2017년 진공기술 현장실무교육

최신 분석장치 산업현황 및 측정방법

2017. 6. 23
안재평
한국과학기술연구원 특성분석센터

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2017년 국가연구장비 현황

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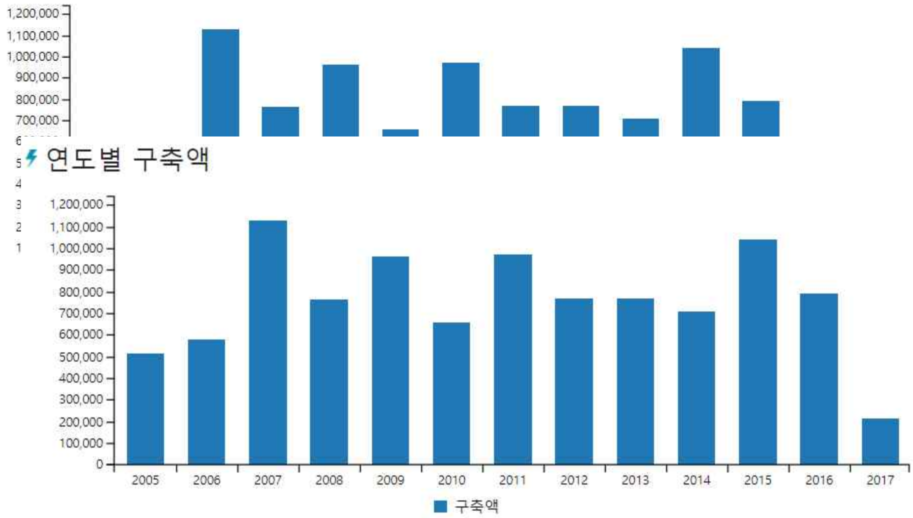
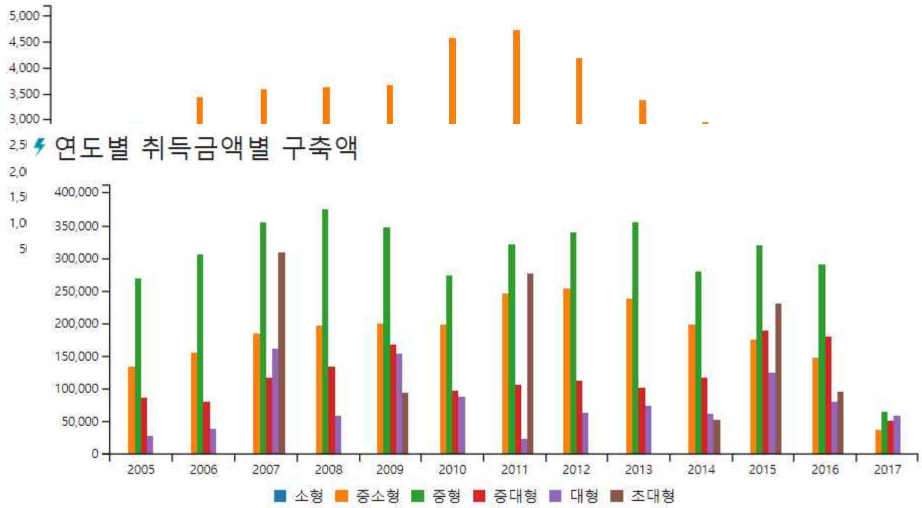


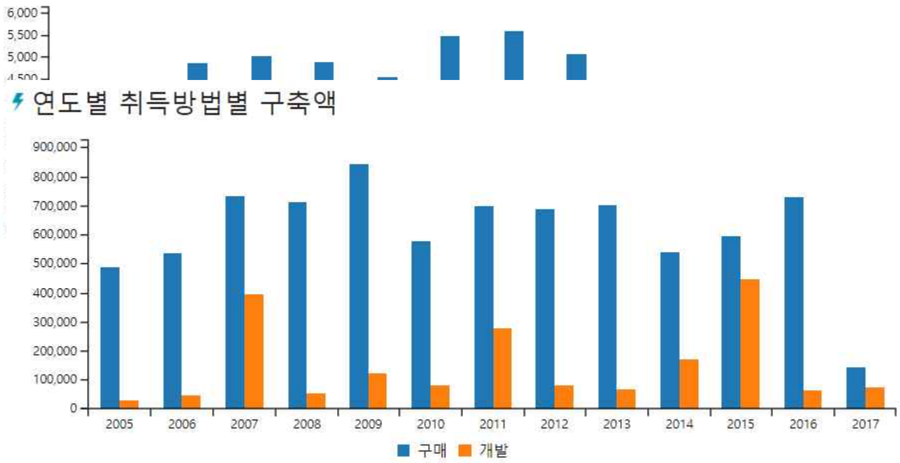
연도별 취득금액별 구축액

연도별 취득금액별 구축수



연도별 취득방법별 구축액

연도별 취득방법별 구축수



연도별 국산/외산별 구축액

연도별 국산/외산별 구축수

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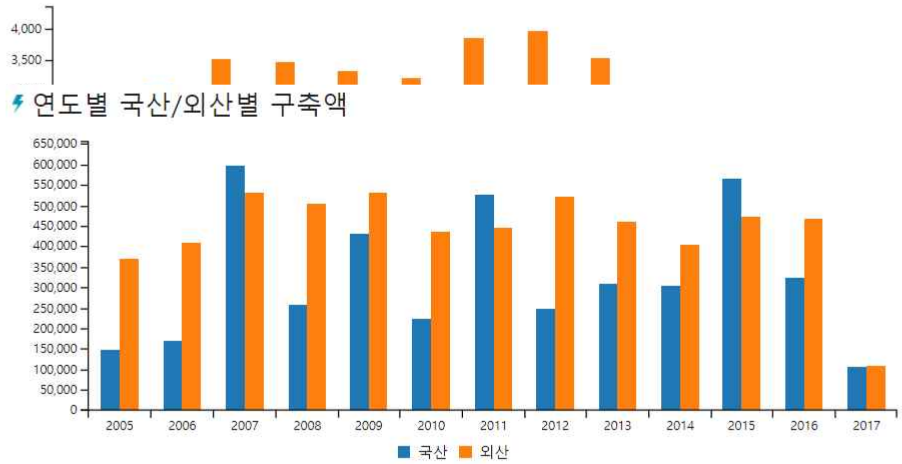
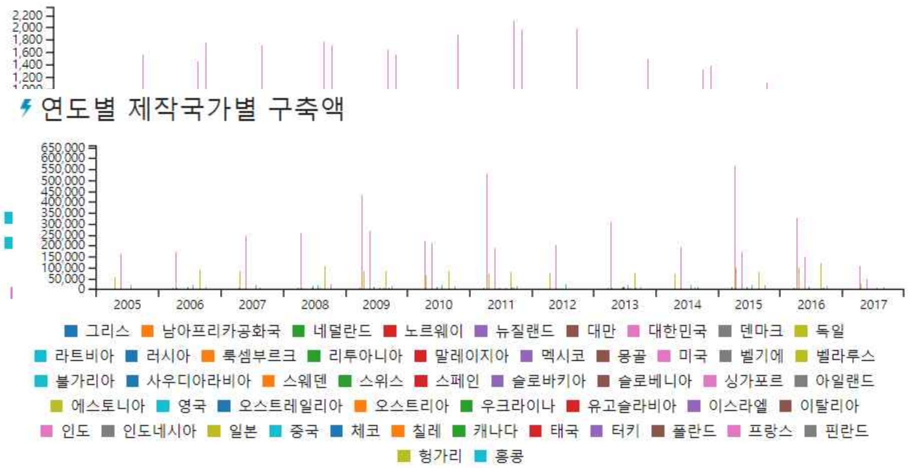


