

## Dragon-type Beamlines

The Taiwan Light Source (TLS) is a third-generation, medium-energy storage ring that provides optimum sources of photons in the VUV to soft X-ray region. Among the twenty-three beamlines at TLS, there are fifteen beamlines equipped with monochromator, and nine of them operate in this spectral region. Except the 1m Seya-Namioka beamline, all the other eight beamline are variations on the Dragon beamline design originally conceived by Dr. C. T. Chen in 1985. These nine beamlines are the LSGM, HSGM, WR-SGM, U5-SGM, HF-CGM, U9-CGM, EPU-SGM, and the world's first Dragon beamline that was transferred back from NSLS, as summarized in Table 1. In this article we will briefly describe the features and performances of each of these dragon-type beamlines, and how they evolved over the years from the original design.

The first three VUV to soft X-ray beamlines developed in NSRRC are the 1m-SNM, LSGM, and HSGM beamlines. They started operation in the same year when TLS was first commissioned and started operation in 1993. The 1m-SNM uses the Seya-Namioka design and delivers photon beams with an average flux of  $1 \times 10^9$  p/(s·0.02% BW·200 mA) and resolving power of 5,000 in energy range from 4 eV to 40 eV. The design of LSGM and HSGM beamlines is based on the concept of the Dragon beamline originally constructed at NSLS. As expected, both beamlines deliver excellent performance and are very easy to operate. The LSGM beamline delivers photon beams with an average flux of  $1.5 \times 10^{10}$  p/(s·0.01%BW·200 mA) and resolving power of 15,000 in energy range from 15 eV to 200 eV. The HSGM beamline delivers photon beams with an average flux of  $1 \times 10^{10}$  p/(s·0.01%BW·200 mA) and resolving power of 10,000 in energy range from 110 eV to 1500 eV. These three beamlines, covering an entire photon spectrum from 4 eV to 1500 eV, are general-purpose beamlines designed for various types of end stations to perform researches in atoms, molecules, surfaces, interfaces, multi-layers, and other

materials.

The world's first Dragon beamline designed by Dr. C. T. Chen, then at the Bell Laboratories, was transferred from NSLS to TLS and re-constructed in 1998, as pictured in Fig. 1. The optical layout is shown in Fig. 2. It features separate horizontal and vertical focusing mirrors which eliminate astigmatic coma aberration, and an exit slit movable to the focal point of each wavelength that eliminates defocus aberration. Combined with proper choices of focusing ratio and minimum number of optical elements, a high flux and high resolution beamline with a simple scanning mechanism is created. After the Dragon beamline set a new record in the resolution of soft X-ray monochromators, its design has been adopted by 19 synchrotron radiation centers worldwide and the spectral range was extended to the VUV range with the construction of the LSGM and HF-CGM beamlines in TLS. This beamline also had a number of improvements

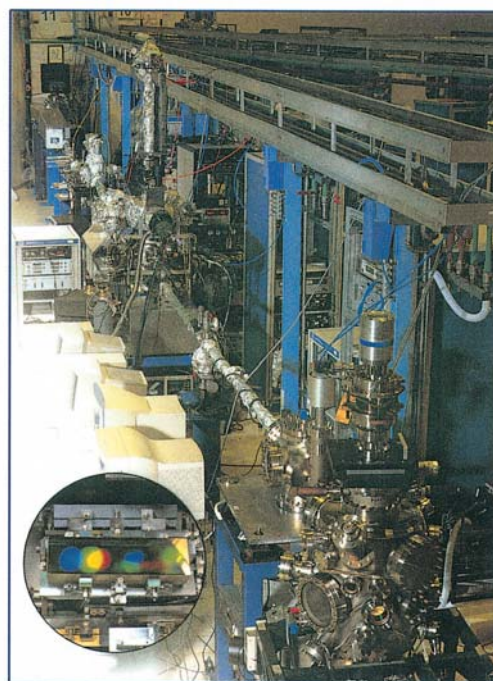


Fig. 1: The Dragon beamline at TLS. This beamline was originally located at NSLS.

