

Improving the Nanotechnology Education for Future Engineers

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Abstract

Nanotechnology education offered by many universities in the USA involves interdisciplinary and multidisciplinary education with courses in nanotechnology, engineering, chemistry, physics, mathematics and biology. The challenge of nanotechnology education is to provide advanced technologies to the students in a wide variety of fields. In the present communication, we will be dealing with the fabrication and characterizations of nanomaterials (e.g., nanoparticles, nanofibers, nanofilms, nanocomposites and micro - nanoscale devices) and devices for undergraduate and graduate students in order to improve the hands-on laboratory experiences. It is assumed that this nanotechnology would be one of the targeted areas for science and engineering in the near future, so the action should be taken on nanotechnology education as early as possible.

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1. INTRODUCTION

Nanotechnology is simply the creation of materials, components, devices and/or systems at the near-atomic or nanometer levels (roughly 1 to 100 nm). A nanometer is 10 angstrom or one billionth of a meter - nearly 100,000 times smaller than the diameter of a human hair. This technology involves fabrication, imaging, measuring, modeling, and manipulating matter at this length scale. The goal of nanotechnology is to control individual atoms, molecules or particles to significantly improve physical, chemical, physicochemical and biological properties of novel materials and devices. It is impacting broad ranges of highly multidisciplinary fields, such as engineering, materials science, colloidal science, physics, chemistry, medicine and biology [1-3].

There are several nanomaterials created using nanotechnology or associated technology. Some of the nanomaterials include carbon nanotubes (CNTs), nanoparticles, nanowires/fibers, nanorods, nanofilms, nanomedicine, DNA based biomaterials, nanocomposites and bionanocomposites. Current fabrication/manufacturing processes for these materials are physical and chemical synthesizing/deposition techniques, lithography, etching and laser machining. It is reported that CNTs consist of higher electrical conductivity, mechanical and thermal properties than their counterparts. They can sustain electrical current densities hundreds of times higher than other conductive materials, and are produced in both metallic and semiconductor forms. They are one of the strongest known materials in terms of their tensile strength (150 GPa) and elastic modulus (1200 GPa). Furthermore, the CNTs are thermally good conductors along the length of the tube, while good insulators laterally to the tube axis. This strength comes from the covalent sp² bonds between the individual carbon atoms and its lower density (1.35 g/cm³) [1-5].

Because of the unique properties of nanomaterials and devices, the nanotechnology and nanotechnology education are increasingly important for undergraduate and graduate students. The nanotechnology brings the education and research communities together in an effort to i) inform students about the advances in the scientific research, ii) develop new methods and approaches at nanoscale and iii) get attention of young engineers who may choose careers in nanoscale science and engineering [6-10].

Our team in the Department of Mechanical Engineering at Wichita State University already started developing a nanotechnology laboratory. The objective of this laboratory is to design, fabricate, analyze, and test structures and systems at nanoscales. In this laboratory, our students will learn nanotechnology to improve their skills, which will also improve their job

finding opportunities and leadership in the near future. We strongly believe that laboratory experiments in nanoscale research and development are essential for engineering students to enhance their practical knowledge after fundamental concepts. For this reason, following tests are planned for ME students, including nanoparticle, nanowire, nanofilm, nanocomposite and nanodevice fabrication and characterizations:

2. FABRICATIONS OF NANOMATERIALS AND DEVICES

2.1 Nanoparticle Fabrications

Recently, a number of nanoparticles (magnetic, optic, conductive, semi-conductive, etc.) have been investigated to determine the properties of these functional materials. It is known that nanosize particles have unique chemical, optical, electronic, magnetic, mechanical or tribological properties when compared with their counter parts. The high saturation magnetization and/or magnetic susceptibility of magnetic nanoparticles are of even greater interest for pharmaceutical, medical and electronic applications [5]. For example, magnetite (Fe_3O_4) nanoparticles that have excellent magnetic saturation (78 emu/g) are desirable for these applications due to the strong ferromagnetic behavior, less sensitivity to oxidation, high storage capacity and relatively low toxicity compared to many other materials (e.g., iron, nickel, and cobalt). These magnetite nanoparticles can be produced by co-precipitation of iron (II) and iron (III) chloride salts in the presence of ammonium hydroxide at above pH 9, and can be easily stabilized by fatty acids in nonpolar solvents. Figure 1 shows a transition electron microscope (TEM) image of magnetite nanoparticles produced using a co-precipitation technique and b) schematic view of the functionalized nanoparticles in a liquid medium [1-3].

