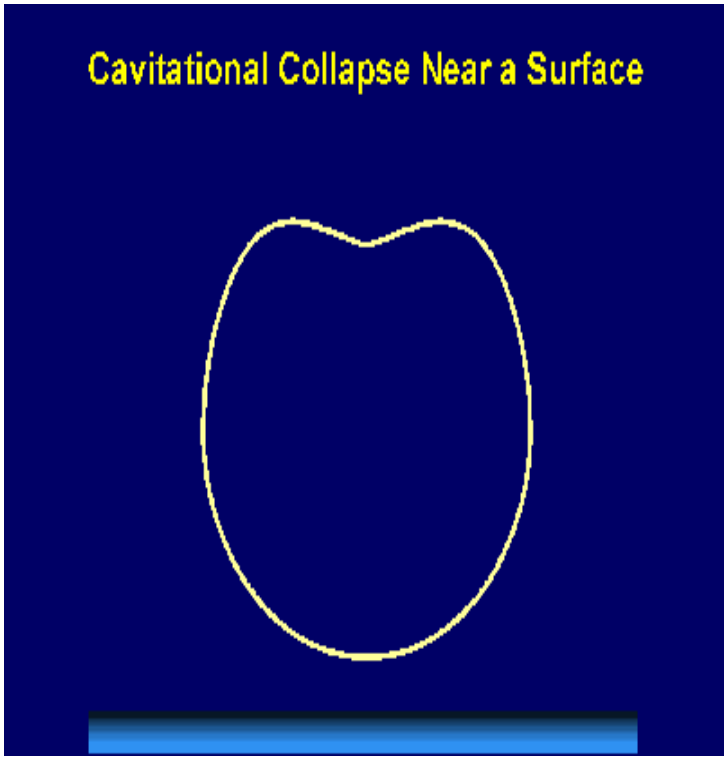
   Ceramic, Polymeric, Metallic, Glass, Textile Substrates.

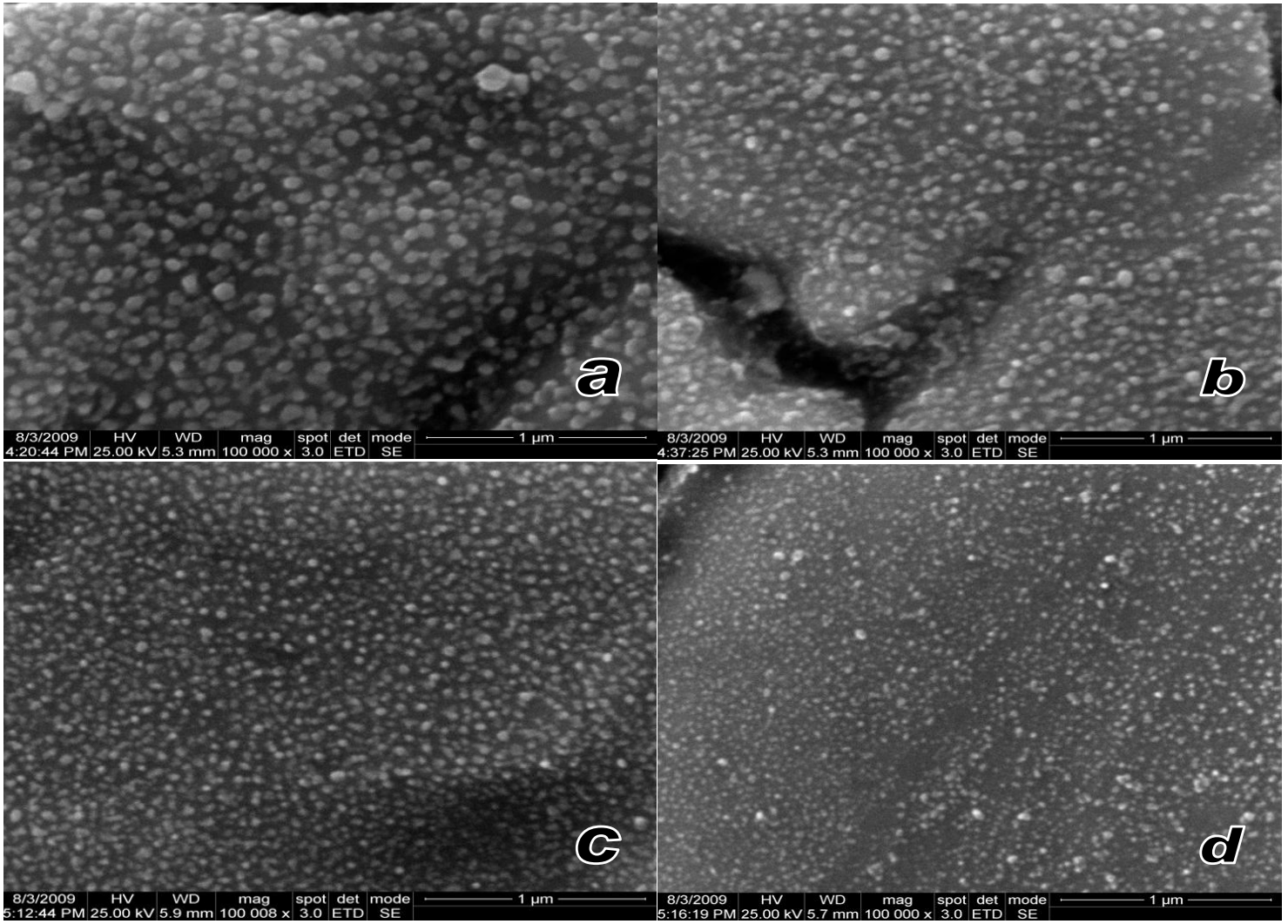
3. Insert Nanoparticles into Small Size Pores

(Mesoporous Materials, CNT)

4. Make Proteinaceous Micro and Nano Spheres.

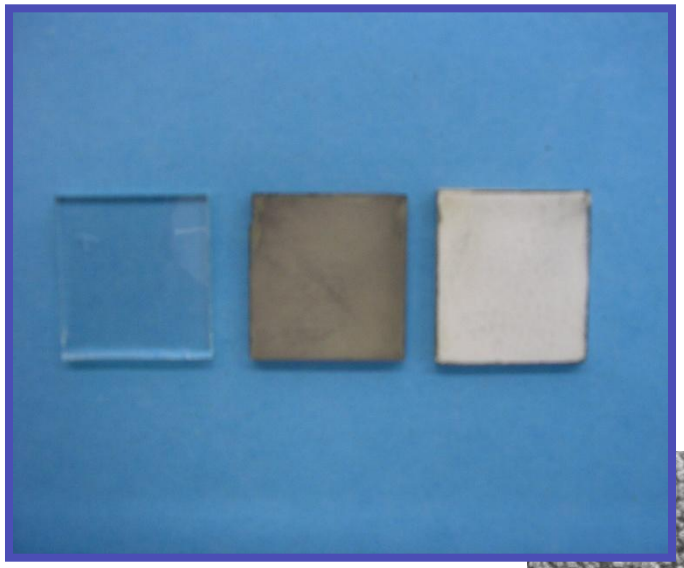
Why Sonochemistry is an effective method for coating?