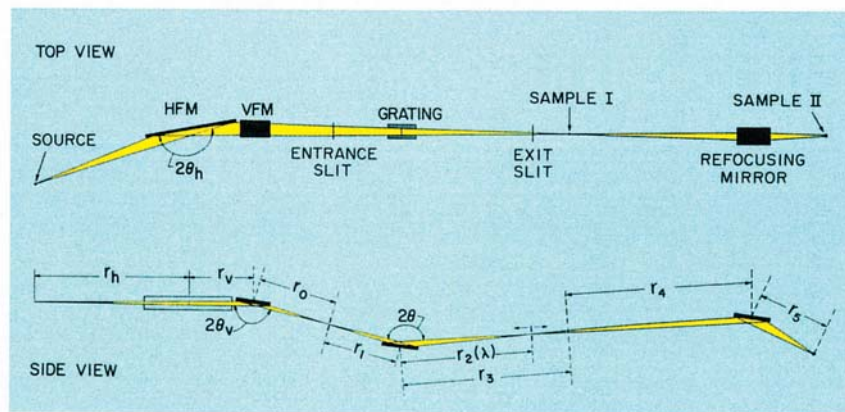


Fig. 2: The optical layout of the world's first Dragon beamline.

after it moved to its new home in TLS, including the addition of two reflection mirrors between the gratings and the exit slit to extend the lowest energy to 10 eV. This revised Dragon beamline, which is primarily used for performing MCD related experiments, has been operational since 1999.

The world's first Dragon beamline sets a new paradigm in the design of soft X-ray beamlines, but its principles are also well suited for the design in the VUV region. In particular, the Dragon-type is superior to other designs in terms of overall performance for the photon source size of TLS at  $400 \mu\text{m} \times 100 \mu\text{m}$ . Therefore following the LSGM and HSGM beamlines, we continue to use the Dragon-type design while adding enhancement or modifications for all the rest of the VUV to soft X-ray beamlines.

The U5-SGM beamline, which is the first undulator beamline developed at NSRRC, uses a design similar to HSGM beamline with modifications to fit the U5 undulator. For example, the first horizontal focusing mirror typical of a bending beamline is not required due to the smaller divergence of undulator source. This beamline has two separate branches that allow connection of two end-stations to the beamline at the same time, with switching done by two refocusing mirrors. This feature is also seen on the HF-CGM, EPU-SGM, and U9-CGM beamlines. The beamline delivers an average photon flux of  $5 \times 10^{11} \text{ p}/(\text{s} \cdot 0.01\% \text{ BW} \cdot 200 \text{ mA})$  and resolving power of 15,000 in the photon energy range from 60 eV to 1500 eV. The U5-SGM beamline delivers intense soft X-ray photon beams and has been in operation since 1999 for researches in nano-structured materials (with a spectro-microscopy station) and other materials science.

The WR-SGM beamline was constructed in 1999 to cover the combined spectral region of LSGM and HSGM, thus alleviating the increasingly heavy demands for those two beamlines. This beamline improves on the Dragon-type beamline by employing two entrance slits instead of one, and a common exit slit to provide two included grating angles for excellent performance in a very wide energy range from 10 eV to 1500 eV. It delivers an average photon flux of  $1 \times 10^{10} \text{ p}/(\text{s} \cdot 0.01\% \text{ BW} \cdot 200 \text{ mA})$  and resolving power of 15,000.

The EPU-SGM beamline shares a similar design with WR-SGM in using two entrance slits to extend the spectral range and to optimize the overall performance. It delivers an average photon flux of  $1.5 \times 10^{12} \text{ p}/(\text{s} \cdot 0.01\% \text{ BW} \cdot 200 \text{ mA})$  and resolving power of 20,000 in the photon energy range from 60 to 1400 eV. This beamline is specially designed to effectively deliver flux and preserve the degree of the circular polarization generated by the elliptically polarized undulator (EPU). The degree of the circular polarization of the photons generated by the EPU is greater than 95%, as demonstrated in Fig. 3. This beamline has been operational since 2000 and is equipped with a Spin Resolved Photoelectron Spectroscopy (SRPES) and a Photoemission Electron Microscope (PEEM) end-stations primarily for magnetic materials studies.

The HF-CGM beamline is a high-flux VUV bending magnet beamline, with a design similar to LSGM but covers a lower energy range from 4 eV to 40 eV. It also differs from the LSGM in that the first horizontal focusing mirror is positioned inside the front-end section and thus closer to the photon source for collecting 50 mrad of horizontal

Table 1. The VUV to soft X-ray beamlines developed at NSRRC.

BL No.	Source	Mono. Type	Energy Range (eV)	Res. Power E/ $\Delta$ E	Flux p/s @E/ $\Delta$ E	Operated in	Applications
03A	BM	CGM	4-40	30000	$1 \times 10^{10}$	2000	PES, PAS
04B	BM	SNM	4-40	5000	$1 \times 10^9$	1993	PES, PAS
05B	EPU5.6	SGM	60-1500	20000	$1.5 \times 10^{12}$	2000	MCD, SRPES, PEEM
08A	BM	SGM	15-200	15000	$1.5 \times 10^{10}$	1993	PES, XPS, PAS
09A	U5	SGM	60-1500	15000	$5 \times 10^{11}$	1999	XPS, XAS, SPEM
11A*	EPBM	SGM	10-1500	15000	$1 \times 10^{10}$	1999	MCD, PES, XPS, XAS
20A	BM	SGM	110-1500	10000	$1 \times 10^{10}$	1993	XAS, XPS, MCD
21B	U9	CGM	4-100	60000	$5 \times 10^{11}$	2001	PAS, PES, XPS
24A	BM	SGM	10-1500	15000	$1 \times 10^{10}$	1999	PES, XAS, MCD
05A	EPU5.6	AGM	350-1400	15000	$1 \times 10^{12}$	Construction	Inelastic Soft X-ray Scattering