Ferrofluid is a magnetic liquid (mixture of liquid and magnetic nanoparticles) that becomes strongly polarised in the presence of a magnetic field. A true ferrofluid is stable enough that even in the presence of an extremely strong magnetic field, the particles will not destabilize (or settle). When a ferrofluid is exposed to a strong magnetic field, the polarized nanoparticles form chains and create spikes. Figure 2 represents the spiking ferrofluid obtained using the functionalized (surfactant molecules adsorption) magnetic nanoparticles [1-3].

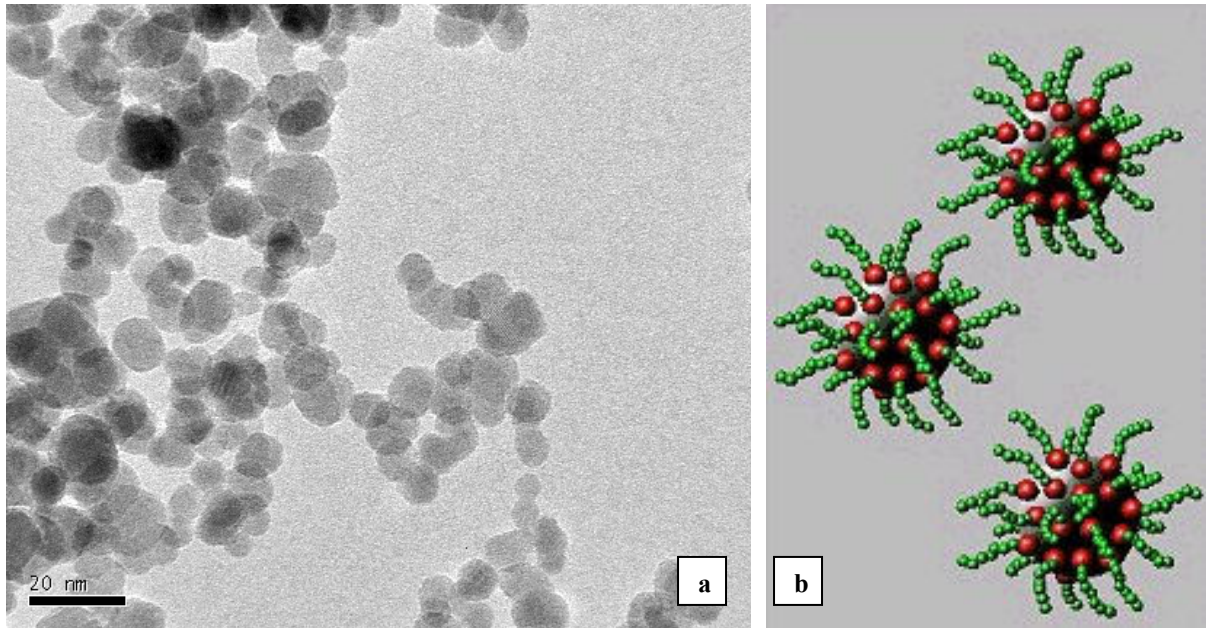


Figure 1: a) A TEM image of magnetite nanoparticles produced using a co-precipitation technique and b) schematic view of functionalized nanoparticles by surfactant molecules in a liquid medium.