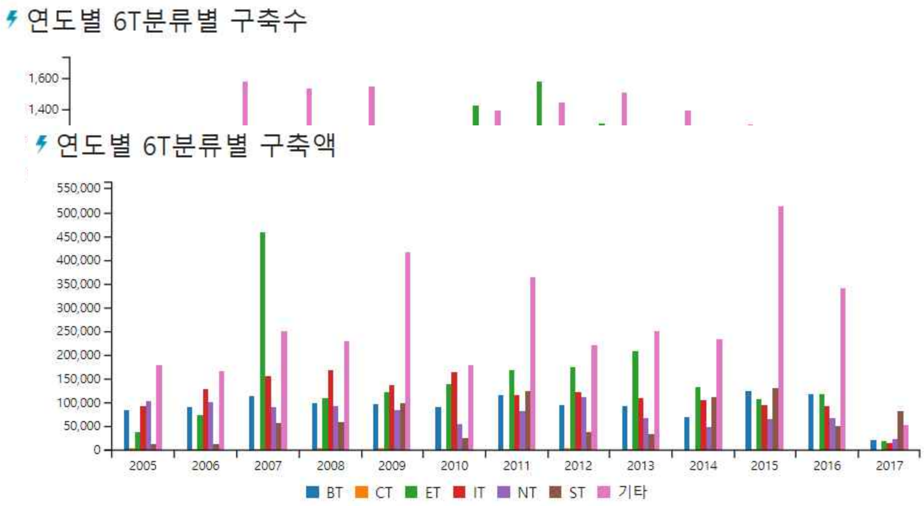
연도별 제작국가별 구축액

연도별 제작국가별 구축수

연도별 제작국가별 구축액



연도별 6T 분류별 구축액



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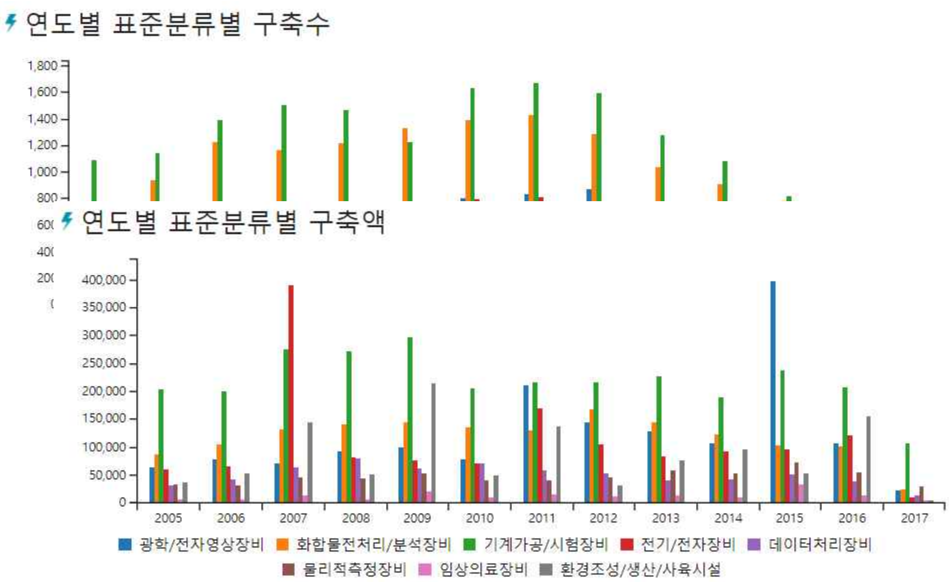
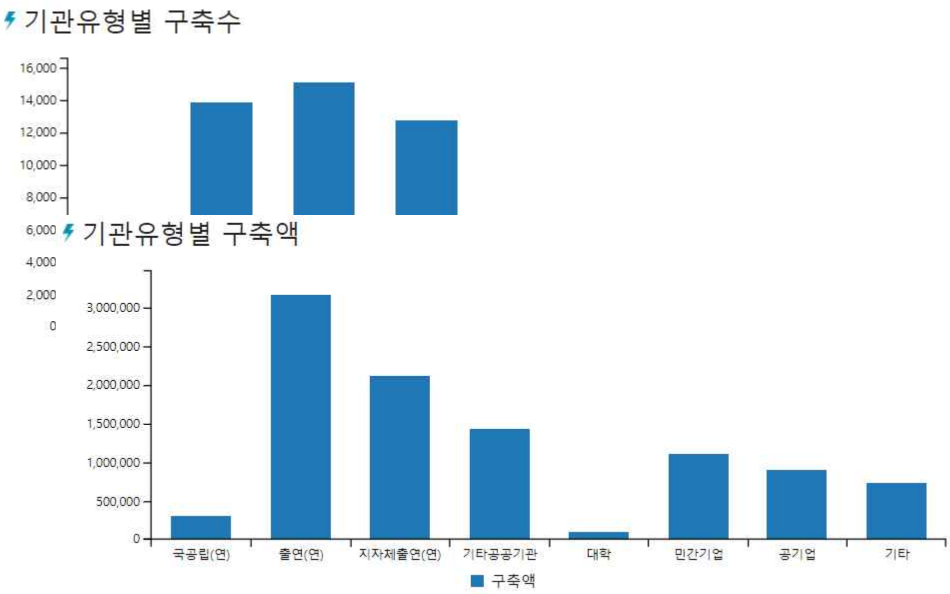


기관 유형별 구축액



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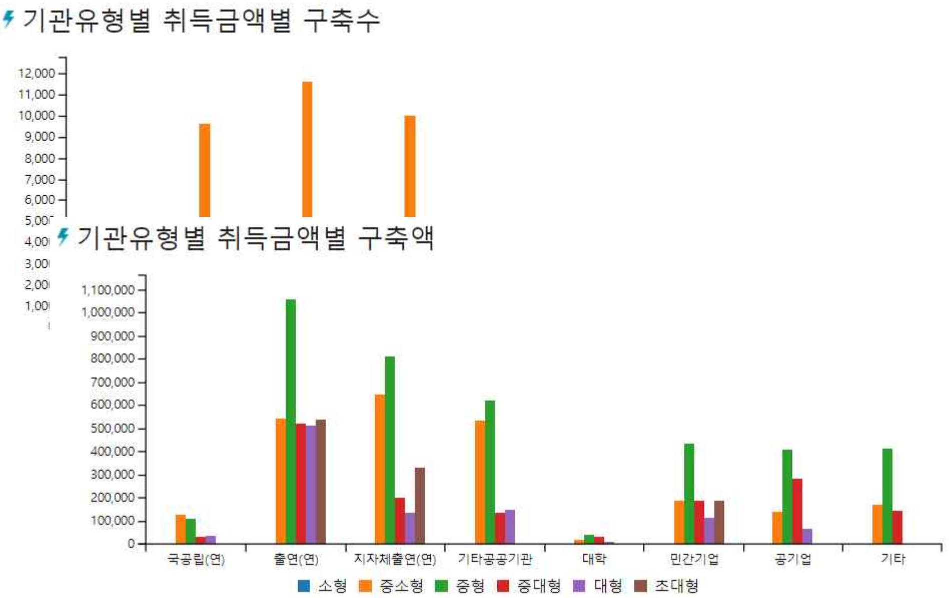

