Vacuum Equipment for Education

Steve Hansen

This article appeared in Vacuum Coating & Technology, March 2010

Introduction

Vacuum-related educational equipment has been around since the advent of the first hand-powered piston vacuum pump. The earliest systems incorporated, in addition to the pump, a pressure gauge (usually a mercury manometer) and a glass bell jar that could be sealed to a cast iron baseplate with beeswax. (See **Figure 1**.) Such simple pump-gauge-belljar systems have been available continuously from science equipment suppliers with the major changes being in the details of the equipment. The standard set up is now a motor-driven rotary vane pump with mechanical (Bourdon) or electronic (Pirani or thermistor) gauges, and the bell jars are frequently made of plastic with synthetic rubber gaskets.

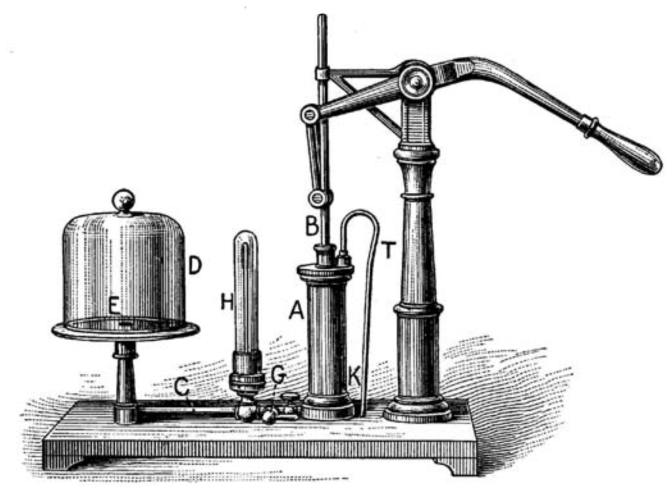

Figure 1. Antique classroom vacuum system ca. 1900.

One of the problems with this type of apparatus has been what to do with it in the classroom. Most of the time these pumping systems are only supplied with rudimentary instructions and it is then left to the instructor to craft some exercises and demonstrations. Too frequently this goes no further than classic demonstrations such as expanding marshmallows or reducing the sound emanating from a buzzer.

The situation changes when the equipment is coupled with a complement of exercises and additional pieces of hardware. In some cases an entire vacuum curriculum can be constructed around an educational tool. In this article we will look at some more recent vacuum educational tools that include a substantial amount of supporting documentation. We will also look at the programs where these systems are being used.

Two Educational Systems from Edwards High Vacuum

In the period from the late 1950s to early 1980s, Edwards High Vacuum produced a couple of items that had many characteristics of the educational vacuum products that were to follow.

The first was a 1960s era kit based on their 1-inch diffusion pump. It was aimed at undergraduate level instruction. Nigel Harris [1] has provided the following description:

> The kit was a collection of items nicely laid out in molded polystyrene in a nice large oak box. It contained much glassware, a small diffusion pump (1-inch), base plate, valve, bell jar etc.
>
> It came with a softback book of examples of experiments that could be carried out with the kit, giving a diagram of the experiment arrangement, method & results expected. Some examples included Magdeberg hemispheres, Crookes radiometer, glow discharge tube, U-tube manometer, evaporative coating fixturing, falling feather and stone, ringing bell in a bell jar, variation of temperature of a hot filament in vacuum, expansion of a balloon in vacuum, weight of air, etc.

The second item was a high vacuum system targeted to universities and technical schools in developing countries. This system was based on an integrated pumping station with a rotary vane backing pump, 63mm diffusion pump, gate valve and cooled baffle.

The pumping station included a host of standard and customized accessories and a manual detailing 20 experiments related to vacuum, vacuum measurement and vacuum processes. The scope of the system's capabilities and exercises included:

- Basic pump and system operation
- Pumping speed, base pressure, conductance effects
- Pressure measurement using different types of gauge (U-tube manometer, dial, McLeod, Pirani and hot & cold cathode ion)
- Gauge calibration procedures
- Residual gas analysis using a quadrupole analyzer
- Outgassing characteristics of various materials; bake out
- Leak detection
- Thin film deposition and basic metrology
- Freeze drying
- Electron microscopy specimen preparation
- Optical and electronic thin films

The primary commercial incentive for this product was a large order from University Technologi Malaysia that took receipt of 11 of these training packages in 1979. The system and the associated curriculum are described in [2].

The AVS Secondary School Program

The AVS (American Vacuum Society) has done an excellent job at providing instruction in low-pressure experiments and modeling to middle and high school physics teachers from across the USA and Canada through their Science Educators Workshops (SEW) and equipment grants. These workshops are conducted at the annual national symposia over the course of two days.