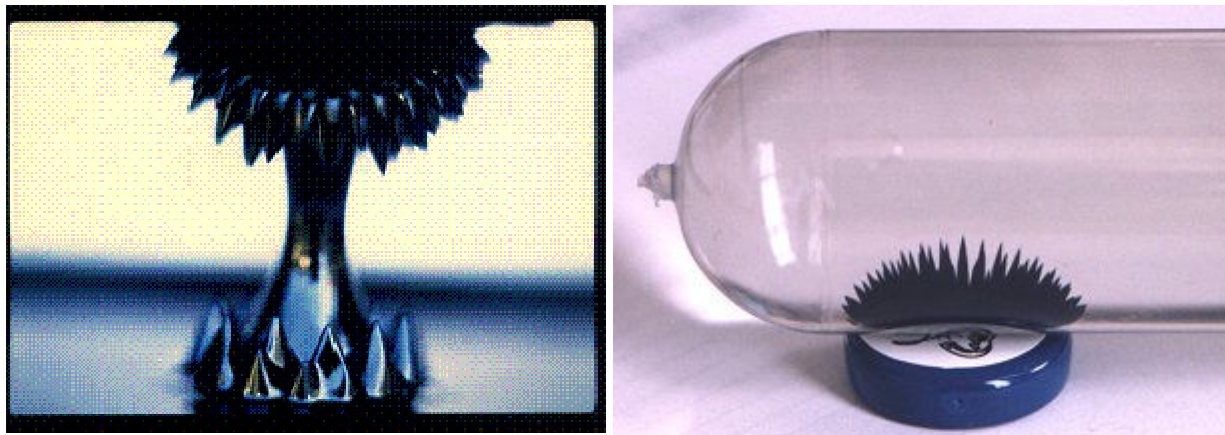


Figure 2: Photographs showing the spiking ferrofluids obtained using the functionalized magnetic nanoparticles.

2.2 Nanowire/Nanofiber Fabrications

Electrospinning is a unique process to produce nanosize polymeric wires/fibers that are at least one or two orders of magnitude smaller in diameter than those produced by conventional fiber production methods (melt or solution spinning). In a typical electrospinning process, a jet is

ejected from a charged polymer solution when the applied electric field strength (and consequently the electrostatic repulsion on the surface of the fluid) overcomes the surface tension. The ejected jet travels rapidly to the collector target located at some distance from the charged polymer solution under the influence of the electric field and becomes collected in the form of a solid polymer filament as the jet dries. During its flight to the target, the jet elongates to undergo large amounts of plastic stretching that consequently leads to a significant reduction in its diameter [6]. Figure 3 shows the Estane electrospun nanofibers obtained at room temperature using 10-20 kV, 3ml/h syringe pump speed, 15 cm separation distance between the target and Teflon tip.