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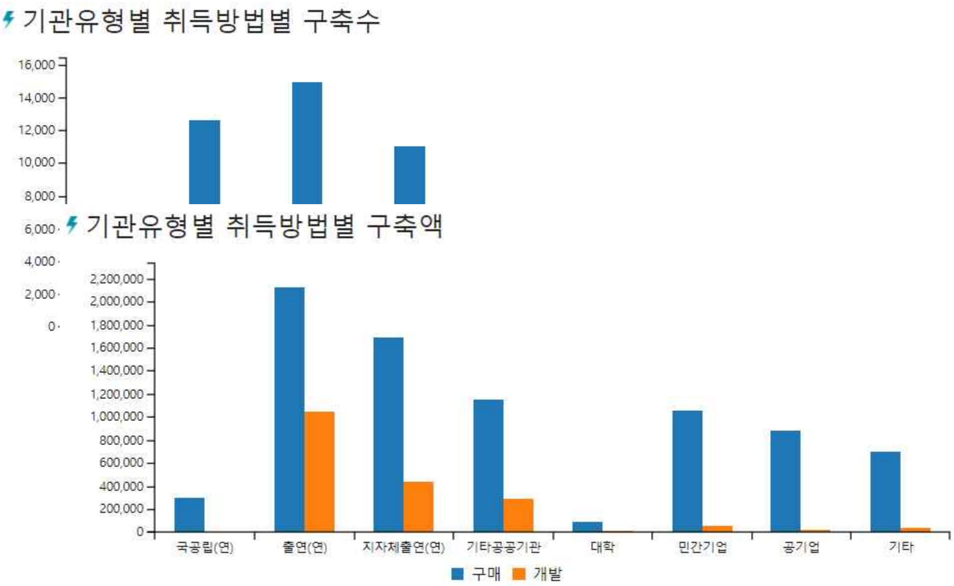

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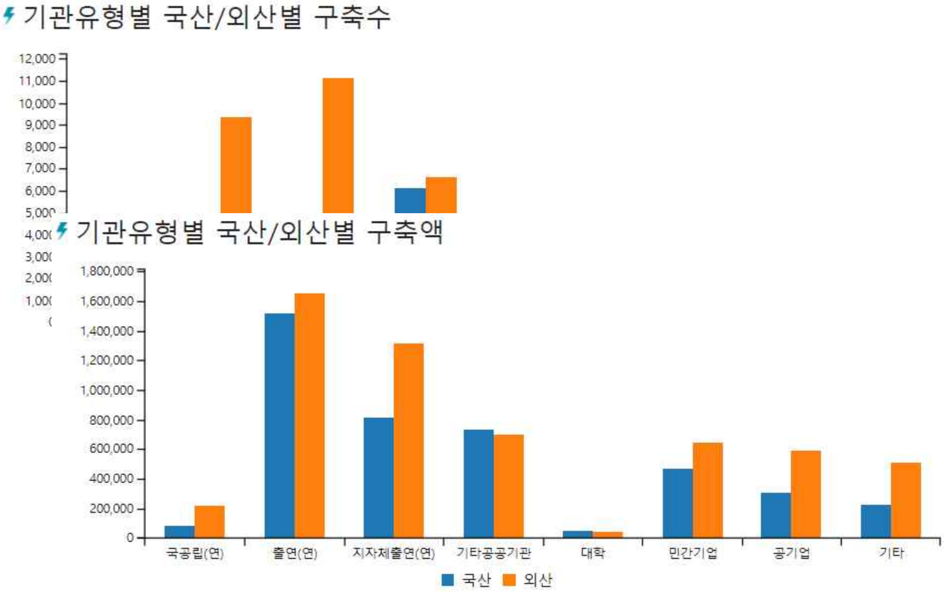