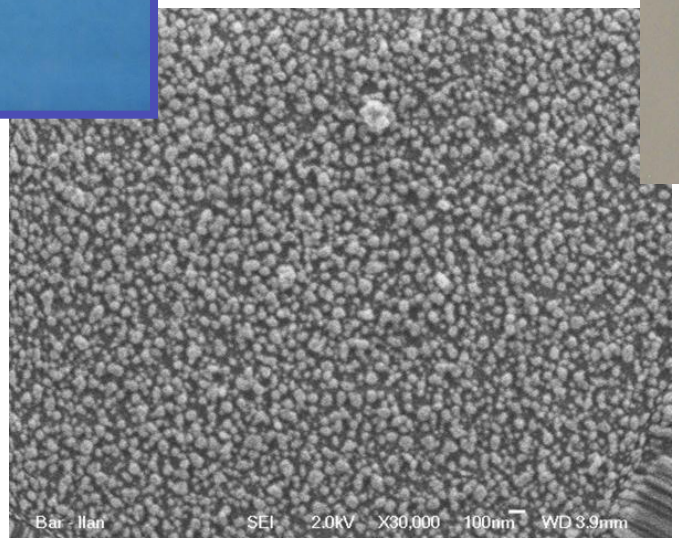




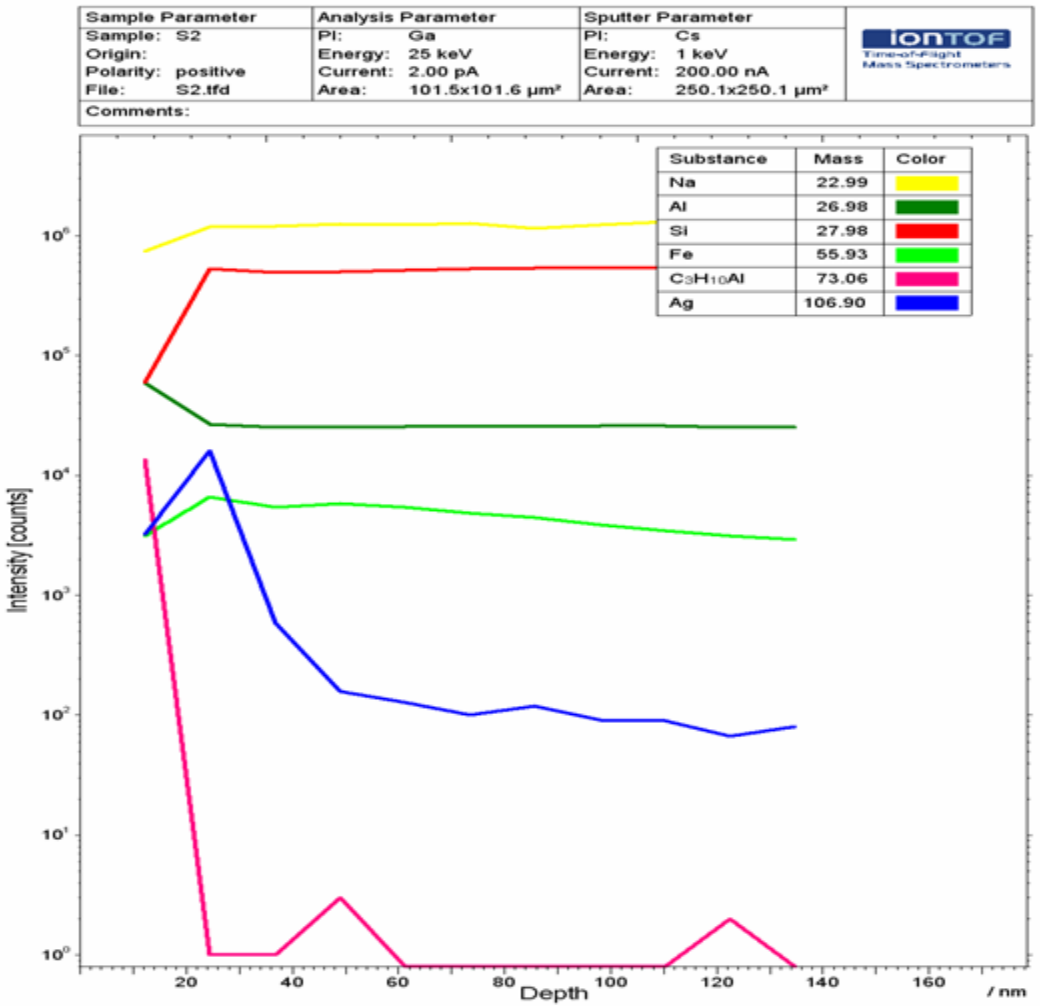
Scanning electron micrographs of a plate of stainless steel positioned at a distance of 1 cm from the tip

Glass coated with silver (Ag) nanoparticles by sonochemical method





TOF SIMS results on penetration of silver into glass



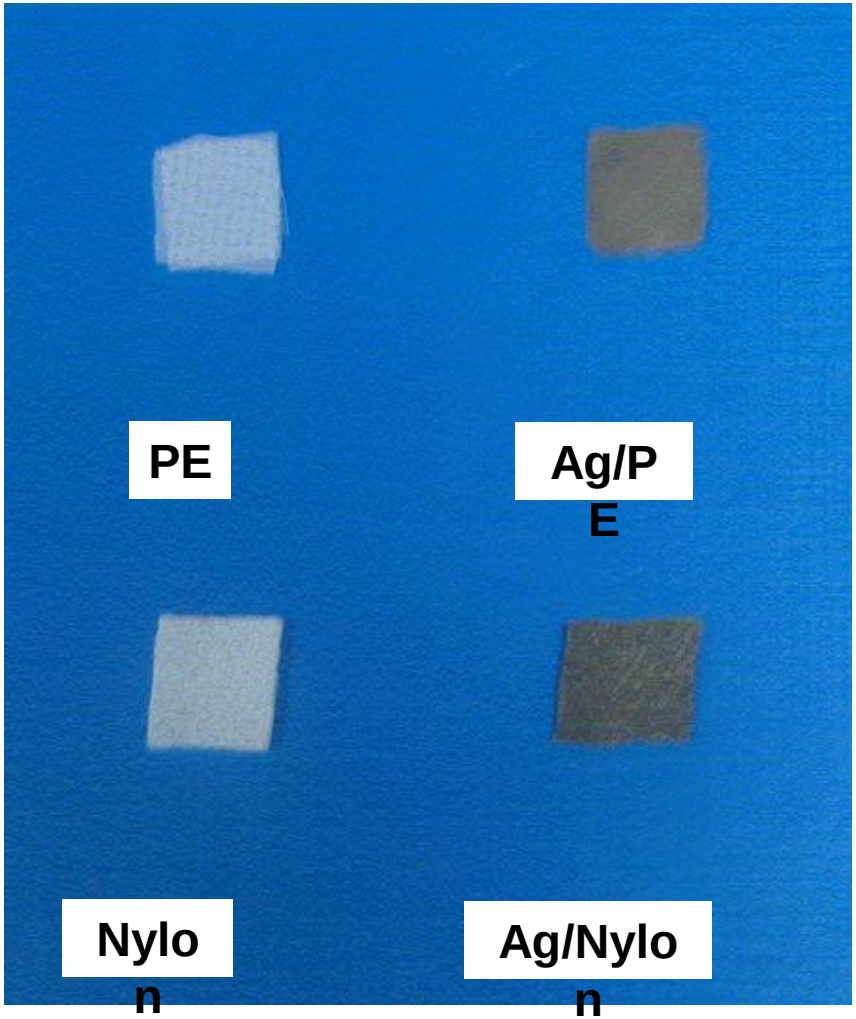
State of The Art

Why? Because 1 in 10 patients are affected by hospital-acquired infections .90,000 deaths are caused by hospital-acquired infections in Europe

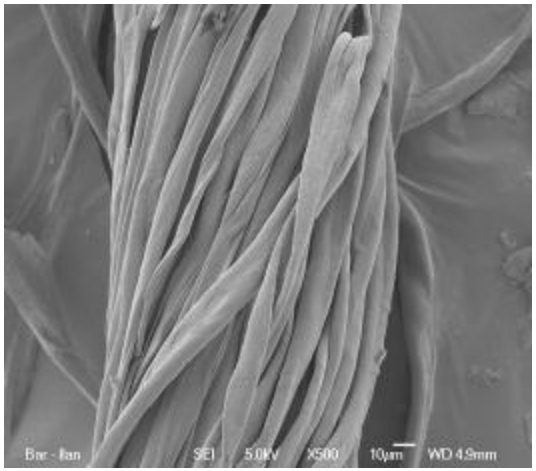
A **hospital-acquired infection**, also known as a **HAI** or in medical literature as a **nosocomial infection**, is an infection whose development is favored by a hospital environment, such as one acquired by a patient during a hospital visit or one developing among hospital staff.

Ag/Nylon composite was used as master-batch for synthesis of Nylon fibers and yarns