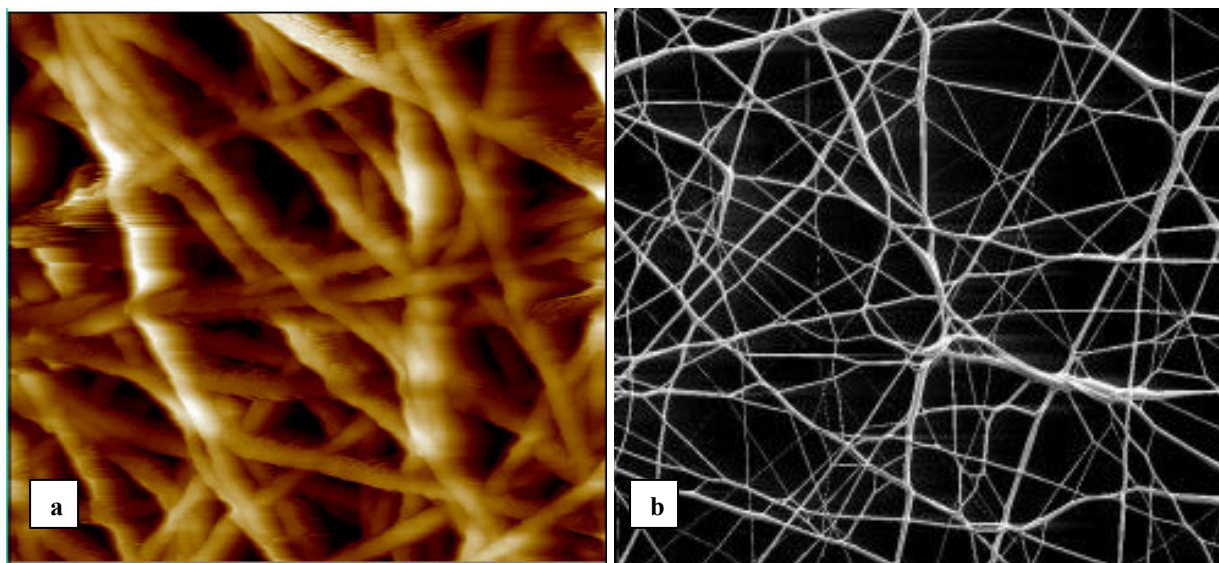


Figure 3: The electrospun Estane nanofiber images taken by a) atomic force microscope (AFM) and b) scanning electron microscope (SEM) methods. The diameters of the fibers are between 100 and 400 nm.

2.3 Nanofilm (or ESA Film) Fabrications

Electrostatic self-assembled (ESA) films have been demonstrated for many specific applications. These films can be fabricated on glasses, metals and alloys, ceramics, polymers and their compounds using a dipping technique to modify the performance (optical, electrical, tribological, thermal, magnetic and electrostatic) of the materials, and also protect the surface from the environmental effects (e.g., humidity, ultraviolet light, temperature, static and dynamic forces, etc.) [3].

In the ESA films, the substrate surface is thoroughly cleaned and electrically charged through chemical processing. Typically, cleaning of the substrate exposes functional groups at the surface, and thus effectively produces a net electrically charged molecular layer. The charged substrate is then dipped into a solution containing cationic (e.g., Poly(diallyldimethylammonium chloride) - PDDA) solution that are attracted to the anionic surface (e.g., gold, glass, etc.) and self-assemble into a single layer of molecules. Subsequent anionic (e.g., PS-119, Heparin, etc.) and cationic monolayers are added in bilayer pairs, by alternately dipping the substrate into those positively and negatively charged solutions, to produce a multilayer thin-film structure. Figure 4 shows positively and negatively charged polymeric bilayer fabrications on negatively charged silica substrates [7]. In this process, appropriately charged inorganic nanocluster particles (e.g., Pt, Au, Ag, CdSe, GaAs, TiO₂, etc.) can be substituted for either or both of the polymer layers to provide a wider range of possible nanoparticle/polymer combinations, and resulting in thin film properties. Figure 5 shows the AFM images of gold only and ESA coating (100 nm in thick) surfaces [7].