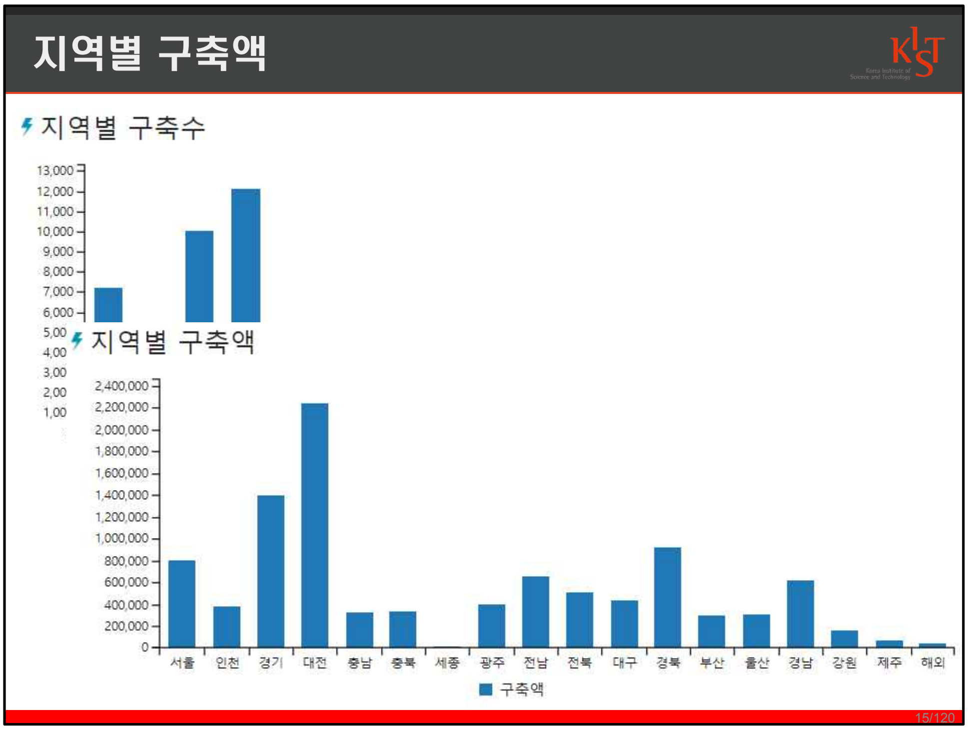
지역별 구축액
지역별 구축수
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
지역별 구축액
2,400,000
2,200,000
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1,600,000
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서울 인천 경기 대전 충남 충북 세종 광주 전남 전북 대구 경북 부산 울산 경남 강원 제주 해외
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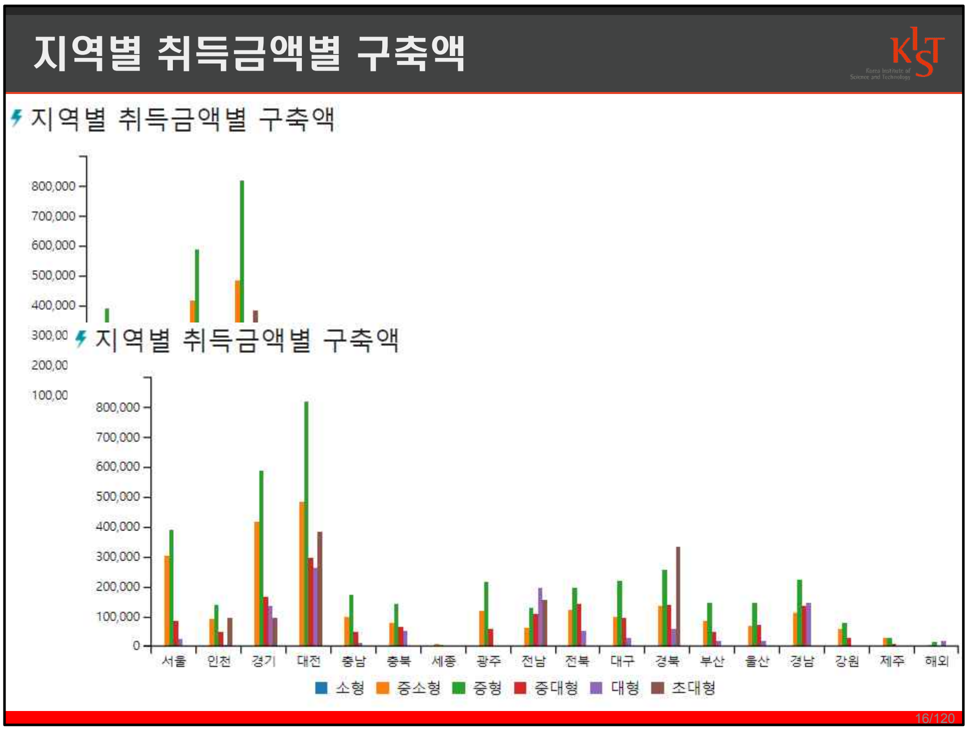
지역별 취득금액별 구축액
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소형 중소형 중형 중대형 대형 초대형
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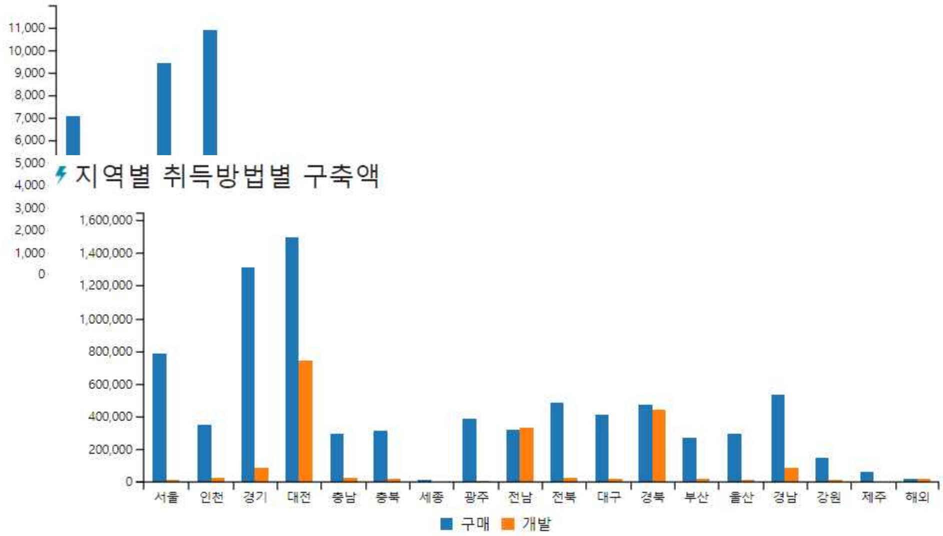
지역별 취득방법별 구축수



지역별 국산/외산별 구축액

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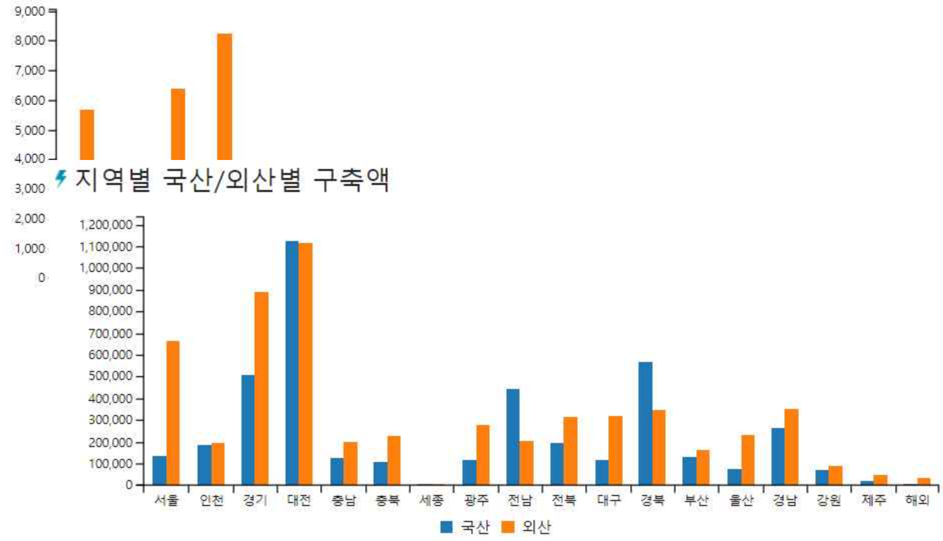

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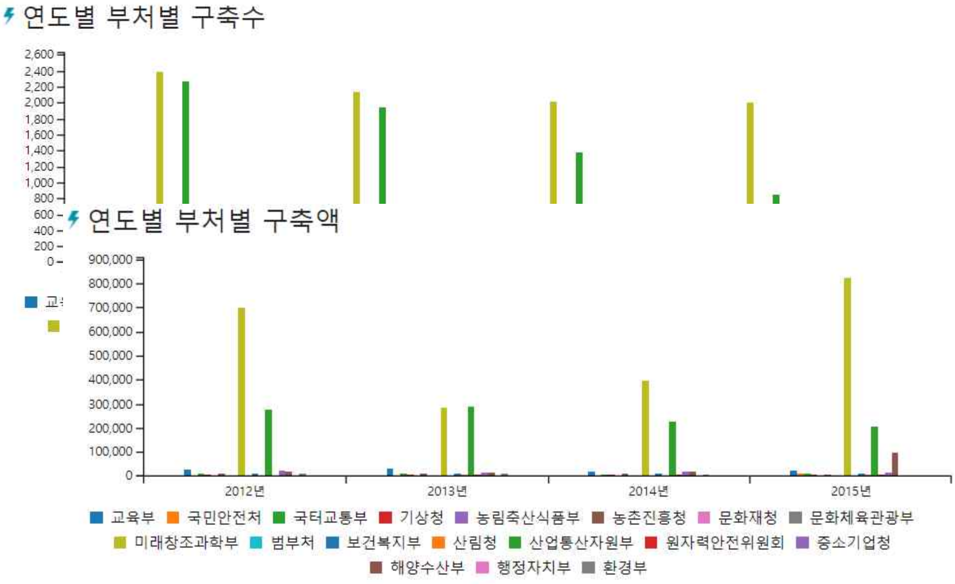
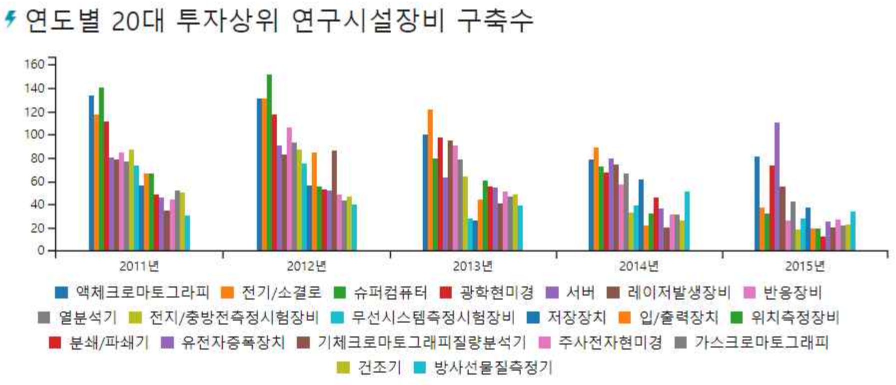