BM:	Bending Magnet	CGM:	Cylindrical Grating Monochromator
EPBM:	Elliptically Polarized Bending Magnet	EPU5.6:	Elliptically Polarized Undulator with 5.6 cm magnetic period
SGM:	Spherical Grating Monochromator	SNM:	Seya-Namioka Monochromator
Ux:	Undulator with x cm magnetic period		

\*: The world's first Dragon beamline was originally located at NSLS and later transported to NSRRC in 1996.

radiation fan of the bending magnet, as compared to the 14 mrad of LSGM. Therefore, the HF-SGM beamline is able to deliver a higher photon flux at  $1 \times 10^{10}$  p/(s·0.01% BW·200 mA) and higher resolving power at 30,000 than the 1m SNM beamline. However, the high-order scattered light contamination in the low energy region < 15 eV is much higher than the 1m-SNM. After removal of the high-order scattered light, the HF-CGM beam-

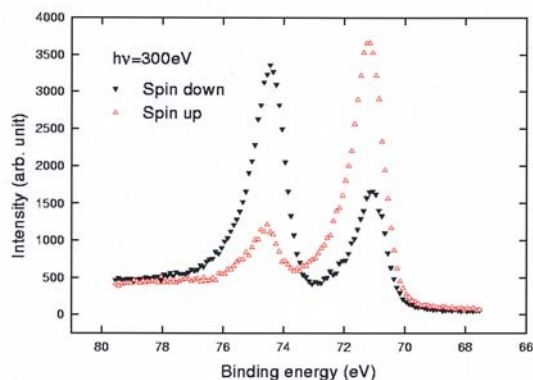


Fig. 3: The spin-resolved Pt  $4f_{7/2}$  and  $4f_{5/2}$  photoemission spectrum obtained at the EPU-SGM beamline. The degree of circular polarization of the excitation source deduced from the spectrum is greater than 95%.

line delivers similar photon flux in the low energy region < 15 eV and much higher flux in the high energy region > 20 eV. It has been operational since 2000, primarily for atomic, molecular, and space science researches.

The U9-CGM beamline, which has a design similar to EPU-SGM but modified slightly for emphasizing the performance in the VUV region using smaller grating included angles, delivers an average photon flux of  $5 \times 10^{11}$  p/(s·0.002% BW·200 mA) and resolving power of 60,000 in photon energy range from 4 to 100 eV. A resolving power greater than 100,000 using first order diffraction of the grating has been demonstrated at 15.8 eV from this beamline, which sets a world record for similar beamlines, as shown in Fig. 4. This beamline has been operational since 2001 primarily for atomic and molecular science and ultra-high resolution spectroscopy studies.

The beamline development at NSRRC can be summarized into two phases. In the first phase, we provided adequate number of multiple-purpose beamlines to satisfy the most common needs of our user community. With continuous development of new beamlines, in phase two we were able

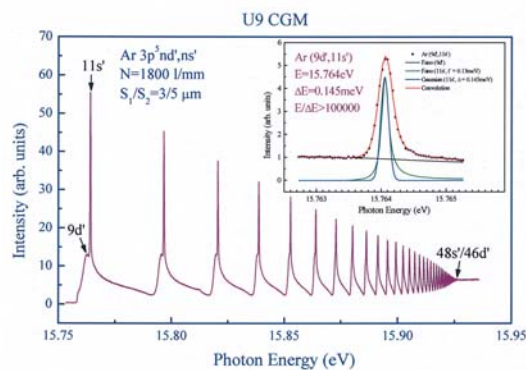


Fig. 4: Autoionization spectrum of Ar obtained at the U9-CGM beamline, containing the Rydberg series resonance lines of  $3p^5ns'$ ,  $n=11-48$ , and  $3p^5nd'$ ,  $n=9-46$ . The insert plot shows that the energy resolving power is greater than 100,000.

to provide more beamtime and to broaden our user community, and at the same time developed special-purpose beamlines to meet the specific requirement of more advanced experiments. In the future, new beamlines will be developed only when request for an advance experiment arises. As of late 2003, beamlines under construction include six hard X-ray beamlines and the most advanced Dragon-type beamline to date, the EPU-AGM beamline.

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