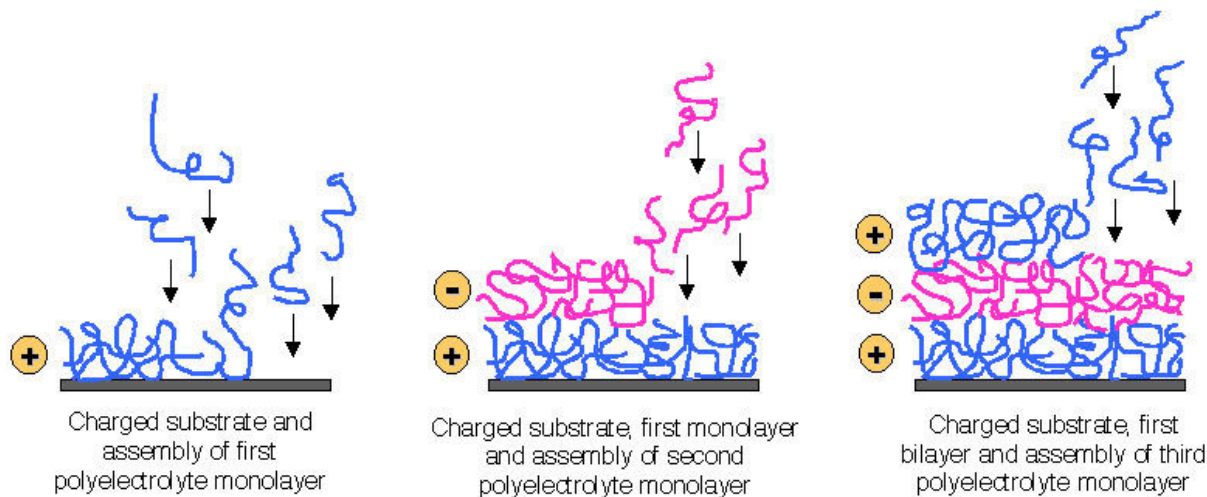


Figure 4: Schematic views of positively and negatively charged polymeric bilayers fabrications on negatively charged substrates.

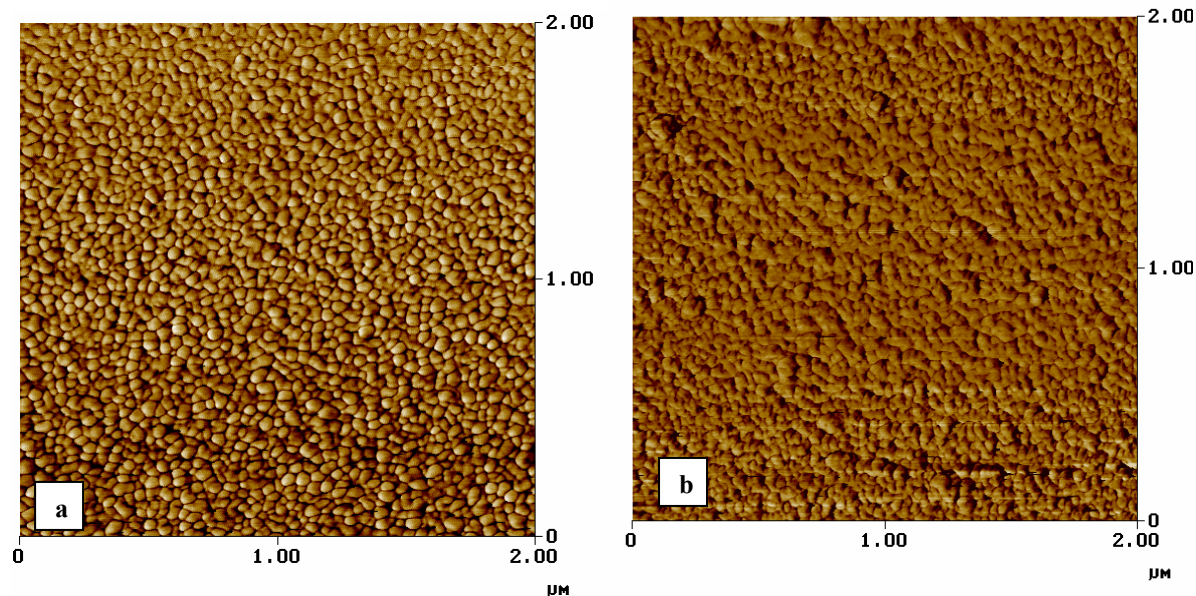


Figure 5: AFM images of a) gold only and b) ESA coated (100 nm) gold surfaces. The surface morphology of ESA coating completely differs from the goal surface.

2.4 Nanocomposite Sphere Fabrications

Several targeted treatment systems including magnetic field, electric field, ultrasound, temperature, UV light and mechanical force are being used in many diseases treatments (e.g. cancer, nerve damage, heart and artery, diabetic, eye and other medical treatments) [1–3]. Among them, the magnetic targeted drug delivery system is one of the most attractive strategies of delivering colloidal magnetic nanoparticles to the area of interest. This is because the targeted systems improve the therapeutic index of drug molecules by minimizing the toxic side effects on healthy cells and tissues [1-3,8,9].