Samples of coated fabrics

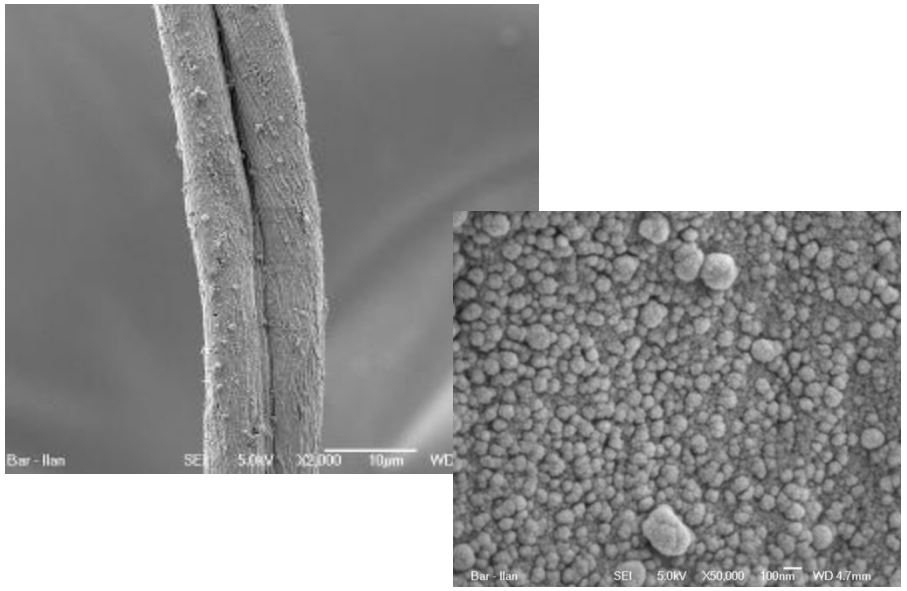


Morphology of Ag-fabric nanocomposite



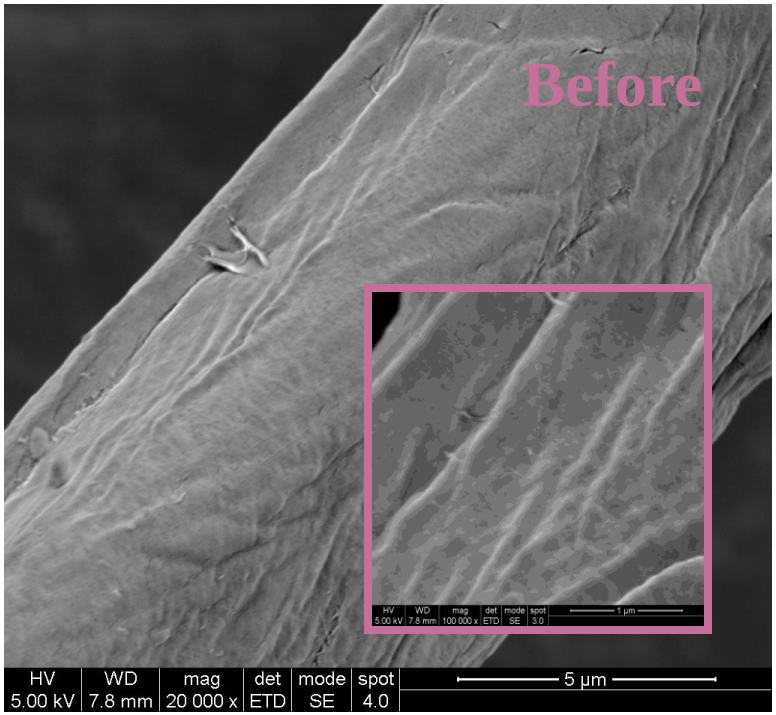
Before coating

After coating with Ag nanoparticles

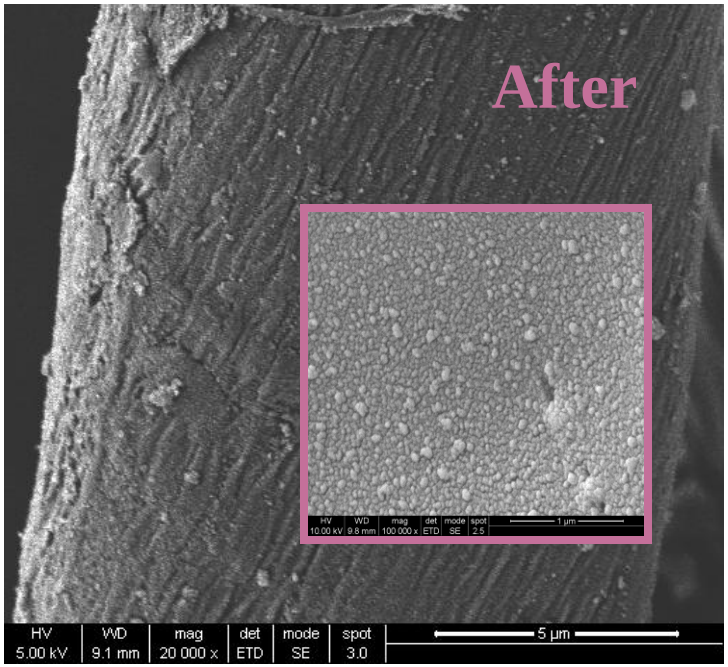


The calculated average size of the silver nanoparticles deposited on the surface of the cotton fibers is 80 nm

Morphology of CuO coated fabric (HRSEM)



A narrow size distribution is obtained and the primary particles are in a very low nanometric range (~ 10-15 nm).



2 Pilots have been built in the frame of the SONO project

Magnetostrictive system at Romania

Piezoelectric system at Italy

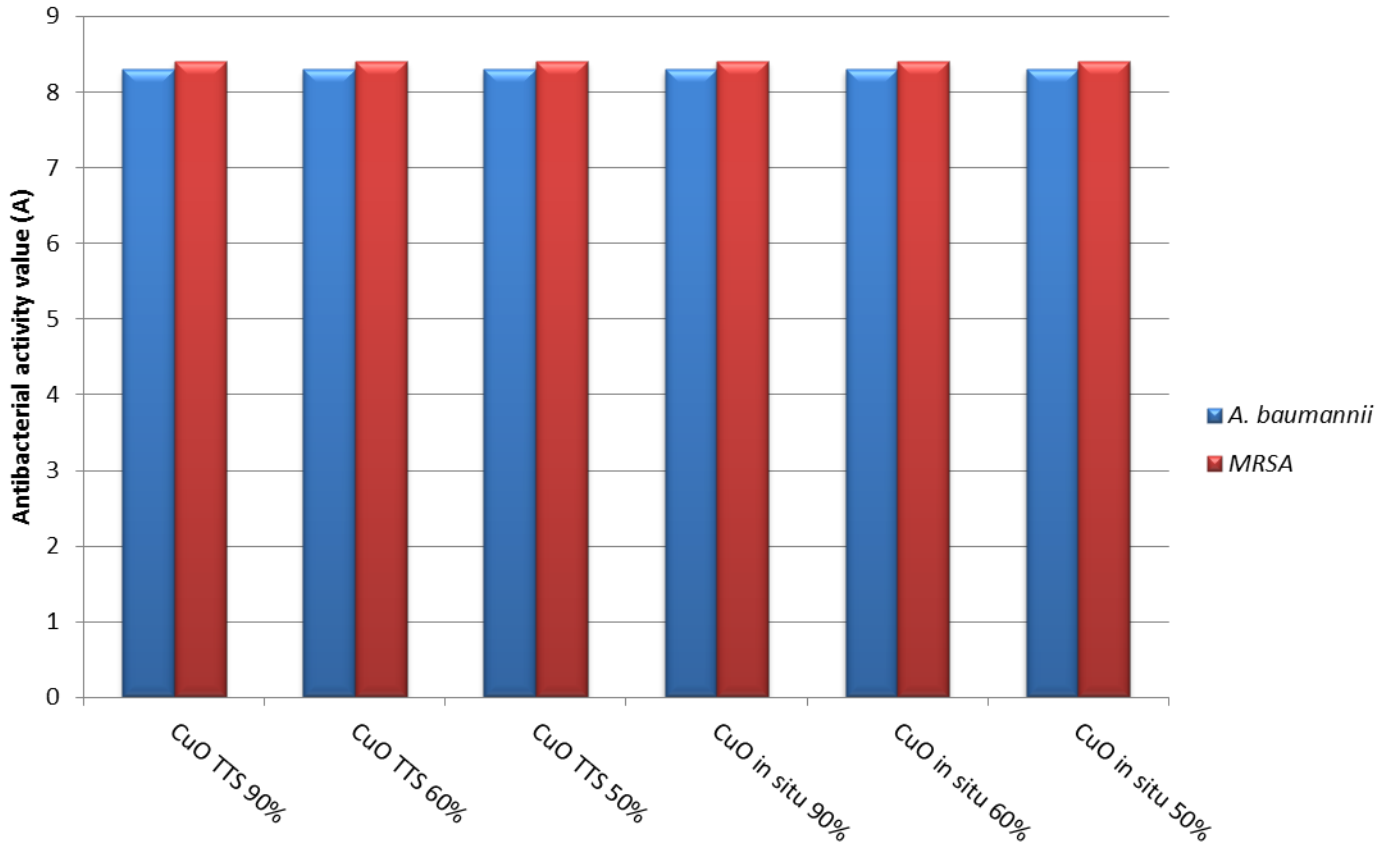
In the deposition reactions, the ultrasound can be applied in 2 modes of operation:

1. *"In-situ" reaction* - the formation of the particles and their following deposition on the fabrics in one step reaction.

