Providing On-Line Access to State-of-the-art Nanotechnology Instrumentation to STEM Programs

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Abstract

In the current economic environment, it is not feasible to equip each college with the state-of-the-art equipment necessary to teach certain technology intensive disciplines. One example of such a discipline is the field of nanotechnology, which encompasses: semiconductor fabrication; medical, pharmaceutical and biological applications; and material science amongst many others. The financial barrier of building a laboratory for this discipline is prohibitive for most institutions. It can range from hundreds of thousands of dollars for a modest teaching lab to several million dollars for a teaching cleanroom. The Electrical Engineering Technology (EET) department at Erie Community College was able to procure the grant funding to build such a laboratory. A Scanning Electron Microscope (SEM) and sputter coater were acquired to begin infusing nanotechnology into the EET curriculum. The next step involved building a semiconductor fabrication course utilizing industry-standard equipment for top-down fabrication of nanoscale devices and the characterization equipment required to measure them. Both steps were funded though Carl Perkins CATEA grants. The final step involves building a state-of-the-art teaching cleanroom at ECC, funded via a NY-SUNY 2020 grant. The cleanroom is expected to be operational by Fall 2016, and both Genesee CC and Jamestown CC are planning to send their students to take one semester of nanotechnology courses at ECC as part of a jointly offered Nanotechnology degree program. The field of nanotechnology is intrinsically multidisciplinary, therefore, the equipment used in nanotechnology can be used for various applications in STEM fields. ECC is a part of Penn State University's effort to provide remote access to nanotechnology equipment through their NACK center. We currently offer remote access to our SEM for any colleges and/or schools interested. We utilize free software for on-line connectivity, and faculty can run an SEM demo in their classrooms after only one practice session.

Educational Needs for Nanotechnology in WNY

According to National Science Foundation (NSF) estimates the demand for the nanotechnology skilled workers in the U.S. will reach one million workers in 2015[1] and two million workers by 2020[2]. By 2020, estimated U.S. market value of products using nanotechnology will be $1 trillion[1]. This indicates there are very favorable projections for the fields of nanotechnology and semiconductor fabrication in the U.S., and it is currently making a huge impact on New York State as well. The College of Nanoscale Science and Engineering has turned the Albany area into a nanotechnology and semiconductor hub[3] that has led to billions of dollars in private investments. The project has been so successful that Governor Cuomo is using it as a model for economic development throughout NY.

On November 21st, 2013, Governor Cuomo in conjunction with the Western NY regional office of the Empire State Development Corporation and the Western New York Regional Economic Development Council, announced the Riverbend project in Buffalo, part of the Buffalo Billion

Investment Development Plan. This project will construct a $750 Million state-of-the-art research and development center for clean energy. The two original anchor tenants, Soraa, a LED lighting manufacturer, and Silevo, a photovoltaic manufacturer, are both semiconductor companies. Later in 2014, Silevo was purchased by Solar City Inc. that is also committed to manufacturing of solar panels in the Buffalo area. Current projections are for 280 technician jobs at this facility in the next 5 years. On October 24th, this same constellation of state and local development forces announced bids were sought for a nanotechnology research center on the Buffalo Niagara Medical Campus. Current projections for technicians with a nanotechnology skill set in biotechnology, clinical/medical, and chemistry is another 100 jobs in the next 5 years. Consequently, the region needs a highly educated workforce to supply the process technician and engineering technician jobs to support researchers and operate manufacturing equipment. It is critical to the WNY region to have community college graduates with these advanced skills in order to attract additional companies to the region.

In March, 2013, it was announced that a failed SUNY center of excellence in Canandaigua, NY was being re-purposed as the Smart System Technology and Commercialization Center of Excellence, run by the CNSE. The Center's 120,000-square-foot, state-of-the-art facility includes over 26,000 square feet of certified cleanroom space with 150mm and 200mm MEMs foundry services, complemented by a dedicated 8,000-square-foot MEMs and optoelectronics packaging facility. This facility has already started hiring technicians and they estimate a total number of 30-50 technician positions within a 3-5 year time frame.

