Interactions Between Microcrystalline ZnO and Extracellular Material of Staphylococcus Aureus

J. Reeks, I. Ali, J. Tzoka, Y. Strzhemechny

Texas Christian University

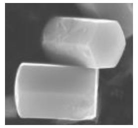
Abstract

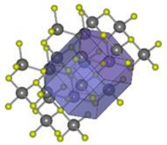
Nano- and microcrystalline ZnO is a low-cost material, employed in many applications due to its optoelectronic, structural and chemical properties as well as a great variety of synthesis methods. Among these applications, antibacterial action of ZnO is a budding field of interdisciplinary research. Despite numerous studies of this antibacterial action, the physical and chemical mechanisms behind it are still largely not understood. In particular, the influence of the crystal surface morphology and surface-surface interactions between the bacteria and ZnO are largely unknown. Hexagonal (wurtzite) ZnO crystals terminate with three different types of crystallographic surfaces: charged polar hexagonal (Zn or O), electrically neutral nonpolar rectangular and partially polar pyramidal slanted. In our studies we employ a hydrothermal growth procedure to synthesize nanocrystals and microcrystals of ZnO with tunable morphology to investigate the influence of surface types on interactions with bacteria as well as surface charge dynamics. To quantify the antibacterial action we employ minimum inhibitory concentration (MIC) assays of staphylococcus aureus with hydrothermally-grown ZnO microcrystals. Scanning electron microscopy (SEM) is used to characterize the morphology of the as-grown ZnO specimens as well as the organization of these particles after their interactions with bacteria. To characterize electronic structure and dominant charge transport mechanisms at ZnO surfaces we performed photovoltage (SPV) experiments. Our results confirm that antibacterial action is a result of ZnO surface interactions with extracellular material, whereas internalization of ZnO particles (happening in the case of nanoscale ZnO) is not necessary for inhibition. We also report that the electronic transitions at the surface of the ZnO particles are consistent the theoretically predicted electronic structure of ZnO, with the spectral signatures of surface states which could be the source of the antimicrobial action.

Introduction

- Fundamental mechanisms driving antibacterial action for ZnO is still unknown.
- Antimicrobial behavior of ZnO is initiated by interactions of surfaces

Zinc Oxide Crystal Structure

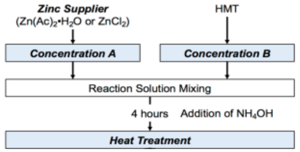




- ZnO has Hexagonal structure composed of alternating layers of Zn^{2+} and O^{2-} ions
- Structure yields net charge at hexagonal (polar) faces and neutral charge on rectangular (non-polar) sides
- Nature of these crystallographic faces (neutral, negative, positive) could be very different.

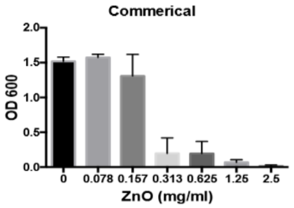
Controlling growth of ZnO structures

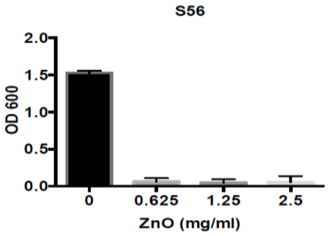
- Hydrothermal chemical method allows us to grow specific ZnO micro-crystals
- Allows us to control the ZnO surfaces interacting with bacteria



Bacterial Growth Inhibition

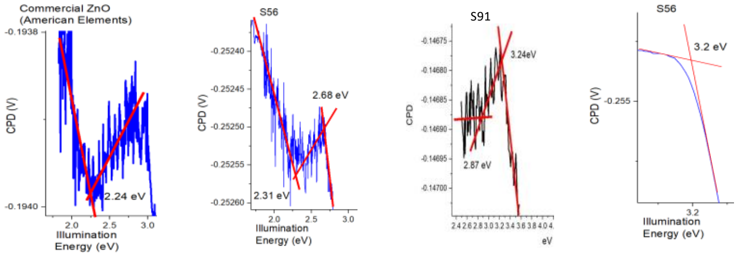
- Internalization is not necessary for growth inhibition





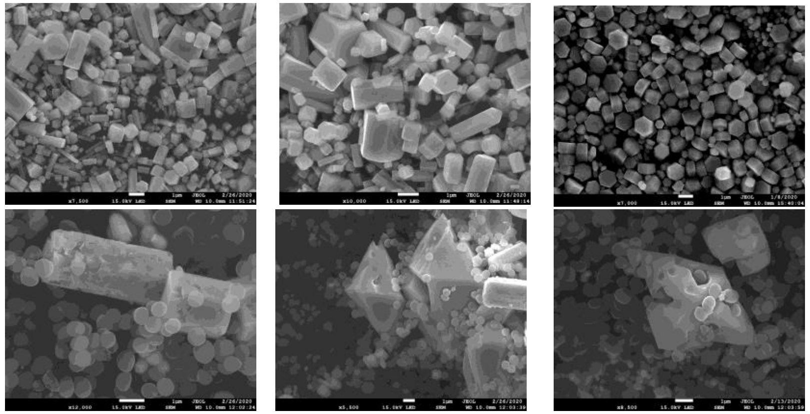
Optoelectronic effects of surface characteristics

- Similar sub-bandgap and bandgap transitions present in most samples
- These transitions influence interactions with media and extracellular material



Morphological changes to ZnO crystals

- Interactions with bacteria and media cause changes in ZnO crystals



Conclusions

- Initial antimicrobial assay trials confirm hypothesis that interactions between ZnO and bacterial surfaces drive this action
- Photoluminescence studies of various particles reflect changing optoelectronic behavior with surface morphology and particle dimensions

Future Directions

- Investigate near surface optoelectronic phenomena (surface photovoltage experiments)
- Correlate antibacterial activity to surface type
- Investigate antibacterial action and optoelectronics of other ZnO micro- and nano-structures
- Investigate influence of media and bacteria components on ZnO crystals