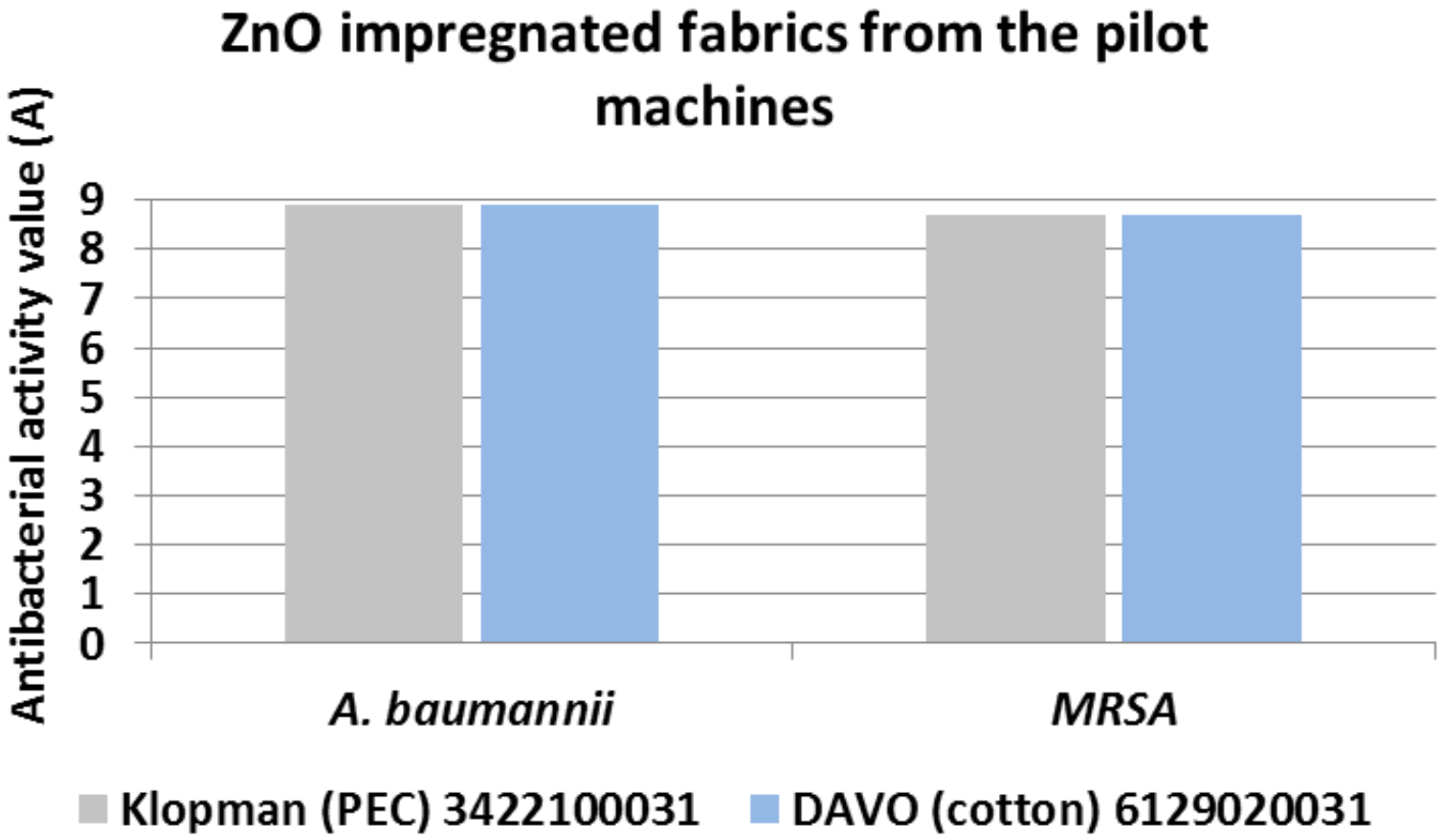
   In the current project the MeO NPs are formed by the basic hydrolysis of $Me(Ac)_2$

2. *"Throwing stones"* technique for deposition of the previously synthesized or commercially available materials. The ultrasonic waves and the microjets throw the commercial NPs at the textile and form a coated layer.

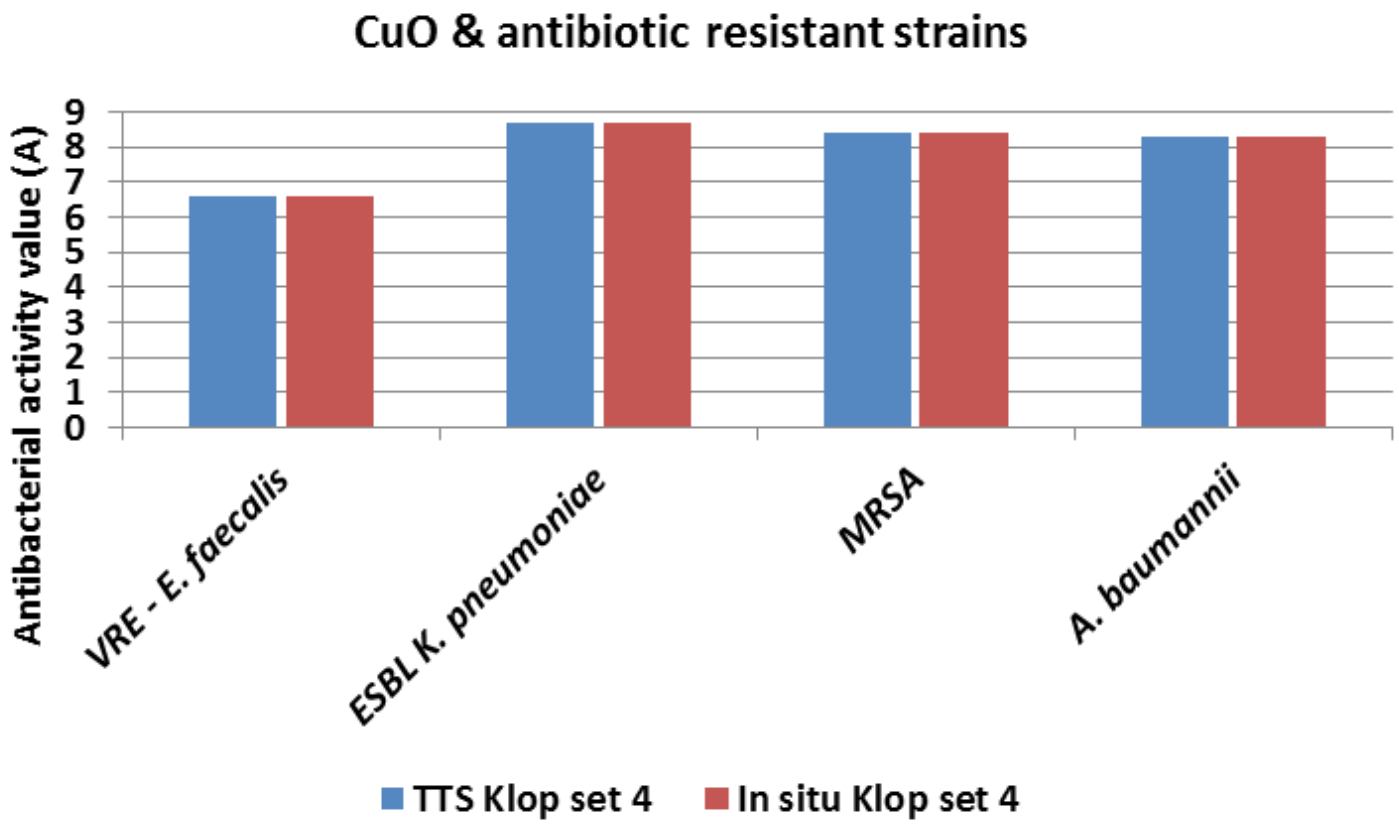
Antibacterial activity of CuO coated textiles



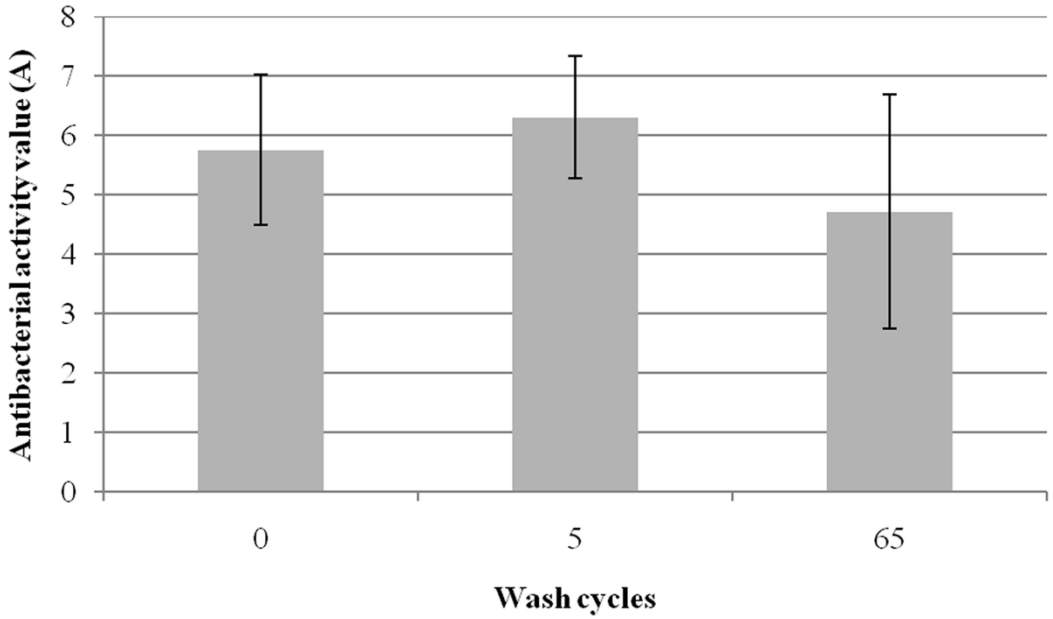
Antibacterial activity of ZnO coated textiles

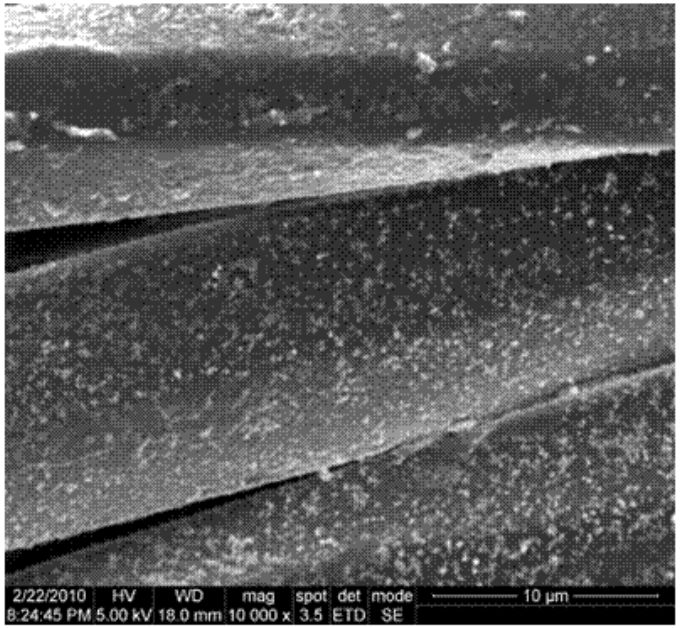


Killing of resistant bacteria



The Sonochemical Coating of Cotton Withstands 65 Washing Cycles at Hospital Washing Standards and Retains its Antibacterial Properties





- Antibacterial activity values of washed CuO coated fabrics against ***Staphylococcus aureus*** (ATCC 6538). Testing was carried out according to the absorption method from BS EN ISO 20743:2007.

