# Rational Design of Nanostructures and Tuning of Photophysical Properties for Robust Cancer Theray and Drug Delivery

Abstract: Prof. Zhang is one of world leading experts in photoelectrochemistry and optical nanomaterials. His lab is equipped with state of the art Femtosecond laser system allowing his team to probe fundamental charge carrier or exciton dynamics on the ultrafast time scale, directing more effective and efficient nanomaterials design with improved properties. We are particularly impressed by his group's recent achievement in the effectiveness of their hollow gold nanospheres (HGHs) in cancer detection and treatment both in vivo and in vitro. Their proprietary HGNs are ideally suited for Photothermal Ablation (PTA) therapy applications, at least 8 times more effective compared with solid Au nanoparticles, due to their strong photothermal conversion profile as a result of their unique combination of small size (average outer diameter of 30 - 50 nm), spherical shape, as well as strong, tunable, and narrow surface plasmon resonance (SPR) absorption in the NIR. The group is also developing novel solar energy conversion system utilizing synergistic effects of three-component (CdSe-$TiO_2$:N) nanocomposite thin film.

Keywords: Nanomaterials, hollow nanospheres, photothermal ablation, photothermal, nanocomposite, cancer detection, targeted drug delivery, Solar cells, PEC, quantum dot

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Photothermal ablation therapy (PTA) based on metal nanostructure has been actively explored for treating cancer due to its advantages of targeting drug delivery, low toxicity, minimal side effect and high efficacy. The hollow gold nanospheres (HGNs) developed by Prof Zhang and his team in the University of California Santa Cruz (UCSC), is ideal for PTA since it is the composition of small size (30 - 50 nm), spherical shape, and strong, narrow and tunable surface plasmon resonance (SPR) absorption in visible light and near infrared light (NIR). NIR region is particularly desirable for minimal absorption or optimal penetration of tissue. The unique properties of HGNs bring the advantage of effective intracellular uptake, convenient delivery, high-efficiency photothermal conversion, full-scale matching for the selected laser wavelength as well as minimizing tissue absorption. Prof Zhang's group used Co nanoparticles as seeds via a galvanic reaction with $Au^{3+}$ ions to produce the HGNs with consistent size and uniform shell thickness. The optical properties can be tuned by varying the particle size and wall thickness. The active targeting at specific sites is enhanced with help of his collaborators led by Dr Chun Li of the M. D. Anderson Cancer Center. They covalently attached a short peptide to the HGNs that enabled the particles to bind to tumor cells. Both *in vitro* and *in vivo* studies show HGNs are ideally suited for PTA applications, and they are at least, eight times more effective compared to solid nanoparticles (see Fig. 1).

Another impressive achievement from Prof Zhang's group is their nanostructured thin films which are desirable for efficient solar energy conversion application. They synthesized and studied the photoelectrochemical (PEC) properties of $TiO_2$ nanoparticles and nanowires simultaneously doped with nitrogen *and* sensitized with CdSe quantum dots (QDs), and they observed significant enhancement of conversion efficiency when it is used as the photoanodes for PEC hydrogen generation. They are the first group in the world to find that the synergistic effect of CdSe sensitization and N-doping, which significantly enhances the PEC activities of the $TiO_2$ nanostructured photoanodes when the relevant band gap states are properly aligned and utilized, and moreover, enhances electron-hole separation and hole transfer/transport by localized, near surface oxygen vacancy states increased by N-doping. In comparison with $TiO_2$

nanoparticles, $TiO_2$ nanorods or nanowires are more desirable in terms of enhanced charge transport.

After the NSTI Nanotech Conference & Expo 2010 in LA, we visited Prof Jin ZHANG, Professor of Chemistry in the Chemistry and Biochemistry Department of UCSC. Prof Zhang received his PhD in Physical Chemistry from University of Washington (US) in 1989 and has been a Full Professor in University of California Santa Cruz since 2004. He is also the adjunct professor of Nanjing University and Beijing Institute of Science and Technology (China) as well as guest professor of Northeast Normal University (China). As a talented scientist with strong passion in research and education, Prof Zhang has published over 170 scientific papers in the peer-reviewed journals such as Nano Letters, Small, ACS Nano, Journal of the American Chemical Society, Journal of Physical Chemistry Letters, etc., and has been the advisor or sponsor for over 30 graduate students or postdocs. He is also the author of the book “Optical Properties and Spectroscopy of Nanomaterials” (World Scientific Publisher, Singapore, 2009) and senior editor of Journal of Physical Chemistry (ACS) since January 2004. In recognition of his outstanding contributions to physics, especially of his efforts in fundamental understanding of photophysical properties and charge carrier dynamics of semiconductor and metal nanomaterials based on ultrafast studies, Prof Zhang is an elected Fellow of the American Physical Society (APS). This is a very prestigious honor as election to Fellowship in the APS is limited to no more than one half of one percent of the membership. He is also being elected fellow of the American Association for the Advancement of Science (AAAS) and awarded the Overseas Young Investigator Award by National Natural Science Foundation (NSF) of China. Details of Prof. Zhang’s research can be found at their website.