The workshops were started in 1990 and each one hosts about 20 teachers. Attendees are sponsored by regional chapters of the Society with all expenses paid by the sponsoring chapter. The workshop is accredited for CEUs and is aligned with the national science and mathematics standards.

The workshop is divided into two parts: (1) lectures on the underlying science and the mathematical calculations and (2) hands-on experience in which a group of teachers perform experiments and develop models under the guidance of a volunteer instructor team.

Participants in the annual workshops receive a certificate of completion, 1.4 CEUs and a grant to each teacher's school for a basic vacuum system consisting of an integrated pump, belljar and mechanical gauge. Over the years a number of improvements have been made to the systems: the older belt driven, single stage pumps have given way to direct-drive 2-stage pumps and the base plates now have provisions for feedthroughs. This has enabled the systems to better handle experiments involving temperature measurements and large gas loads – a prime example being the triple point of water experiment.

The experiments and methodology are detailed in the AVS Education Committee's document *Low Pressure Experiments & Modeling for High School Science Curricula* [3]. **Figure 2** shows an experiment being conducted at one of the SEW Workshops. More information on the AVS workshops may be found at [4].

Figure 2. Teachers at the AVS Science Educators Workshop view structural changes to a marshmallow that is being exposed to vacuum. *Photo courtesy of James Solomon.*

The "Modern Era" of Industrial Vacuum Technology Training & Equipment (1995 to Present)

SEMATECH and MATEC

In the early 1990s the rapidly expanding semiconductor industry was facing an increasing shortage of trained technicians to work in IC fabrication facilities.

In 1993 SEMATECH's Technician Training Curriculum Task Force began a project to establish standards for education and training and in 1995 the group completed a report outlining the structure and content of a two-year associate degree program. In 1997 the Curriculum Task Force transferred its responsibilities to the Maricopa Advanced Technology Education Center (MATEC) in Mesa, AZ.

Vacuum was identified as a key curriculum component along with elements in process technology, quality, safety and RF energy systems. With regard to the vacuum technology section, topics that were defined included fundamentals (terminology, gas laws, conductance, etc.), gas transfer and entrapment pumps, gauges, mass flow controllers, leak detection and other troubleshooting methods. MATEC's curriculum materials and exercises are available to institutions that have advanced manufacturing curricula [5].

Portland Community College and Varian Vacuum Products

Another curriculum developer was David Hata, an instructor at Portland (OR) Community College (PCC). As part of a NSF grant, he formed a collaboration with Varian Vacuum Products to introduce an up-to-date vacuum trainer. This system, known simply as the Varian Vacuum Trainer is shown in **Figure 3**. It was based on a standard pumping station with a turbomolecular/drag high vacuum pump and a diaphragm backing pump. Additional standard components included a glass bell jar chamber, a variety of vacuum gauges, a roughing line and manual valves for simple pressure control.

Figure 3. Varian Vacuum Trainer ca. 1995. *Photo courtesy of David Hata.*

As with the Edwards and AVS teaching systems, a standard set of student laboratory exercises were developed as part of the project. Exercises included basic system operation, pumping speed determination and time constants, vacuum gauge principles, outgassing effects on system performance, etc. A number of modifications were incorporated into the systems including a quadrupole gas analyzer and the addition of parallel plate electrodes for use with small RF generators and matching networks. As we will see later in this article, RF and plasma have become an increasingly important part of advanced manufacturing focused curricula.

In addition, Hata has captured much of his project in his recent *book Introduction to Vacuum Technology* [6]. This book is targeted specifically to process technicians and instructors of technician level courses involving vacuum.

MKS Instruments' VTS-1B

MKS Instruments jumped into the vacuum training equipment arena in 1997 with their VTS-1B vacuum training system, a product that remains in production. The base unit includes a mechanical vacuum pump although high vacuum capabilities may be added.

The VTS-1B incorporates some unique features:
- It is supplied as a kit which required the class and instructor to assemble and test the unit as part of the classwork
- It includes control and graphical display software
- It includes a PID pressure controller and throttle valve as well as a mass flow controller.
- An included manual details the assembly and use of the device along with about 2 dozen exercises.
- Standard accessories included a turbo-pumped high vacuum section with an RGA and sampling manifold.

Further information on the VTS-1B and details on its capabilities may be found at [7] and [8]. **Figure 4** shows a VTS-1B in use at a workshop in Florida.