연도별 20대 투자상위 연구시설장비 구축수



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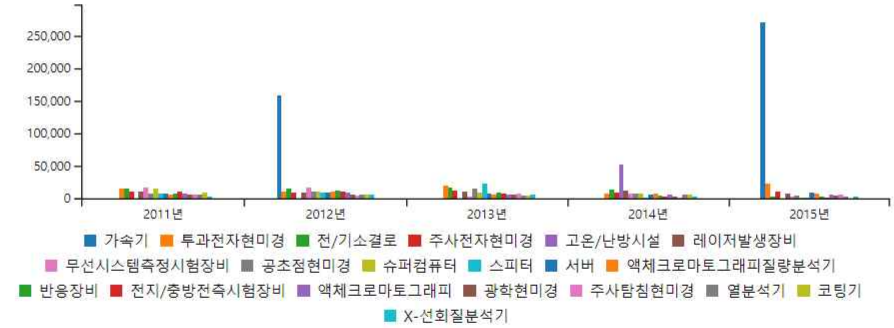

연도별 장비수

장비구분 / 취득년도	구매장비	개발장비	연구시설	Totals
2005	3,573	66	23	3,662
2006	4,038	60	22	4,120
2007	4,820	112	32	4,964
2008	4,986	152	29	5,167
2009	4,843	222	33	5,098
2010	4,507	308	39	4,854
2011	5,441	437	38	5,916
2012	5,540	487	46	6,073
2013	5,019	452	40	5,511
2014	4,001	418	48	4,467
2015	3,634	446	82	4,162
2016	3,104	241	109	3,454
2017	824	26	16	866
Totals	54,330	3,427	557	58,314

연도별 장비 구축액

장비구분 / 취득년도	구매장비	개발장비	연구시설	Totals
2005	480,694,562,254	28,214,871,628	7,054,017,033	515,963,450,915
2006	537,588,817,852	19,582,792,660	21,170,699,680	578,342,310,192
2007	704,003,482,751	382,159,125,692	41,118,012,803	1,127,280,621,246
2008	696,163,547,951	39,125,353,919	27,919,277,170	763,208,179,040
2009	736,972,996,509	48,747,918,573	175,375,395,042	961,096,310,124
2010	569,153,953,728	78,578,296,308	8,946,939,932	656,679,189,968
2011	691,541,165,003	269,191,657,828	10,699,286,575	971,432,109,406
2012	680,970,941,804	77,127,481,179	10,709,554,696	768,807,977,679
2013	696,368,580,754	65,037,018,599	5,882,372,778	767,287,972,131
2014	528,605,661,284	86,816,677,960	92,621,072,369	708,043,411,613
2015	580,360,338,645	415,321,150,604	43,074,293,983	1,038,755,783,232
2016	581,869,381,223	55,133,984,290	154,765,088,991	791,768,454,504
2017	136,970,262,704	70,396,621,225	4,757,773,403	212,124,657,332
Totals	7,621,263,692,462	1,635,432,950,465	604,093,784,455	9,860,790,427,382

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우리는 왜 재료분석을 하는가?

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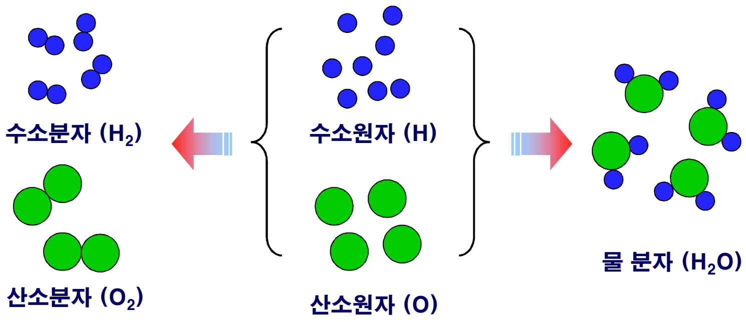
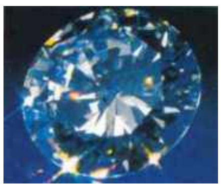
물질의 성질을 결정하는 최소단위는?



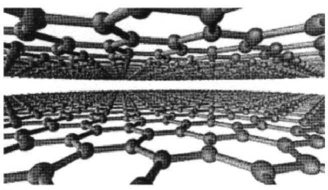
물(H_2O)은 수소분자(수소가스)의 성질도, 산소분자(산소가스)의 성질도 아닌 액체로서의 성질을 갖는다. 물을 수소가스와 산소가스로 분리하면 물의 성질은 사라진다.

같은 원자도 결합형태가 달라진다면?

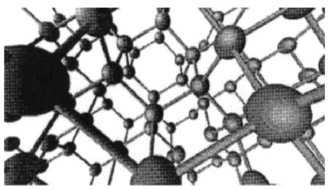




탄소원자로 이루어진 숯, 흑연, 다이아몬드가 서로 성질이 다른 것은 같은 탄소원자라도 결합하는 방법(결정구조)에 따라 성질이 달라지기 때문



흑연의 결정구조



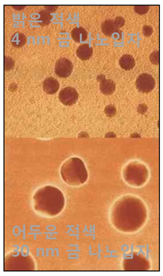
다이아몬드의 결정구조

Key factors in Nanotechnology

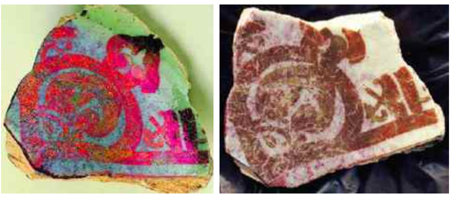
Enhanced surface properties : Catalysts, color

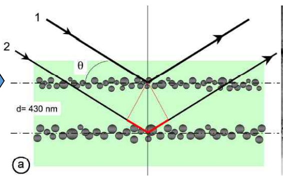
Roman Lycurgus cup (1600년 전)

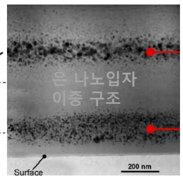
청나라 유리 (300년전)



중세 도기 유약 (700년전)







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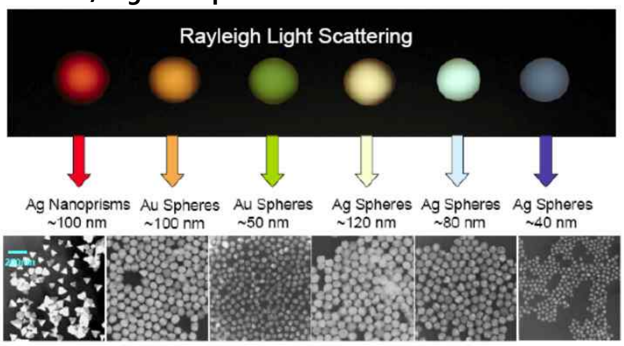
Key factors in Nanotechnology

Enhanced surface properties : Catalysts, color

Au / Ag Nanoparticles : TEM Observation



Properties depend on particle size, shape and composition.