Prof. Zhang is leading a team of young and passionate scientists from USA, Mexico and China focusing on the designed synthesis, characterization, and application of advanced materials (nanostructured semiconductors, metal oxides, metals and others) with novel physical (both optical and electronic) and chemical properties due to quantum confinement and exceedingly large surface to volume ratio. The group adopts mostly designed synthesis of the materials based on inorganic colloidal chemistry methods. The synthesized materials are characterized systematically and extensively using a variety of experimental techniques including optical spectroscopy (UV-visible, fluorescence, IR, and Raman), femtosecond laser spectroscopy (for probing ultrafast charge carrier dynamics), x-ray (XAFS, XRD, x-ray photoemission), electrochemical, and microscopy (HRTEM, SEM, AFM).  Prof. Zhang has developed strong interest in exploring emerging technological applications particularly in photovoltaics and early stage cancer detection and treatment. They are the first group in US that systematically studies the ultrafast dynamics of nanomaterials using femtosecond laser spectroscopy to directly probe of charge carrier or exciton dynamics on the ultrafast time scale. At the fundamental level, they dynamically characterize the materials with moleculear details such as particle size, shape, crystal structure, interface, and environment that influence the properties and functionalities of the nanomaterials. Dynamic characterization plus other fundamental understanding of photophysical properties of nanomaterials allows them to rationally design complex nanostructures showing superiorly promising potentials in biomedical and solar energy conversion applications.

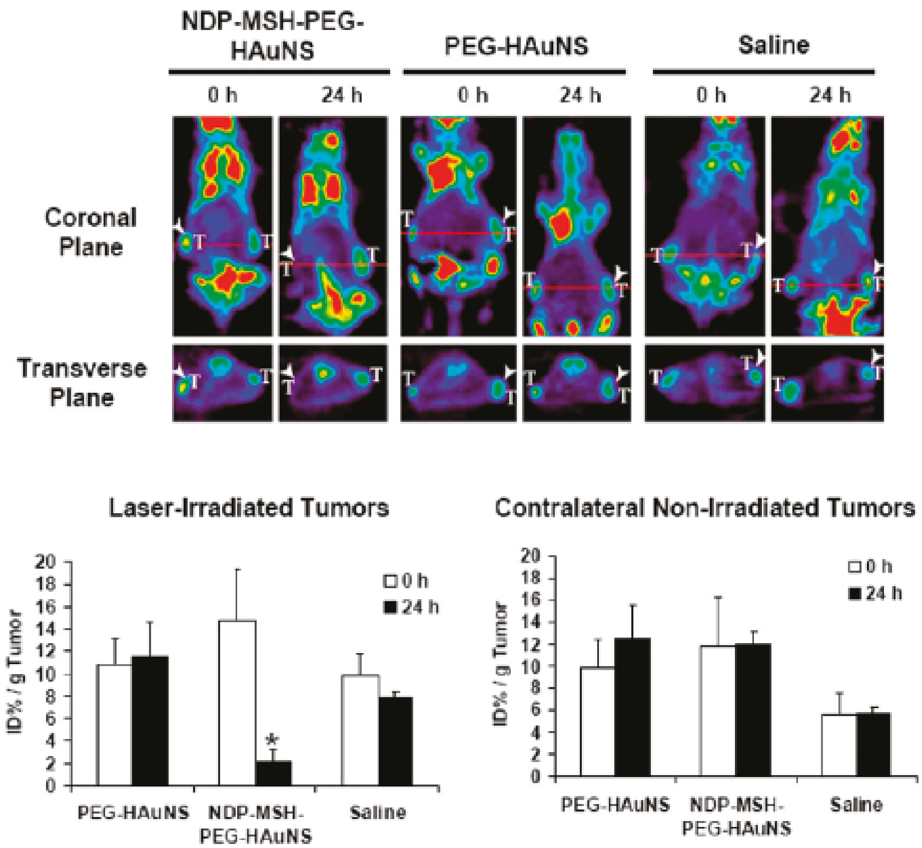


Figure 1. In vivo PTA with targeted NDP-MSH-PEG-HGNs induced selective destruction of B16/F10 melanoma in nude mice.PET imaging shows significantly reduced metabolic activity in tumors after PTA in mice that were pretreated with NDP-MSH-PEG-HGNs but not in mice pretreated with PEG-HGNs or saline.PET was conducted before (0h) and 24 h after NIR laser irradiation (0.5 $W/cm^2$ at 808nm for 1 min), which was commenced 4 h after iv injection of HGNs or saline (T for tumor). The arrowheads in the figure indicate tumors irradiated with near-IR light. [$^{18}F$] fluorodeoxyglucose uptakes (%ID/g) before and after laser treatment are shown graphically at the bottom. Bars, SD (n=3). * P<0.01 for %ID/g posttreatment versus %ID/g pretreatment. HAuNS or HGNs termed in this original work are the same as HGN. The number of NDPMSH-PEG-HGNs per mouse is around $2.5 \times 10^{12}$. (Ref 1)

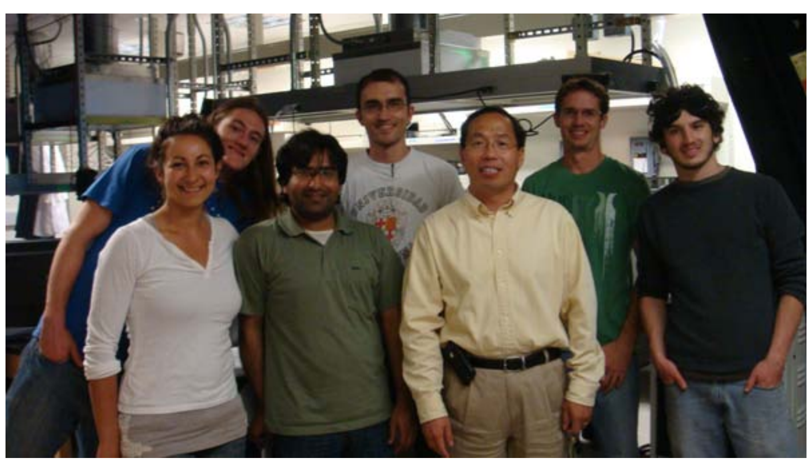

Figure 2. Group photo of Prof Zhang and part of his current team members.

Reference 1: J. Z. Zhang, J. Phys. Chem. Lett., **1**, 686–695, (2010).