In July of 2013, CNSE revealed plans to set up shop in a former Eastman Kodak Co. building in Greece, NY as part of a $100 million initiative to attract solar energy companies to the area. It has been reported that over $19 million in tools and equipment were getting relocated to the site. The U.S. Department of Energy was providing nearly $11 million in cash funding to support procurement and installation of tools and equipment. Investment from private industry partners was expected to exceed $65 million to support the development and operation of the facility. New York State will invest $4.8 million through NYSERDA.

WNY STAMP (Science and Technology Advanced Manufacturing Park) is poised to establish its research and manufacturing facilities on a 1,250 acre site in Genesee County, approximately 45 minutes from the Pembroke exit of the NYS Thruway. Dr. Michael Jackson of the Rochester Institute of Technology has projected that a 450 Mega-Fab will likely employ a total of 2,500 workers with the majority of approximately 2000 having BA degrees or under. It will be essential for the local community colleges to make a coordinated effort to educate and train students to fill these positions as soon as possible. STAMP is close to signing the first company for this park, a photovoltaic cell manufacturer.

In 2013, the only three community college programs in nanotechnology or semiconductor fabrication in New York were located at Hudson Valley CC, Mohawk Valley CC and Schenectady CC, and supported the existing companies in the Albany area. The semiconductor companies are still importing more than 50% of their employees from out of state. With the number of new projects underway throughout the state, there is a serious shortage of workers to fill the expected number of jobs. In order to fulfill the high tech and advanced manufacturing vision for WNY and NY as a whole, it was and is imperative that new college programs are

created to fill this need. The cost barrier to enter these fields is quite high, so additional state or grant funding is essential and urgently required to jumpstart this effort.

Typical Cost of the Semiconductor or Nanotechnology Teaching Laboratory

The cost of building a laboratory space for nanotechnology or semiconductor fabrication can be prohibitively expensive for most high schools, and two-year and four-year colleges. On the lower end of the spectrum, $400-$500K could buy basic fabrication and characterization equipment suitable for demonstrating nanotechnology processes in a teaching environment. Such a laboratory would include teaching-grade equipment such as a wet bench with fume hood, sputter coater/thermal evaporator, spin coater, hot plates, profilometer, optical Bright Field/Dark Field microscope, simple Atomic Force Microscope (AFM) and/or SEM, vacuum system trainer, and a basic manual Reactive Ion Etch (RIE) tool. Optional extended equipment would include an ellipsometer, semiconductor analyzer, tube furnace, plasma asher, RIE tool with more gas options, and a mask aligner, to name a few. The cost of a higher quality teaching cleanroom with the above mentioned equipment would run in the range of several million dollars. On the higher end of the spectrum, a state-of-the-art research-level nanotechnology lab with cleanroom could cost tens of millions of dollars. Only major research universities or research centers are able to fund such facilities, with additional funding from grants. For most non-research oriented institutions, such as high schools, community colleges, and four-year teaching colleges, the cost of even a modest teaching cleanroom is completely out of reach without some sort of external funding. For example, the average technology department's equipment/supply budget can range from $5,000 to $20,000 per year, which is not sufficient to cover the cost of even a single equipment unit for the nanotechnology lab.

Building Partnerships in Nanotechnology

Erie Community College has been working towards offering an AAS degree program in Nanotechnology for the past three years. Faculty in the Electrical Engineering Technology (EET) department identified the field of nanotechnology as a promising potential area for economic development in Western New York. The gradual start took place during the 2013-2014 academic year when the department was awarded a Carl D. Perkins CATEA grant to cover the cost of a Scanning Electron Microscope ($140K) and infuse nanotechnology into the EET curriculum. As a part of this effort, several laboratory experiments were developed and included into various courses such as electronics, electrical circuits, and photovoltaic systems. ECC collaborated with the University at Buffalo on the development of experiments and a sample base for the SEM to support the experiments.

The next step was the development of an AAS degree program in Nanotechnology. Faculty in the Electrical Engineering Technology program have been undergoing training and identifying laboratory equipment needs over the last several years. While the original goal was to develop a semiconductor fabrication program, it soon became obvious that the same skill set was applicable to a much broader nanotechnology field than just electronics. Our faculty have been working with Engineering faculty at the University at Buffalo (UB) for several years, and have collaborated on grants. The mentoring and advice provided by the university faculty have been invaluable to the process, and that partnership will continue.