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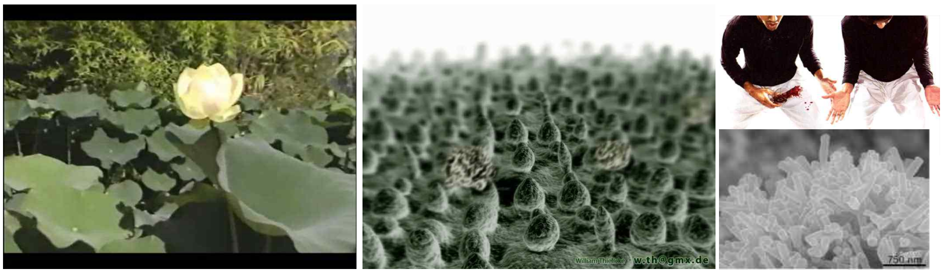
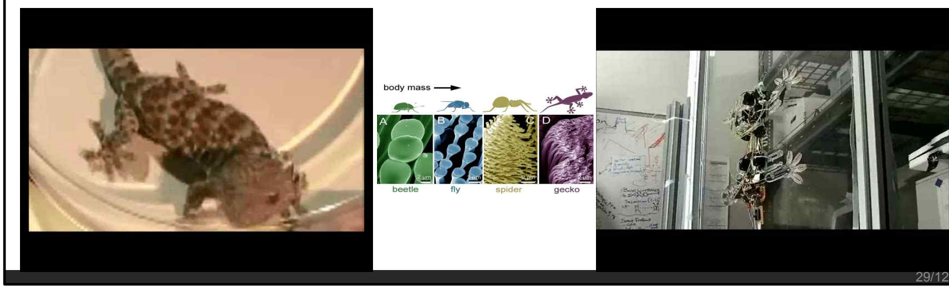
Characterization in Nanotechnology



관찰하기 – 따라하기 – 따라잡기

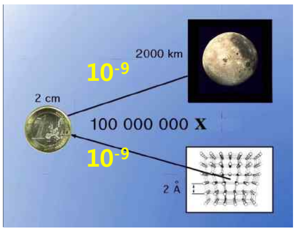


재료의 구조는 재료의 물성을 결정한다!!!

- 구조
  - 원자
  - 결정, 비정질
  - 화학구조 조성,
  - 형태, 크기, 복합화, 결함
- 이것이 왜 중요한가?
  - 기계, 전기, 화학, 광학, 자기, 열전, 촉매, 반응성
  - 물성을 결정하기 때문

무엇을/어떻게 분석할 것인가?

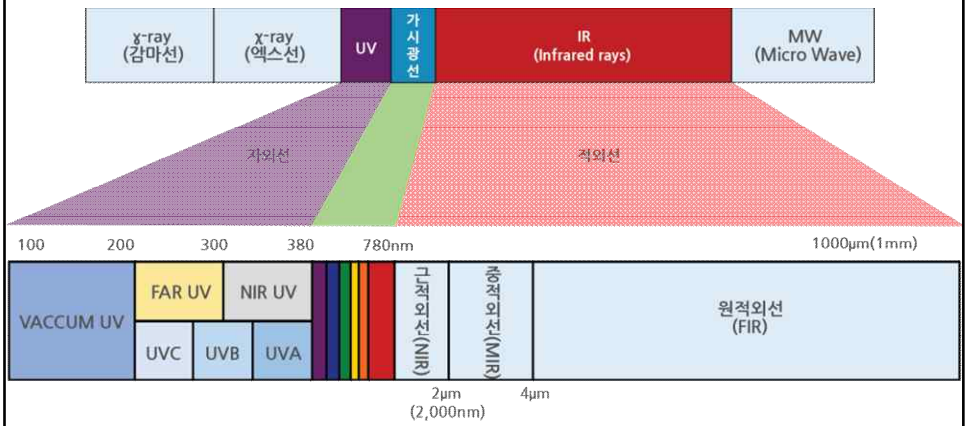
Scale of things (Nanoscale)



Earth from space

Nanostructure of Seashell

파장



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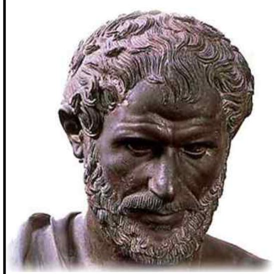
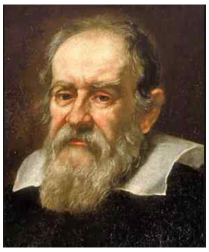
History of vacuum



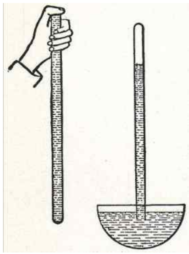
Αριστοτέλης, BC384-322



Galileo Galilei, 1564-1642

Evangelista Torricelli, 1608-1647

Blaise Pascal, 1623-1662



760 Torr
= 760 mmHg

1 Pa
= 1 N/m^2 = 1 $(kg \cdot m/s^2)/m^2$ = 1 $kg/m \cdot s^2$
= 0.01 mbar
= 0.00001 bar
= 7.5006×10^{-3} torr

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진공내의 전자 운동

(1) 전기장 내의 전자 운동

- 전자가 B극판의 방향으로 받는 힘 : $F=eE=eV/d[N]=m_0\alpha[N]$
- 가속도 : $\alpha=eE/m_0=e/m_0\cdot V/d[m/s^2]$

[1] 초속도를 가지는 전자의 전기장 내에서의 운동

① E[V/m]의 평등 전기장 내에 있는 전자가 t초 후의 속도
$v_t=v_0+\alpha t[m/s]=v_0+eE/m_0 t[m/s](\leftarrow\alpha=eE/m_0)$,
v_0 : 초속도[m/s], α : 가속도[m/s^2]

[2] 전자의 속도와 에너지

① B극판에 도착한 순간 전자의 속도 v_d
② 운동 에너지 $W=1/2m_0v_d^2=eV=1.602\times10^{-19}V[J]$

[3] 전자 에너지의 단위

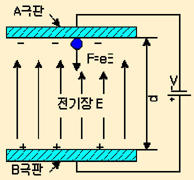
① 단위 : 1 전자 볼트 (1[eV]), $1[eV]=1.602\times10^{-19}[J]$

[4] 전자의 정전 편향

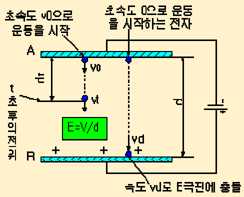
① 정전 편향 : 평등 전기장 E[V/m] 중에 전기장과 직교하는 방향으로 초속도 v_0[m/s]의 전자가 진입되도록 하면, 전자에는 전기장에 의한 힘이 작용하여 양극(+)판 방향으로 진로가 구부러지면서 포물선으로 전자가 진행됨(자기장에 의하여 전자의 진로가 구부러지게 되는 것)