ROS Production On ZnO Surface

Suggested mechanism:

$$H_2O + Os^- \longleftrightarrow \cdot OH + OHs^-$$

$$2OHs^- \longleftrightarrow H_2O + \square + Os^{2-}$$

$$O_2 \longleftrightarrow 2Os$$

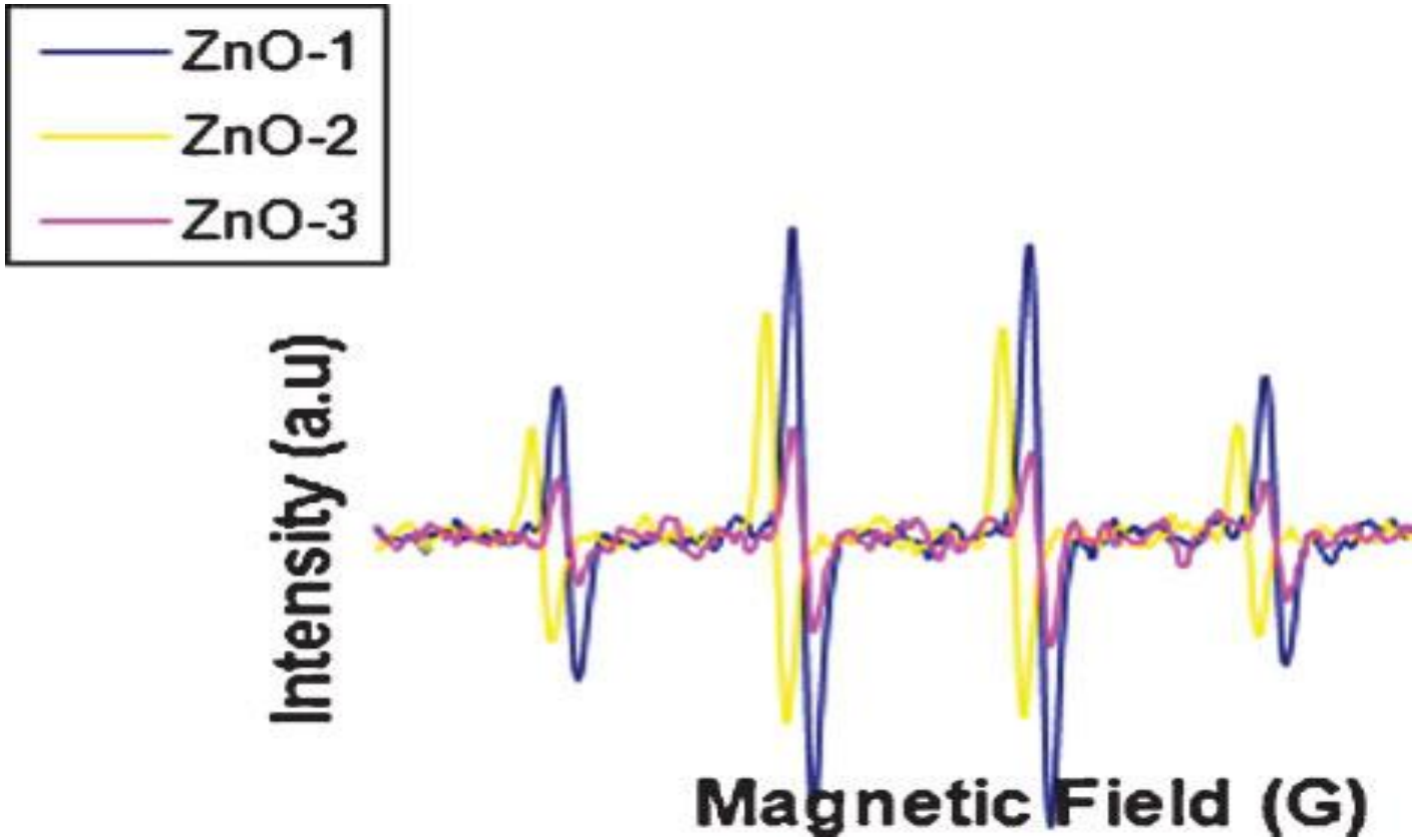
$$Os + \square + Os^{2-} \longleftrightarrow 2Os^-$$

$\square$ refers to an oxygen vacancy and the subscript "s" refers to surface species.

The net reaction can be written as follows:

$$O_2 + 2H_2O \longrightarrow 4OH\cdot$$

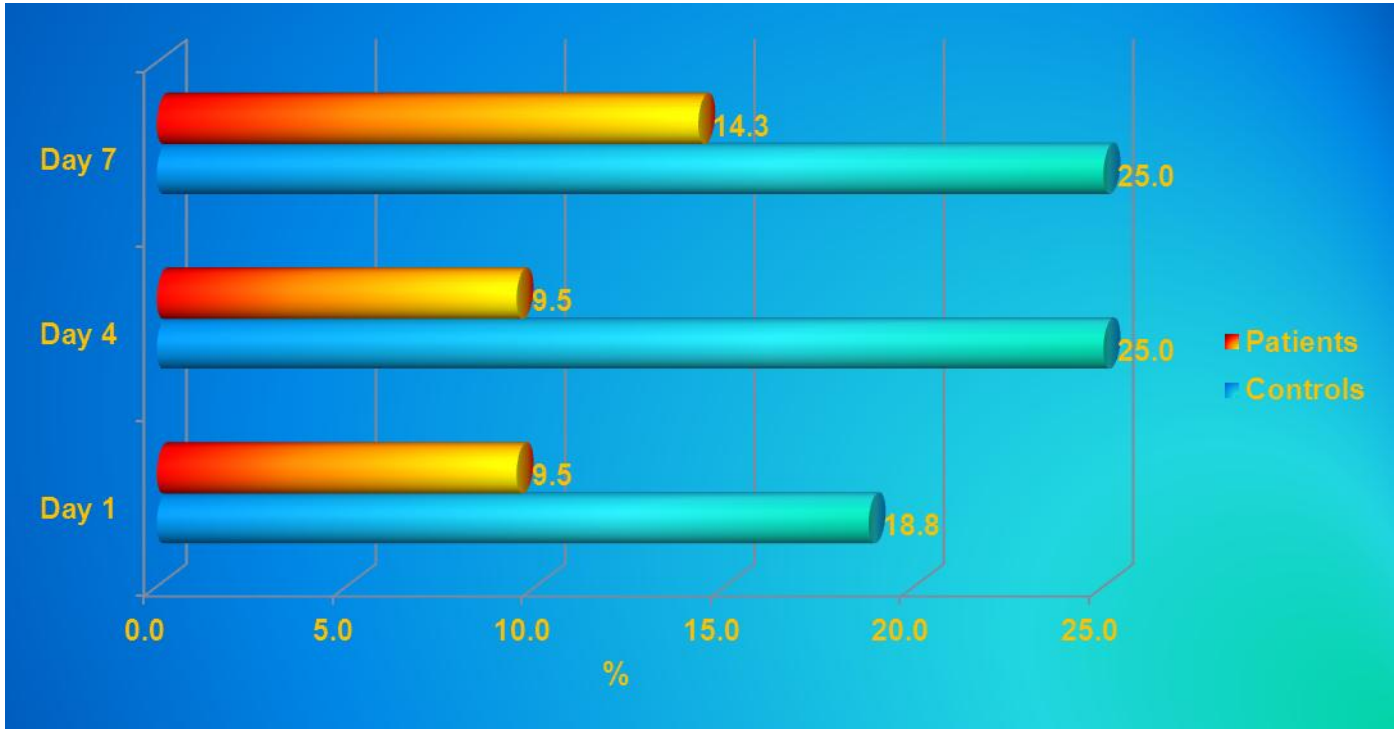
ESR-Spin Trapping Technique



Smaller sizes of ZnO produce greater amount of hydroxyl radicals

Clinical Results

Microbiology assessments – Colonization of throat

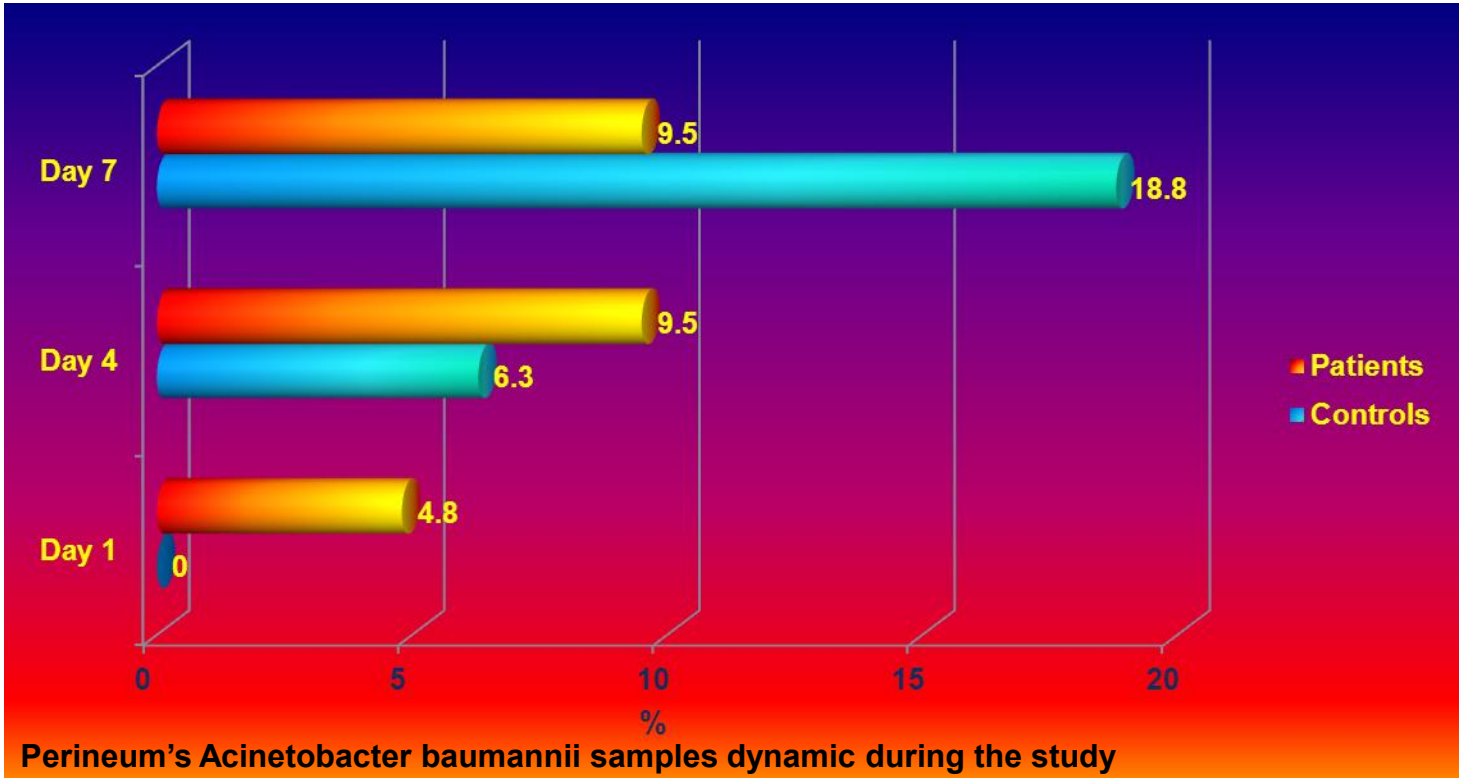


Throat S. aureus MSSA samples dynamic during the study

Throat contamination in patients remains at stable levels, while in controls increases from Day 0 to Day 4

Clinical Results

Microbiology assessments – Colonization of perineum

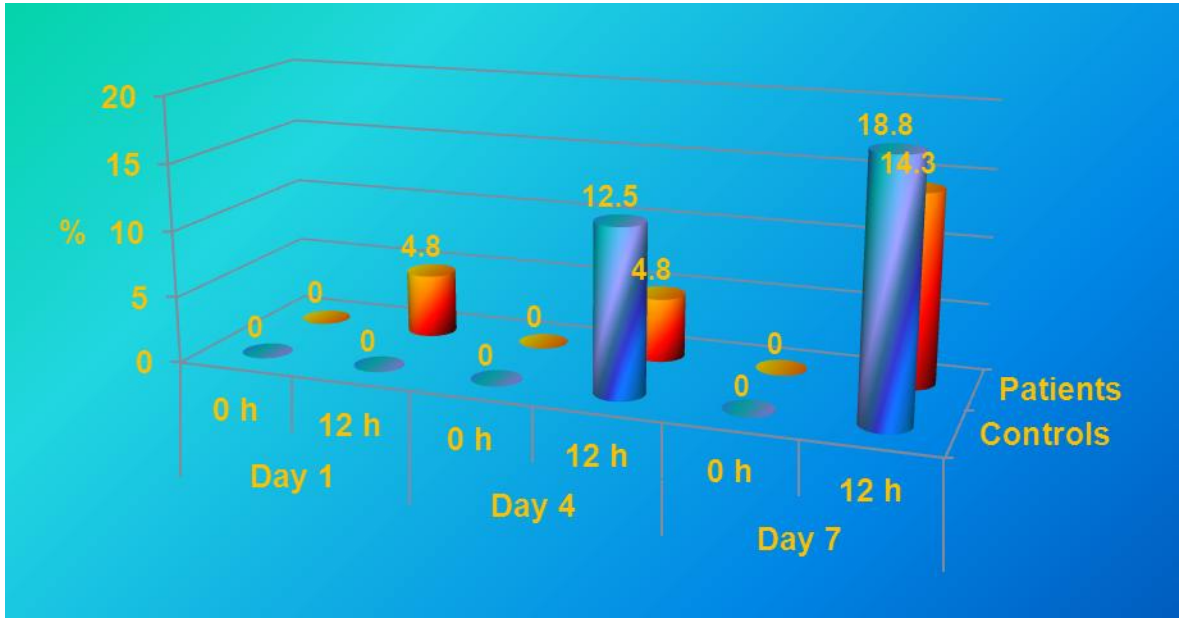


Perineum's Acinetobacter baumannii samples dynamic during the study

Perineum colonization of controls with Acinetobacter baumannii (representative of nasocomial infections) increases from Day 0 to Day 7 from 0% to 18%, while in patients remains comparatively stable

Clinical Results

Microbiology assessments – Colonization of textiles



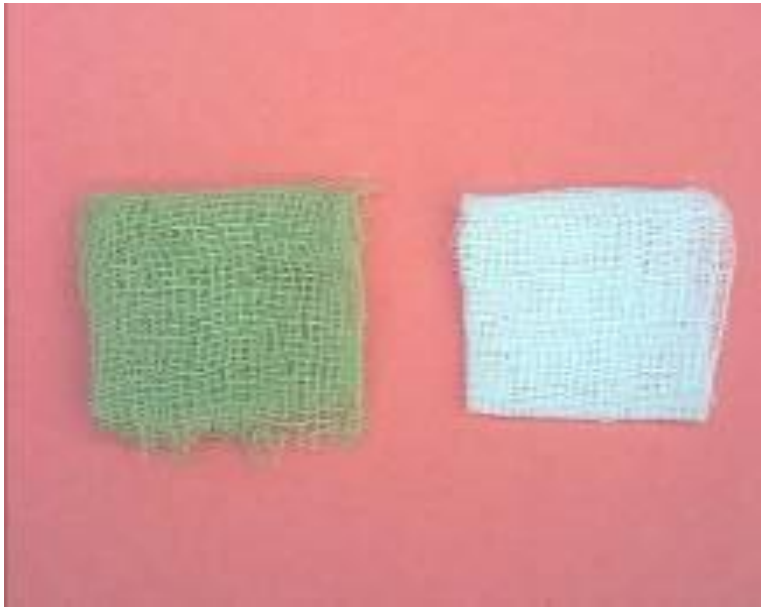
Colonization of bed linen of controls with Acinetobacter baumannii increases significantly from Day 0 to Day 7 (from 0% to 18%) , while in patients remains comparatively stable with small increase in the end of the studied period.

Note: One of the most difficult for managing nasocomial agents not affected by the known antiseptics and lots of antibiotics) .