In our previous tests, first 0.85 g stabilized magnetite nanoparticles was dispersed in 10mL of dichloromethane. Second, 0.5 g phenoxy resin was dispersed in the dichloromethane/magnetite solution to make the organic phase. Finally, 0.5 g of poly(vinyl alcohol) (98% hydrolysis, 13– 3,000 g/molMw) was dispersed in 100mL of nanopure water to make the aqueous phase. The organic phase was tehn injected into the aqueous phase with an 18-gauge needle over a 2 min period while the solution was being homogenized at 13,700 rpm. The solution was homogenized for 5 min whereupon it was poured into a round-bottom flask containing 100mL of a 4% isopropanol/water solution and stirred for 6 h. The resulting solution was centrifuged to isolate the microspheres, which were subsequently dried under vacuum to

obtain magnetic spheres. Figure 6 shows the SEM image of the nanocomposite spheres to be used for drug delivery [8].

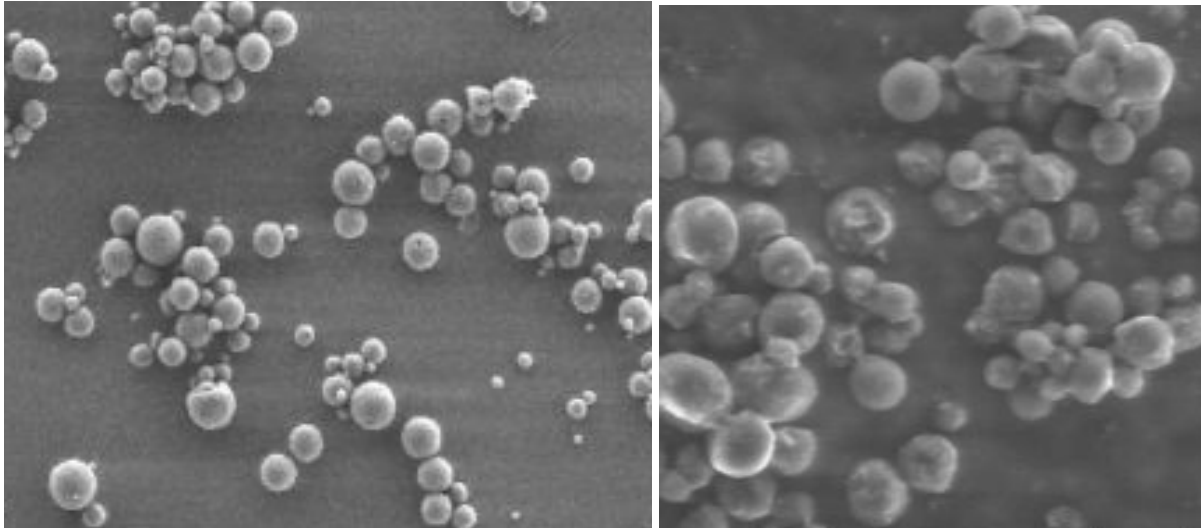


Figure 6: SEM images of the nanocomposite spheres to be used for drug delivery. The diameters are between 200 nm and 1000 nm.

2.5 Microfluidic Device Fabrications

For the microfluidic device fabrication, a spin coater and photolithograph techniques are usually chosen. Spin coating (Figure 7a) is one of the simplest and most common techniques for photoresist coating onto wafers where micro and nanopatterns are created. The process involves simple fluid flow and evaporation behaviors that generally give rather uniform coatings. Hotplate is an enclosed compartment for heating, baking or drying. It is most commonly used in film densification and moisture reduction.