[5] 편향 거리

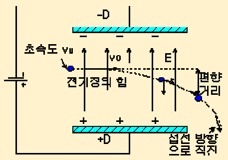
- 편향 거리는 편향 전압 V_d에 비례



전기장 내의 전자



전기장 방향으로 초속도를 가지는 전자의 운동



수직 전기장에 직교하는 방향으로 전자가 진입할 때의 궤도

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(2) 자기장 내의 전자 운동

<원 운동의 반지름과 각속도>

① 원운동의 구심력 : $F=BIl=ev_0B$, 원심력: $m_0v_0^2/r$, $ev_0B=m_0v_0^2/r$ [N]
② 원운동의 회전 각속도 : $\omega=v_0/r=eB/m_0$[rad/s]

<나선 운동>

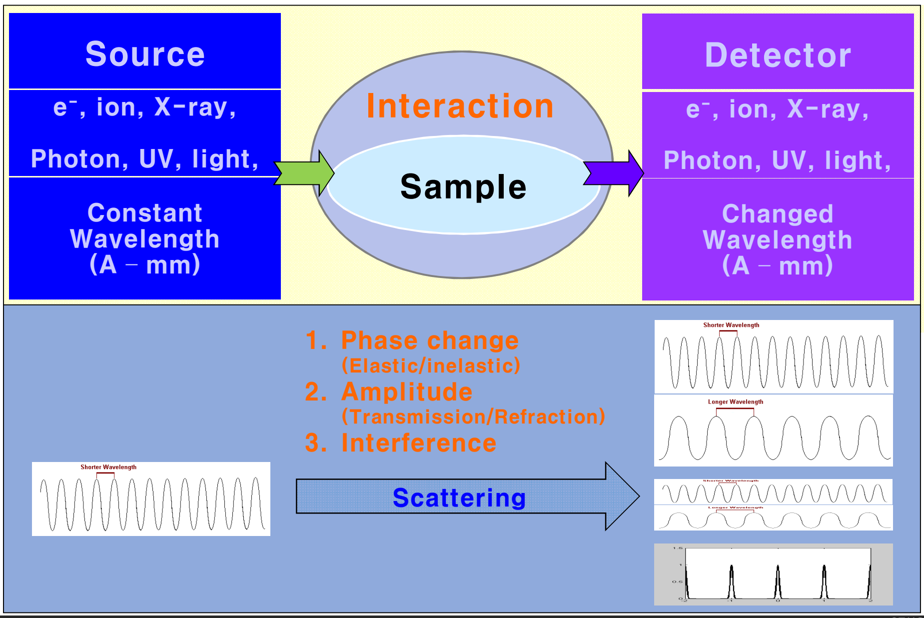
① v_0의 자기 방향의 속도 $v_x=v_0\cos\theta$[m/s]
② v_0의 수직 방향의 속도 $v_y=v_0\sin\theta$[m/s]

(3) 전자 빔

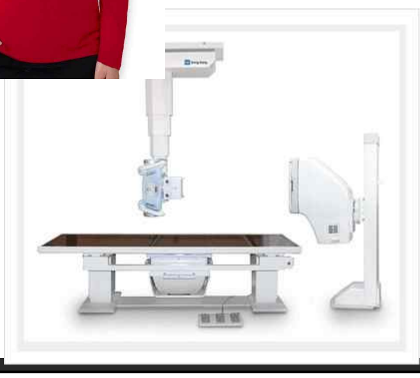
<전자 빔의 작용>

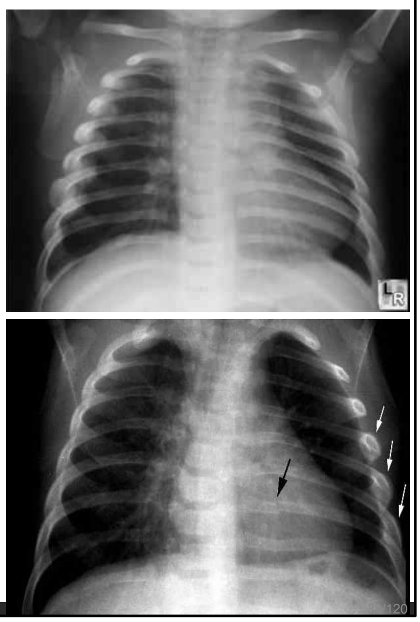
(가) 형광 작용 : 황화 카드뮴(CdS), 아연(Zn) 등의 염기류에 구리(Cu)등의 불순물을 넣은 형광도료에 전자빔을 쬐면 발광.
(나) 사진 작용 : 사진의 감광판에 전자 빔을 쬐어 현상하면, 빛을 비쳤을 때와 같이 감광되어 검게 됨.
(다) X선 방사 : 고진공 내를 고속으로 운동하는 전자빔이 물질의 표면에 충돌해서 전지되면, 거기에서 극히 파장이 짧은(10^{-18}~10^{-12}[m]정도)전자기파 발생.
(라) 열 작용 : 전자 빔이 물체에 충돌할 때, 그 운동 에너지는 열 에너지로 변함

Common principle of analytical instruments

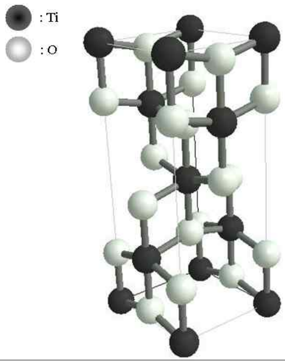


Information from scattering?





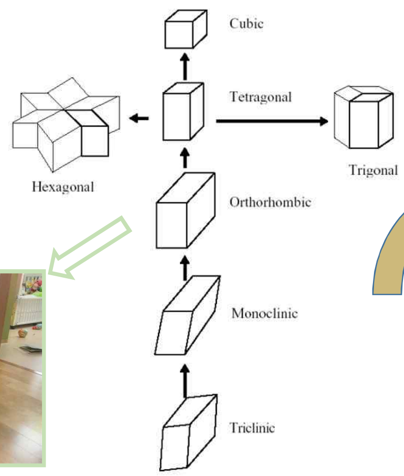
International Table for Crystallography



Ti atom	atom #	O atom	atom #	O atom	atom #
(0, 0, 0)	8	(0, 0, 0.2064)	4	(0.5, 0.5, 0.7064)	1
(0,0.5,0.25)	2	(0, 0.5, 0.4564)	2	(0.5, 0, 0.9564)	2
(0.5,0.5,0.5)	1	(0, 0.5, 0.5436)	2	(0.5, 0, 0.0436)	2
(0.5,0,0.75)	2	(0.5, 0.5, 0.2936)	1	(0, 0, 0.7936)	4