Zn-doped CuO Nanocomposite

- ✓ ZnO is known for its bacterial growth inhibition initiated by the catalysis of reactive oxygen species (ROS) produced in water
- ✓ The creation of ROS depends on the presence of defect sites in the structure of the metal oxide NPs
- ✓ The doped metal oxides are characterized by increased defects that can make them more effective antibacterial agents due to higher ROS production
- ✓ ZnO- CuO NPs were synthesized and simultaneously deposited on cotton fabric using ultrasound irradiation

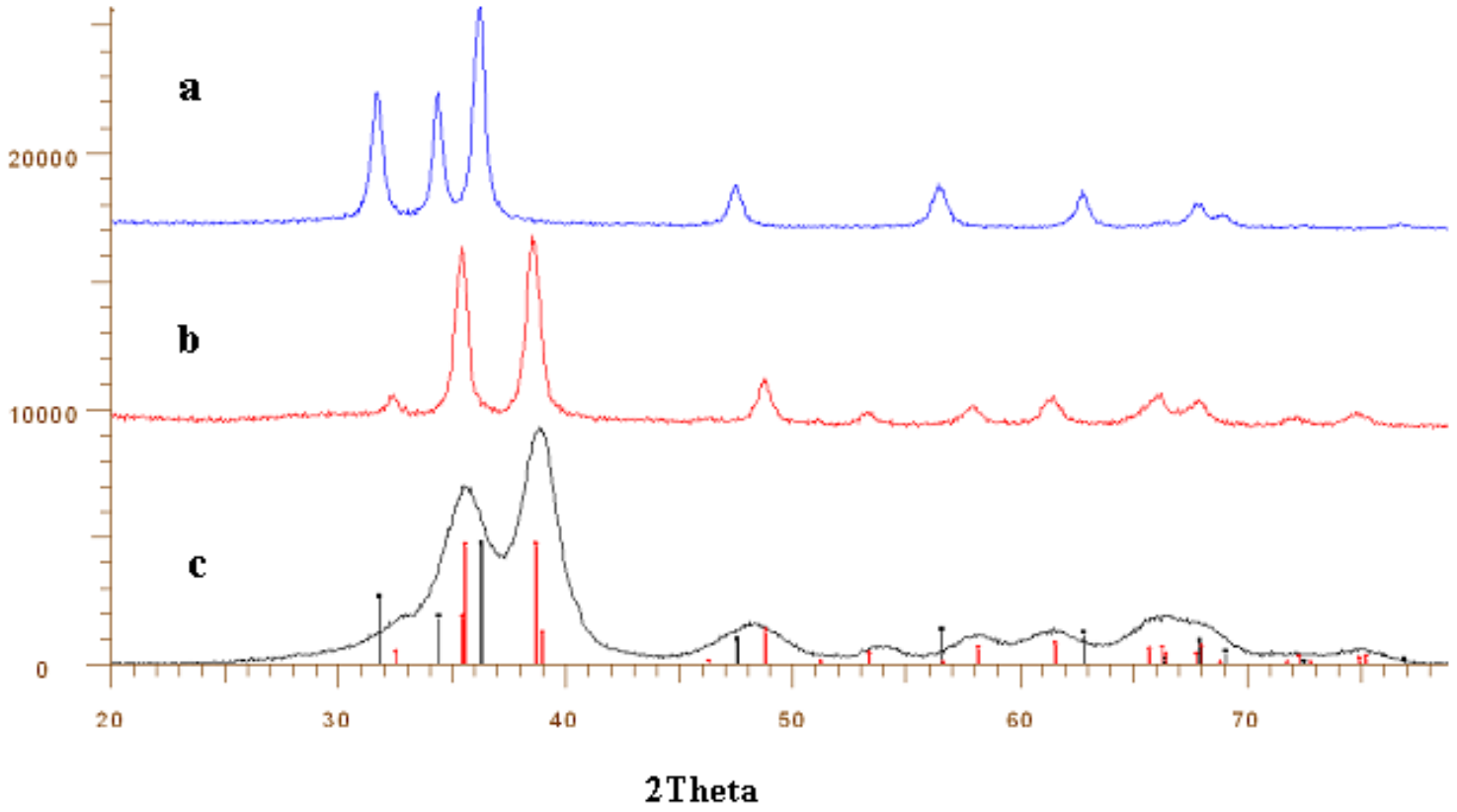
Deposition procedure



Content of metal ions on the coated cotton fabrics (by ICP method)

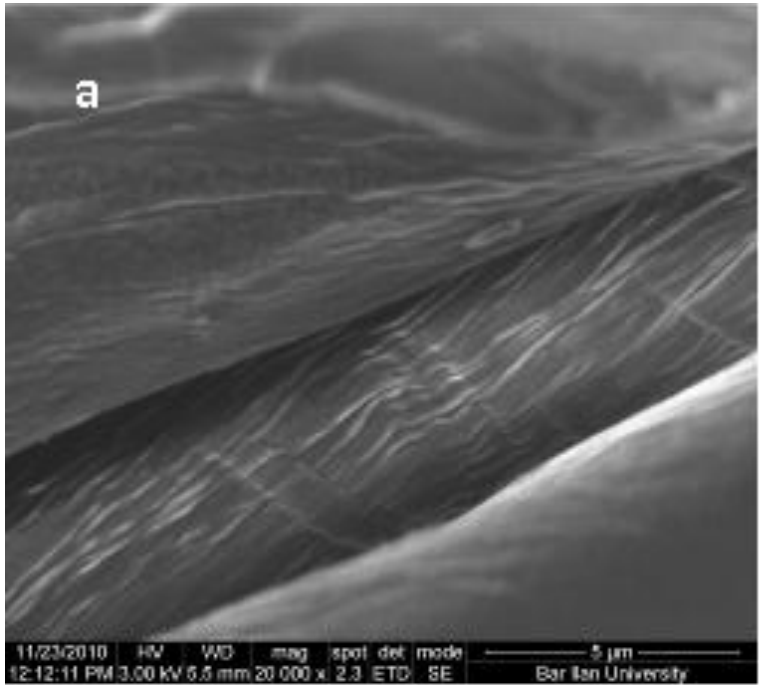
Sample name	Concentration in working solution (mol/L)		Deposition (wt %)	
	$[Cu^{2+}]$	$[Zn^{2+}]$	$[Cu^{2+}]$	$[Zn^{2+}]$
1 - low	0.015	0.005	0.41	0.05
2 - medium	0.0075	0.0025	0.95	0.12
3 - high	0.00375	0.00125	2.15	0.27

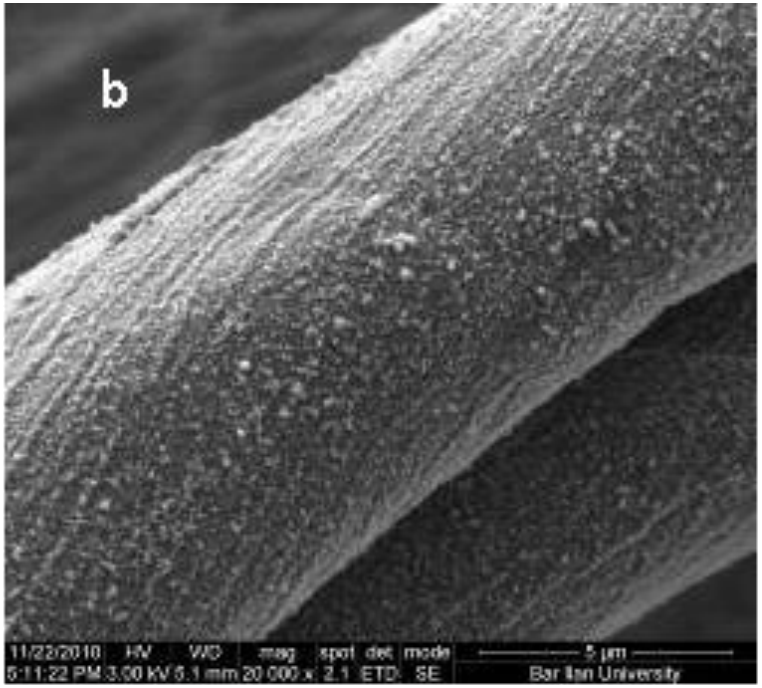
XRD diffraction patterns of: (a) ZnO (b) CuO (c) Zn-CuO