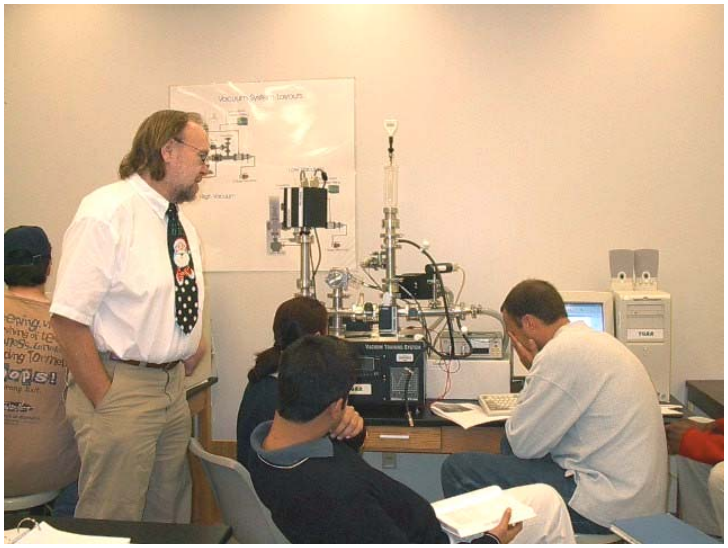

Figure 4. Dr. Richard Gilbert overseeing a workshop at Hillsborough Community College, Tampa, FL. The VTS-1B is equipped with an RGA. *Photo courtesy of Dr. Marilyn Barger.*

The Science Source's VPAL-A

A newcomer to the scene is the "Vacuum Principles and Applications Lab" (model VPAL-A) from The Science Source [9] of Waldoboro, ME. This expandable, relatively low cost teaching system is also intended for technical college and undergraduate level use. The VPAL-A comes with a manifold with inlet leak & isolation valves, Bourdon & wide-range Pirani gauges, plastic chamber with electrical feedthroughs, glass chamber for low pressure exercises, 6 cfm mechanical pump and full documentation. Optional accessory kits currently include data logging hardware & software for data capture, a 50 sccm mass flow controller and a package of equipment for plasma, dc sputtering and thermal evaporation exercises.

Exercises that may be performed with the VPAL-A include vacuum system baseline characterization, pumpdown time constant, absolute and atmosphere pressure references, characteristics of direct and indirect vacuum gauges, mass flow measurement & control, pressure control principles, real and virtual leaks, permeation, outgassing, evaporative cooling, mean free path, the glow discharge and sputter deposition of metals. The basic system is shown in **Figure 5**.

Figure 5. Basic VPAL-A vacuum trainer from The Science Source. *Photo courtesy of The Science Source.*

The VPAL-A is in active development and new features are being added on a regular basis.

RF and Plasma Equipment

As noted earlier, RF and plasma topics were defined as key elements in the advanced manufacturing technology curriculum. Elements included the fundamentals of plasma processing systems, RF generators, transmission line theory and impedance matching, power measurement & control, safety and troubleshooting.

Initially, a number of attempts were made to couple small 100-300 watt generators to electrodes mounted within the chambers supplied with the Varian and MKS trainers. This had some level of success but the implementations tended to be very limited in their capabilities.

As part of another NSF project, David Hata received funding for a standardized RF/Plasma training curriculum and platform. This resulted in a product produced jointly by MKS and Manitou Systems of Danbury, CT. This was called the Plasma Process Training System (MKS model PPTS-1A). Manitou supplied a 300 watt 13.56 MHz generator with manual match along with a 6 inch chamber and 4-inch magnetron cathode, and MKS completed the package with pressure measurement and control products, 1 or 2 MFCs (the latter for reactive sputtering) and the pumping system. MKS also provided documentation and installation support. .

Portland Community College placed 6 of these systems into their program in 2003 and a number of these trainers have been supplied to other colleges in the US and Singapore.

Vacuum and RF/Plasma Technology Programs Today

A review of vacuum training equipment and programs was published in this magazine in 2001 [10]. This predated the availability of the dedicated plasma trainers and the VPAL-A product. This section covers several interesting new programs.

Over the past decade the microelectronics manufacturing technology programs have expanded to cover other technologies that make use of vacuum and thin film processing.

PCC and Normandale Community College Programs

The Portland Community College's Microelectronics Technology program is seeing strong enrollment due to a growing local focus on photovoltaic technology. The vacuum and plasma courses are required for the associate of applied science degree. PCC's vacuum lab relies mainly on six Varian vacuum trainers and the plasma lab includes six MKS PPTS trainers. Auxiliary equipment includes MFJ-259B SWR analyzers, Manitou L-type manual matching units and Ocean Optics USB-2000/4000 Fiberoptic Spectrometers.