In late 2013, ECC administration met with administrators from Genesee Community College (GCC) to discuss issuing a joint program announcement for an AAS degree in Nanotechnology. A SUNY Form 1A New Program Announcement was jointly issued in January 2014 by the two colleges. GCC intends to send their students to ECC for the nanotechnology laboratories, as ECC is much farther along in building a laboratory. Jamestown Community College (JCC) joined the effort later in 2014.

ECC's EET faculty have been attending workshops offered by Pennsylvania State University in nanotechnology. Penn State is the National Science Foundation-funded Advanced Technological Education national center of excellence in Nanotechnology. The Penn State entity, known as the Nanotechnology Applications and Career Knowledge (NACK) Center[2], receives federal funding to train community college faculty in nanotechnology, as well as foster University – Community College partnerships to offer nanotechnology programs. Penn State has been offering an 18 credit hour capstone semester in nanotechnology to Pennsylvania community and private two-year colleges (at the community college tuition rate) for 15 years, as part of the Pennsylvania Nanofabrication Manufacturing Technology (NMT) partnership. Students complete their first 3 semesters at their local college, then complete the capstone semester at the Penn State - University Park campus. The 6 courses used in the capstone semester are freely available, including curriculum, power point and video presentations of all lectures, and laboratory experiments[2]. They also offer remote-access to their instrumentation for laboratory experiments while colleges acquire equipment and build their own labs[4]. The graduates from the NMT program are working in various nanotechnology industries across the country, and their program is widely recognized as producing excellent process technicians. This seemed to be an excellent program on which to base our own.

The programs at ECC and GCC use much of the PA coursework, modified as necessary to meet the needs of local industry, with help from the University at Buffalo and the Colleges of Nanscale Science and Engineering at the SUNY Polytechnic Institute. Students will benefit from the expertise offered by three preeminent research universities, as well as the varied professional work experience of ECC faculty. Students will have an opportunity to interact with faculty from Penn State and other community colleges and universities as they access tools remotely, and gain the same experiences on state of the art instruments that university students use. ECC has been awarded over $6 Million in grant funding to construct a state of the art nanofabrication laboratory. This funding is about equally split between construction and equipment funding. Our facility will be completed by the Fall 2016 semester. Once the facility is up and running, students will still access tools remotely that we cannot afford, even with the large amount of grant funding to date.

Offering Remote Access to Nanotechnology Instruments

ECC is working with regional BOCES centers and several local high schools to develop a pipeline of students into the Nanotechnology program. These high school students will be able to remotely access ECC instruments to enrich their coursework. Currently the SEM is available for the remote access sessions, free of charge. Interested parties need to contact the EET department to arrange remote access sessions: first a practice session to get high school teachers

familiarized with the equipment; and a second session to let high school students control the instrument remotely and examine samples of interest. The high school teacher can either send us their own samples or use samples previously acquired by ECC.

ECC's Scanning Electron Microscope is available for use by other community colleges nationwide as part of Penn State's Remote Access Instrumentation Network (RAIN)[4]. This collaboration will allow ECC to promote its program in collaboration with GCC and other SUNY partners on a national scale. This will allow ECC to be a regional resource in WNY to attract out-of-state students into the field of nanotechnology as well. As we acquire new nanotechnology instrumentation, we are planning to make several of these instruments web enabled for remote access as well.

There are 6 schools participating in the RAIN network at this time, with more in the planning stages as additional programs are created nationwide. Those colleges are: ECC; Northcentral Technical College (WI); North Seattle College (WA); Pasadena City College (CA); Penn State University; and Salt Lake Community College (UT). A selection of tools are available via the RAIN network including:

- Two different Scanning Probe/Atomic Force Microscopes,
- Two different Scanning Electron Microscopes with Energy Dispersive Spectroscopy (EDS) units,
- A Field Emission Scanning Electron Microscope with EDS,
- A Confocal Microscope,
- Two Surface Profilers,
- An Optical Microscope with both brightfield and darkfield capability, and
- A UV-Vis Spectrophotometer.

The instruments are all characterization tools, it is not practical at the moment to attempt remote fabrication. A network of colleges offering instrumentation is very important, as it will allow institutions throughout the country to begin offering introductory nanotechnology courses with a hands-on component. It also allows schools to acquire fabrication instruments as they build a program while using characterization tools remotely. This reduces the up-front cost of building a laboratory.