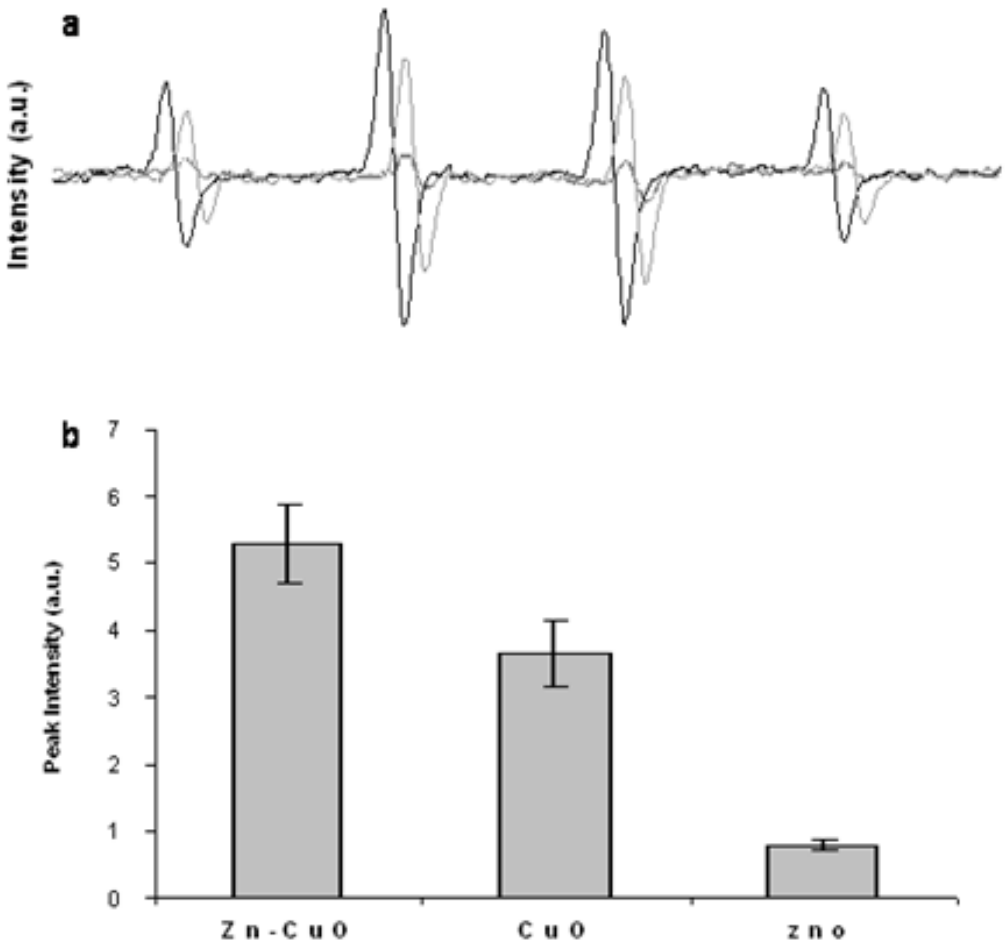
The cell parameters of the CuO lattice changed from: a = 4.6890; b=3.4200; c=5.1300 for CuO to a = 4.6829; b=3.4201; c=5.1429 for the Zn-CuO

SEM images of the cotton fabric:
(a) pristine cotton fabric ,
(b) cotton fabric coated with Zn-doped CuO NPs



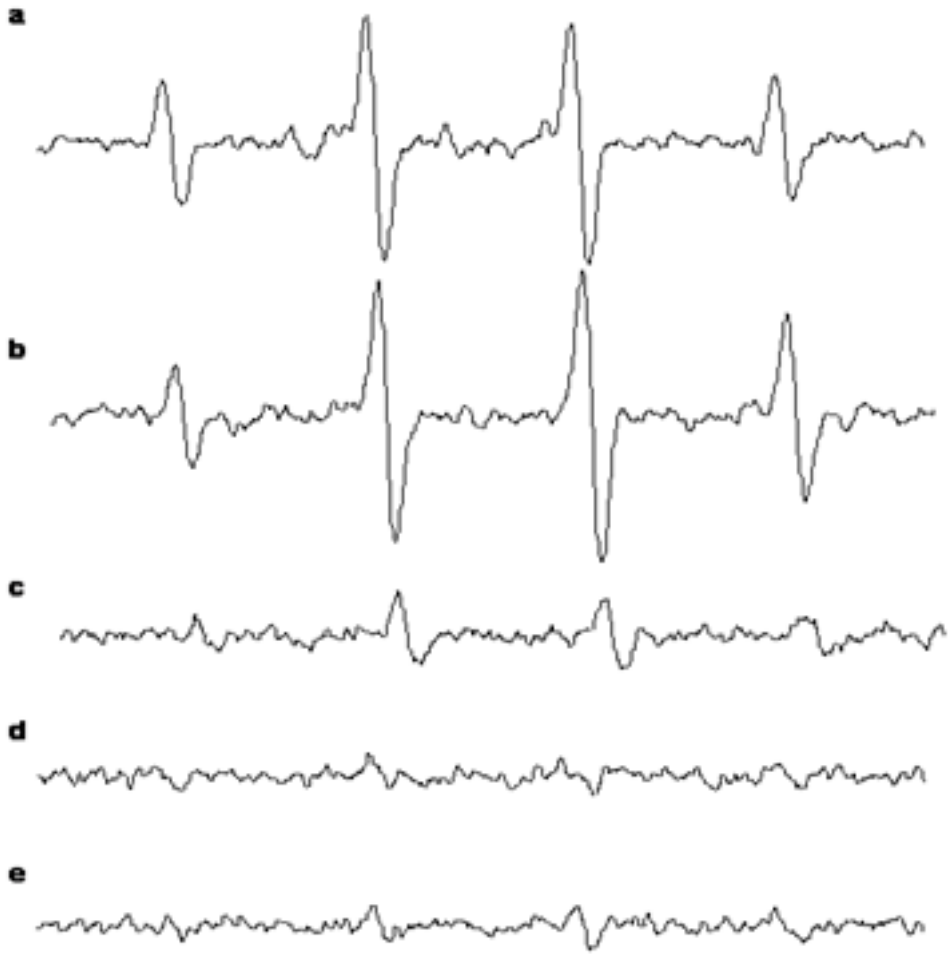


ESR studies



(a) ROS generation by ZnO (bold gray line), CuO (gray line) and Zn-CuO (black line) NPs'; **(b)** The relative ESR signal intensity of the DMPO-OH spin adduct generated from Zn-CuO, CuO and ZnO NPs'

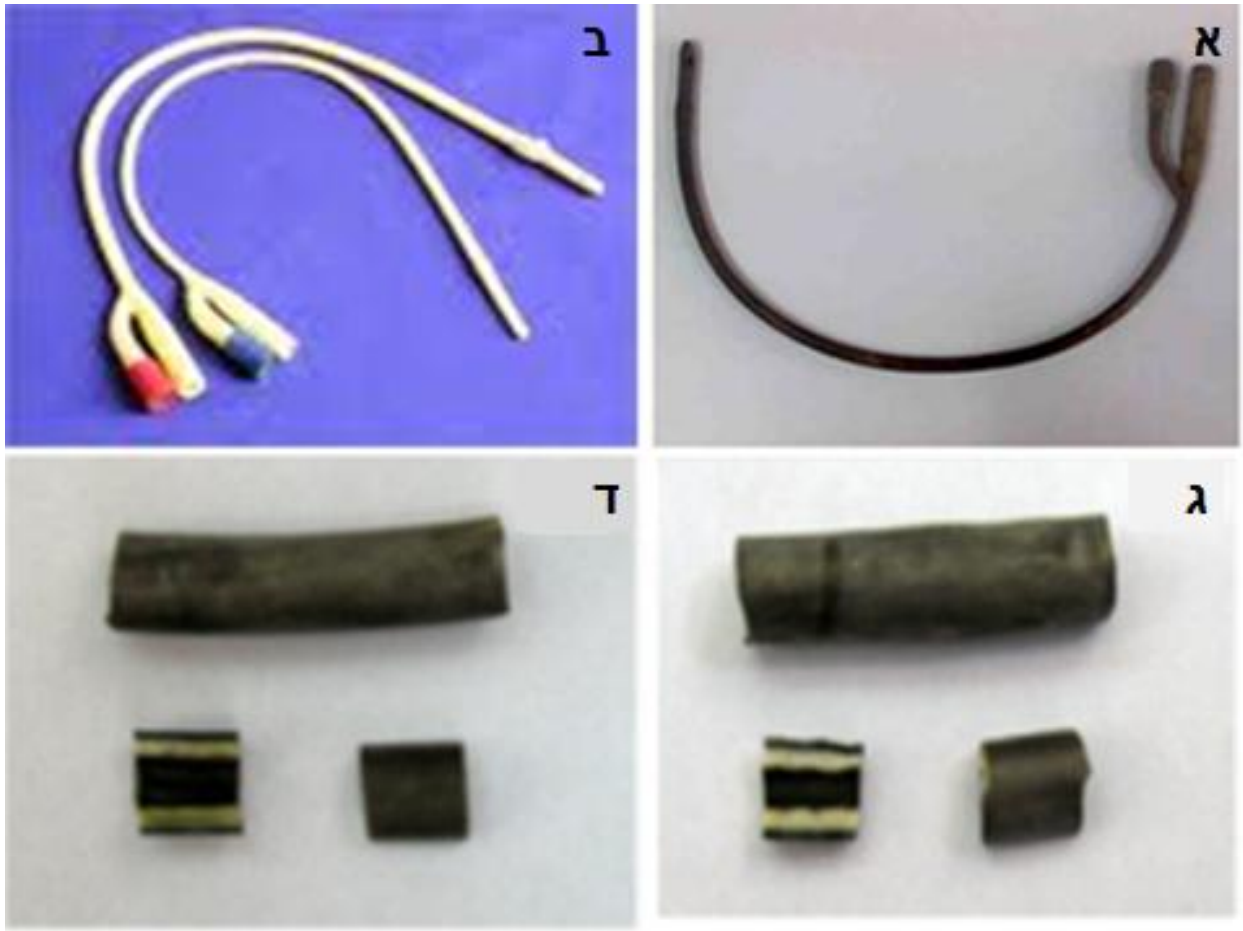
(a) Zn-CuO (b) Zn-CuO after 300 C under air (c) Zn-CuO after 550 C under air (d) Zn-CuO after 550 C under N_2 (e) DMPO control.



Propionibacterium acnes
is the bacterium
responsible for
inflamed acne breakouts.

Controlling *Propionibacterium acnes* population is a crucial step in reducing acne

Ag coated catheters



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