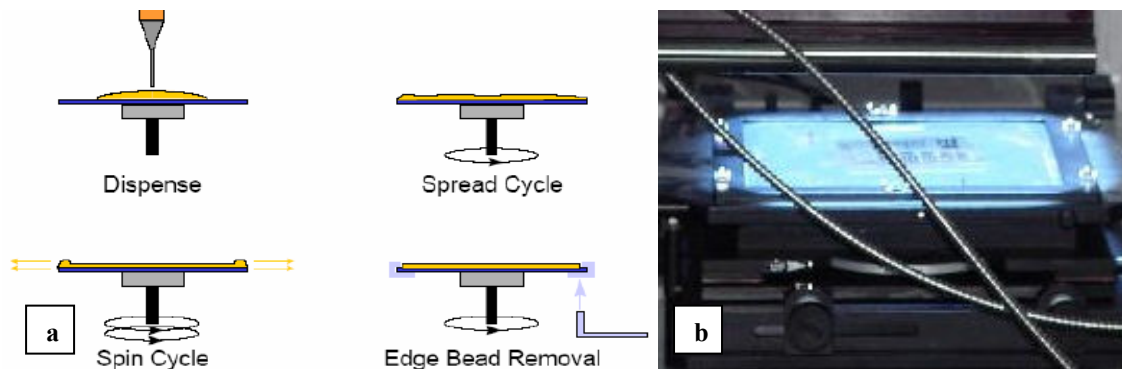


Figure 7: a) A schematic view of forming spin coated films, and b) UV light exposes on the films for patterning.

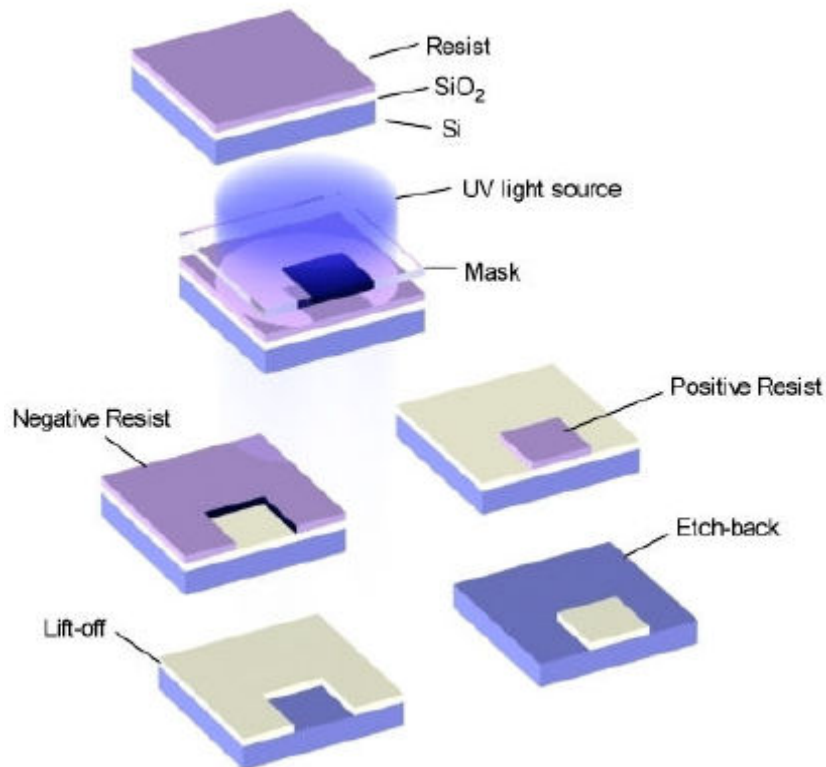


Figure 8: A step-by-step process for microelectronic device fabrications using UV photolithograph technique.

UV photolithography (optical lithography) is a process used in micro and nanodevice fabrications by transferring a pattern from a photomask (also called reticle) to the surface of a substrate (Figure 7b). Often crystalline silicon in the form of a wafer is used as a choice of substrate, although there are several other options including, but not limited to, glass, sapphire, and metal. Photolithography bears a similarity to the conventional lithography used in printing and shares some of the fundamental principles of photographic processes. Figure 8 shows the UV photolithograph technique used for the fabrication of microelectronic devices [3].

3. CONCLUSION

Because of the enormous potential of nanotechnology, nanotechnology education should be integrated into the undergraduate and graduate education at Wichita State University. Students should be given opportunities to work directly with nanotechnology research laboratory to gain hands-on experience. This will improve the knowledge of the students on how to design, analyze and manufacture nanomaterials and devices using various techniques. Therefore,

government agencies and private companies are encouraged to collaborate with the university and discuss further about the enhancing of the nanotechnology education.

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