We currently offer our Scanning Electron Microscope, a Jeol JSM-6010LA for remote access sessions. Some of the specifications for this instrument are given below:

- resolution 4.0 nm (at 20kV), resolution in low vacuum mode 5.0 nm,
- magnification 8X to 300,000X,
- accelerating voltage 500V to 20kV,
- touch-screen computer control,
- dual live image, split live image, flexible live image and signal mixing is available,
- built-in movies and capture of live video,
- on-screen measurements,
- secondary electron detector and backscattered electron detector,
- X=80mm, Y=40mm, Z=5 to 48mm specimen chamber with motorized X and Y stage,
- X-ray analysis detector for detecting materials composition,
- rough and turbomolecular pumps,
- infrared chamberscope to view samples in the chamber.

Figure 1 shows the Jeol JSM-6010LA SEM that is currently used for classroom instruction, as well as for remote session instruction. Figure 2 gives an overview of different samples used for in-class and for remote instruction and hands-on sessions.

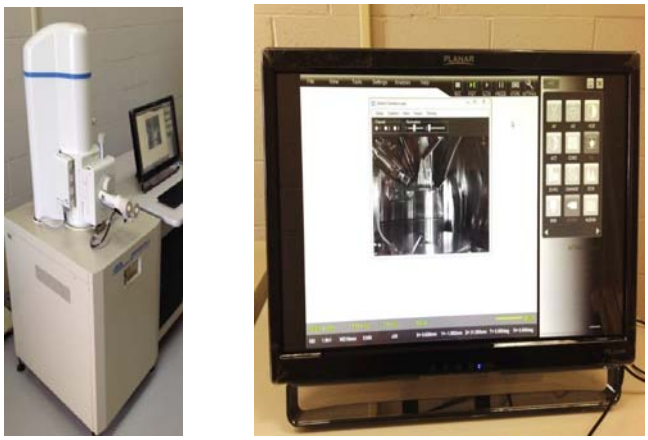

Figure 1. Jeol JSM-6010LA Scanning Electron Microscope

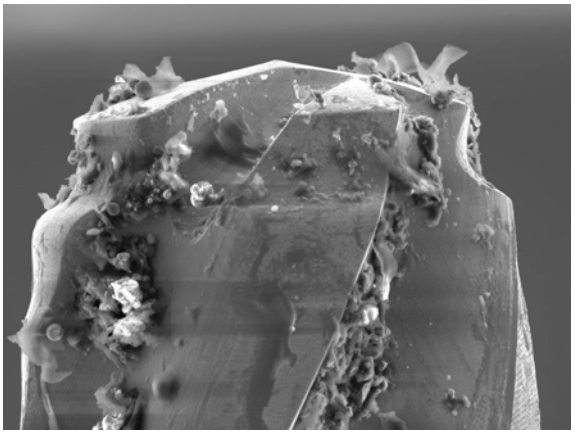