Another college that has a long established program is Normandale Community College in Minneapolis, MN. Here Hata's materials have been extended through NSF programs with Normandale's James Dockendorf. His current NSF grant has adapted the PCC materials for use in their nanotechnology program. Plasma training has also been added to their suite of laboratory capabilities. The plasma training materials and lab equipment have also been used to support faculty development workshops in basic plasma technology and advanced workshops in RF Measurements and on plasma measurements and characterization using Langmuir probes.

MVCC and NaMCATE

Robert Decker, Professor of Engineering Technologies at Mohawk Valley Community College (Utica, NY) is participating in curriculum development for nanoscale manufacturing under a collaborative NSF project known as NaMCATE (Nanoscale Manufacturing Curriculum for Advanced Technological Education). The project, under direction of Dr. David Shaw of the University of Buffalo, is developing benchmarks for nanomanufacturing education including eleven curriculum modules for community college levels. The collaboration includes two community colleges in New York, a local high school, and university faculty from SUNY at Buffalo.

Decker has a VPAL-A at MVCC with one at each of the partner schools including the high school where some of the vacuum activities are being integrated into a technology classroom. He is currently engaged in developing plasma deposition and etch capabilities using the VPAL-A trainers, along with simple lithography tools.

Figure 6 shows a VPAL-A training system with a hot wire evaporation chamber.

Figure 6. VPAL-A configured for metal evaporation. *Photo courtesy of Robert Decker.*

Hudson Valley Community College and TEC-SMART

HVCC, located in Troy, NY, began it's Semiconductor Manufacturing Technology program in 2006 as part of an effort with the Albany NanoTech to develop a nanotechnology research and manufacturing hub in the region [11].

Professor Fred Strnisa has guided the vacuum and thin film program since its inception. He began with an equipment base containing 3 MKS vacuum trainers and he has since expanded it with several VPAL-A trainers.

As a cooperative program with the New York State Energy Research & Development Authority (NYSERDA) there is a new training and education center for Semiconductor Manufacturing and Alternative & Renewable Technologies (TEC-SMART). Located in Malta, NY, programs at this center also will support local industries including the Global Foundries fab.

The vacuum trainers are going to remain at the Troy campus. Students will gain further skills with actual PVD process equipment at the Malta facility.

Other Programs

Another new program in the US is the one at Schenectady County (NY) Community College which has a new Nanoscale Materials Technology program. This program involves a cooperative arrangement with Superpower, Inc. and the labs include several MKS vacuum and plasma training systems.

As noted in [10], Singapore has a significant infrastructure of vacuum and plasma technology courses at the various polytechnics. More recently a substantial program has been established at Republic Polytechnic. Commissioned in 2008, their equipment base includes 10 training systems, evenly divided between vacuum and RF trainers. **Figure 7** shows part of the RF/Plasma laboratory.

Figure 7. Equipment in Republic Polytechnic’s RF/Plasma laboratory.

Summary

Formal training in vacuum equipment and processes has become increasingly important as industry is increasing using vacuum technology in their manufacturing lines. There has been a thread of consistency in the types of training equipment that have been offered over the past century and proper documentation has been a necessary adjunct to the hardware. Over the past decade, vacuum training equipment has been supplemented with school lab level equipment for the teaching of plasma processing and deposition. Although this remains a niche market, we are fortunate that a number of companies and institutions have supported this important market, both in terms of equipment and curriculum development.

Acknowledgements

The author wishes to thank Nigel Harris, David Hata, Robert Decker, Fred Strnisa and James Solomon for their valuable input to this article.

References

[1] Nigel Harris, private communication
[2] N S Harris, *A laboratory package for training in vacuum technology*, J. Vac. Sci. Technol. 20 (4) April 1982, pp. 1408-1411.
[3] http://www.avs.org/pdf/SEWworkbook.pdf
[4] http://www.avs.org/education.workshop.aspx
[5] http://www.matec.org
[6} David M Hata, *Introduction to Vacuum Technology*, Pearson Prentice Hall, 2008.
[7] http://www.mksinst.com/docs/ur/vactrain.pdf (Brochure for MKS VTS-1B)
[8] http://matec.org/about/Prod/vendors/mks/matec.shtml (Detailed overview of VTS-1B exercises
[9] The Science Source, http://www.thesciencesource.com
[10] Steve Hansen, Vacuum Training for Manufacturing: Why and How, Vac Tech and Coating, October 2001, pp. 22-28.
[11] Joel Stashenko, *HVCC students start specializing in semiconductor manufacturing*, The Business Review (Albany), September 15, 2006, http://www.bizjournals.com/albany/stories/2006/09/18/story2.html?i=55986&b=1158552000^1345242

Update January, 2012: The MKS training hardware (VTS-1B and PPTS-1A) are no longer available.