Figure 2a. End Mill, magnification 330X

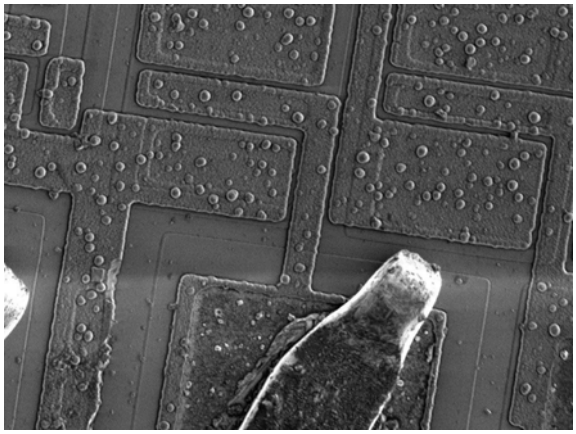

Figure 2b. Old IC, magnification 300X

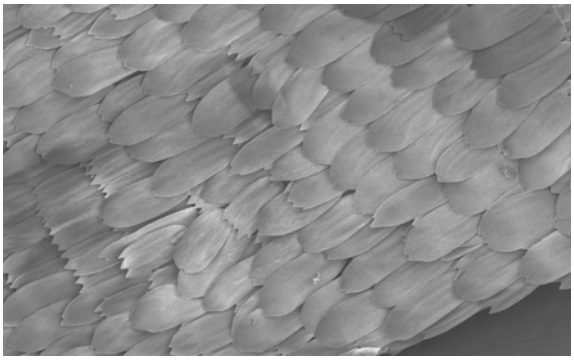

Figure 2c. Blue morpho butterfly wing, magnification 120X

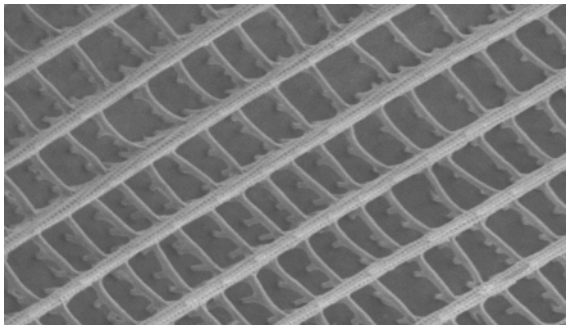

Figure 2d. Blue morpho butterfly wing, magnification 8,500X

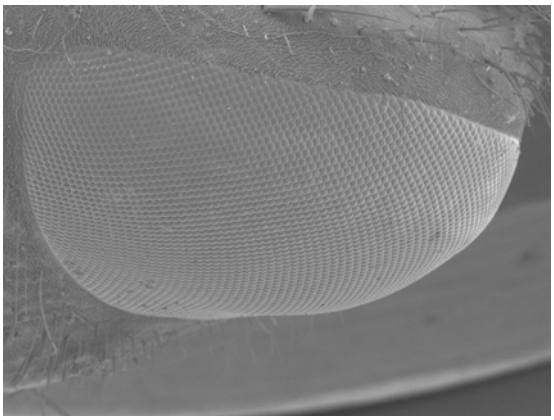

Figure 2e. Fly eye, magnification 100X

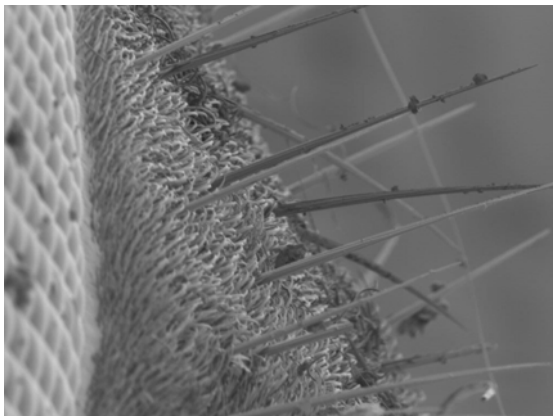

Figure 2f. Fly – near eye, mag. 650X

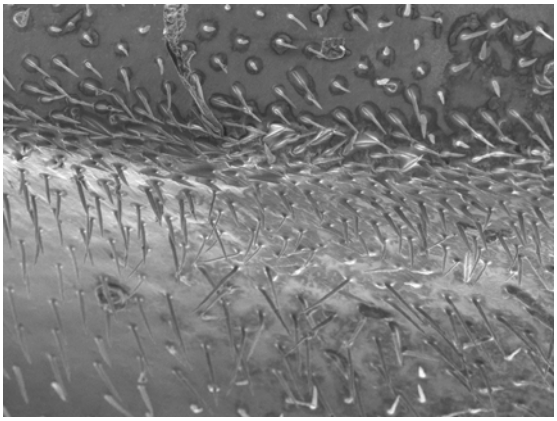

Figure 2g. Bee wing, magnification 250X

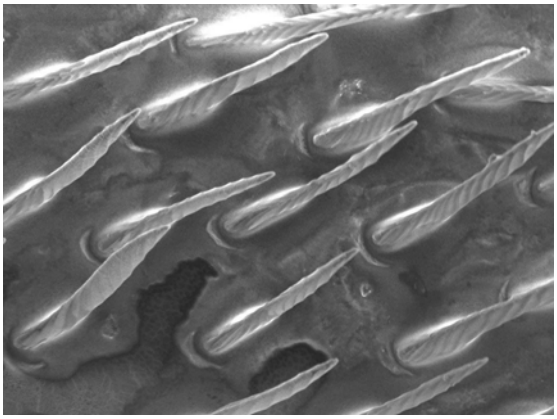

Figure 2h. Bee wing, magnification 1,900X

For example, Figure 2a shows debris on a high precision end mill after only a couple of uses. Figure 2b shows deterioration of the surface of an integrated circuit with time. A blue morpho butterfly wing is depicted in Figure 2c and 2d. The periodic structure in Figure 2d has dimensions of 400-500nm and is responsible for the shimmering blue hue coloring of the wing. Figures 2f, 2g and 2h show microscopic hair on the surface of a fly's skin and bee's wing that are responsible for keeping each surface dry when exposed to water.

Remote sessions with the Scanning Electron Microscope can be utilized for various STEM courses such as biology, chemistry, physics, and technology courses. They are also extremely useful for workshops or themed camps. In the past, the department used remote SEM sessions for girl scouts camps and a career day at a middle school; both generated a lot of interest amongst middle and high school students.

To conduct a successful remote SEM session, you will need the following:

- computer with administrator access to install plug-ins and software,
- high speed Internet connection (preferably wired connection to reduce latency issues),
- speakers, microphone, and (optional) projector connected to the same computer,
- web browser (Mozilla Firefox is preferred),
- Zoom video conferencing from www.zoom.us/signup (signing up is free).

The protocol for the remote SEM session currently includes the following steps[4]:

- Step 1: give homework assignment to students to watch videos on the introduction to remote access, to background/operation of various characterization tools, and on the detailed instructions on remotely controlling specific tools;
- Step 2: complete the remote access request form to request a remote test session and a live session, to select an instrument and topic areas to focus on, and provide lab instructor with information on students' knowledge level;
- Step 3: run a remote test session to check your audio, video, and Internet connections, and to practice instrument control via video conferencing platform. You will need to download Zoom video conferencing software (free) from 222.zoom.us/signup;
- Step 4: choose in-house samples or send your own samples to the address provided on the www.nano4me.org site or directly to ECC (for ECC's SEM instrument):
  Erie Community College – North Campus
  Electrical Engineering Technology Department, Attn: Remote Manager
  6205 Main Street, Williamsville, NY 14221
- Step 5: run a live remote session with students (15 min to 2 hours);
- Step 6: complete instructor survey and student survey to provide the feedback on the remote access session.

The remote session requires free installation of Zoom software at the remote site for videoconferencing and remote access to the instrument computer. The Zoom host software is run at the instrument site at a cost of $99 per year. Zoom software unifies cloud video conferencing, simple online meetings, and group messaging into one easy-to-use platform. The host site initiates a meeting and send a unique code to the users so only they can join the conference. At the remote site, it can be one on run computer or in an entire computer laboratory giving instrument access to each system. The faculty member can allow individuals to run the instrument from their individual lab computer. The faculty member, if using a smart classroom, can also project the video to a larger screen. The software allows the remote user to control the instrument using a remote desktop. They see everything on their screen that the technician sees on the screen at the host site. There is also a video conferencing window so the people at the remote site can interact directly with the technician at the host site. If the student or faculty member at the remote site gets "lost" trying to image a sample, the technician can always bring the image back into focus at the instrument or coach the remote user. Latency can be an issue when the remote site is connected via wireless, especially if remote session is run on several computers. The system seems to run better when the remote end is in a laboratory or lecture hall with a hardwired internet connection. In addition to several local remote sessions in Western New York, we successfully ran a remote session at the 2014 Micro Nano Technology conference in Albuquerque, New Mexico.

Conclusion

The economic projections for a skilled workforce in nanotechnology and semiconductor fabrication are very favorable. It is imperative to start building a pipeline of students to prepare them for various careers in this field: starting with process or equipment technicians for semiconductor or medical manufacturers that require only a 2-year degree; engineers working on product development (requiring a 4-year engineering degree); and ending with research scientists

(requiring Masters or PhD degrees). Exposing middle and high schools students, as well as students in 2-year and 4-year colleges, to state-of-the-art nanotechnology equipment can spark their interest to continue their education in this field or to apply nanoscale science in other fields such as biology, chemistry, and physics. ECC is planning to make nanotechnology instruments available to schools and colleges in WNY directly and nation-wide through the Penn State's national RAIN network. Currently, our Scanning Electron Microscope is available for the remote access to student from any such institutions.

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