31개의 원자를 포함하고 있는 TiO_2 단위셀

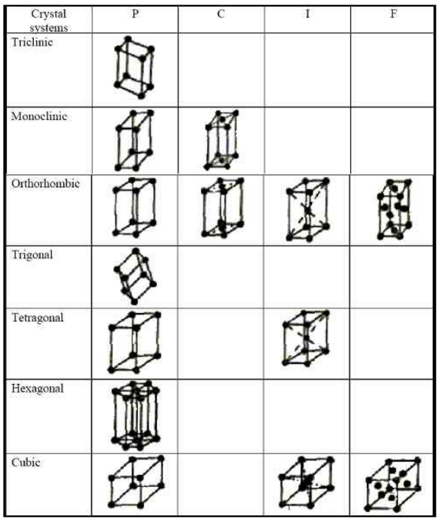
Symmetry of crystal system



Crystal system 7
Bravais lattice 14
Point group 32
Space group 230

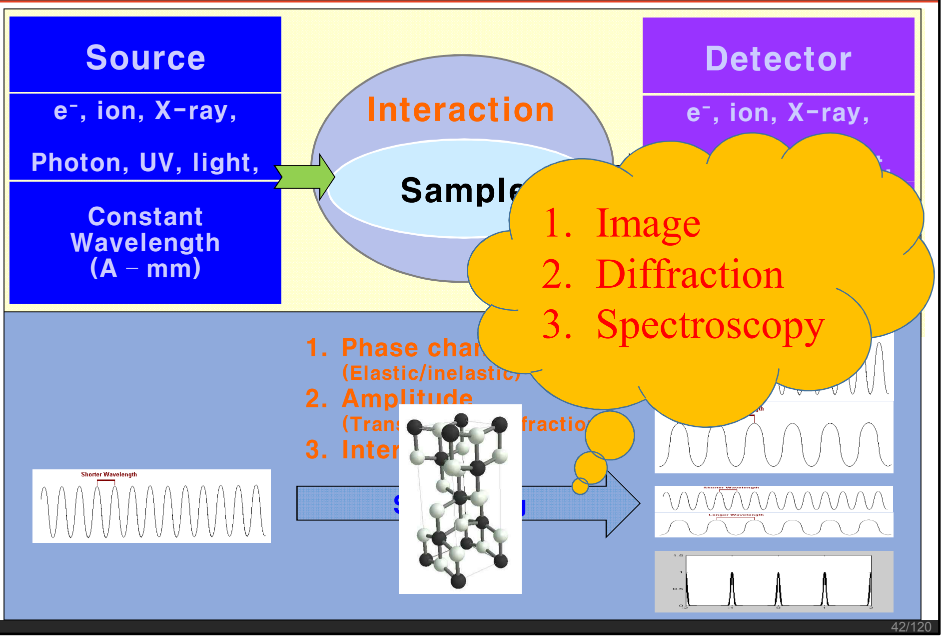
단위격자의 길이와 각도에 따른 대칭성과 주기성의 변화

Bravais Lattice



7개의 결정구조와 14개의 Bravais lattice와의 관계

Common principle of analytical instruments



TEM과 물성

우리가 보고 싶은 것	TEM에서 할 수 있는 것
• 물리, 화학, 역학, 광학, 자성 • 미세조직 – 직접관찰 • 물리 – 원자결합형태 (밴드갭) • 화학 – 조성분석 – 화학결합계면 결함 • 역학 – 응력, 변형 • 혼합 – 계면 화학성분 이동 – 계면 변형량 • 결정학 – 결정성 – 방위	• 이미지 형성 – 미세조직 – 비정질, 결정 – BF/DF – 석출물, 경계면 세우는 방법 • HRTEM의 형성원리 및 해석 방법 • STEM 이미지 (Z contrast) • 회절 형성 – SAD, Kikuchi, CBED, NED • 조성 분석 – EDS, EELS • 맵핑 – EDS, EFTEM

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재료 분석장비들

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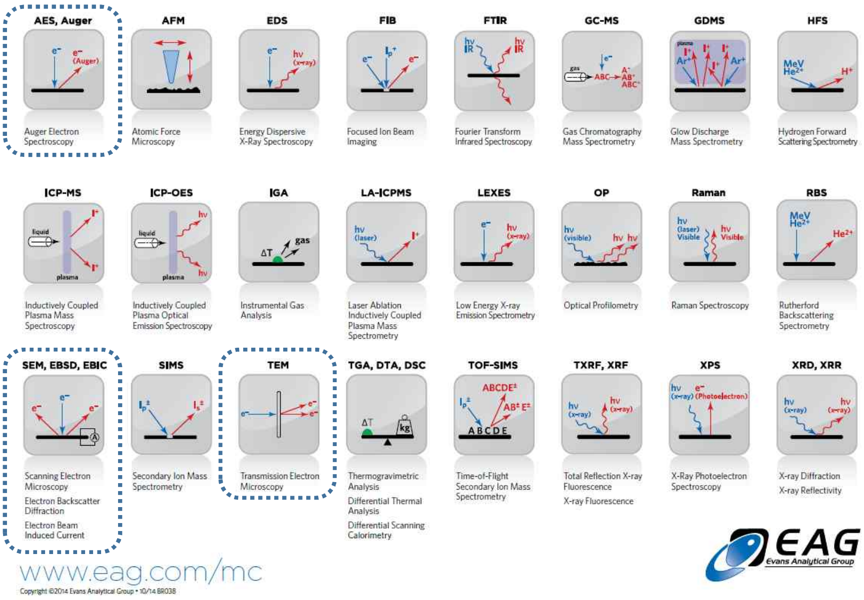
Nano-materials and analytic methods



Various analytical techniques

Acronyms Glossary

This glossary lists all the acronyms referred to in the encyclopedia together with their meanings. The major technique acronyms are listed alphabetically. Alternatives to these acronyms are listed immediately below each of these entries, if they exist. Related acronyms (variations or subsets of techniques; terminology used within the technique area) are grouped together below the major acronym and indented to the right. Most, but not all, of the techniques listed here are the subject of individual articles in this volume.

AAS	Atomic Absorption Spectroscopy
AA	Atomic Absorption
VPD-AAS	Vapor Phase Decomposition-Atomic Absorption Spectroscopy
GFAA	Graphite Furnace Atomic Absorption
FAA	Flame Atomic Absorption
AES	Auger Electron Spectroscopy
Auger	Auger Electron Spectroscopy
SAM	Scanning Auger Microscopy
SAM	Scanning Auger Microprobe
AED	Auger Electron Diffraction
ADAM	Angular Distribution Auger Microscopy
KE	Kinetic Energy
CMA	Cylindrical Mirror Analyzer
AIS	Atom Inelastic Scattering
BET	Brunauer, Emmett, and Teller equation
BSDF	Bidirectional Scattering Distribution Function
BRDF	Bidirectional Reflective Distribution Function
BTDF	Bidirectional Transmission Distribution Function
CL	Cathodluminescence
CLSM	Confocal Scanning Laser Microscope
EDS	Energy Dispersive (X-Ray) Spectroscopy
EDX	Energy Dispersive X-Ray Spectroscopy
EDAX	Company selling EDX equipment
EELS	Electron Energy Loss Spectroscopy
HREELS	High-Resolution Electron Energy-Loss Spectroscopy
REELS	Reflected Electron Energy-Loss Spectroscopy
REELM	Reflection Electron Energy-Loss Microscopy
LEELS	Low-Energy Electron-Loss Spectroscopy
PEELS	Parallel (Detection) Electron Energy-Loss Spectroscopy
EXELFS	Extended Energy-Loss Fine Structure
EELFS	Electron Energy-Loss Fine Structure
CEELS	Core Electron Energy-Loss Spectroscopy
VEELS	Valence Electron Energy-Loss Spectroscopy
EPMA	Electron Probe Microanalysis
Electron Probe	Electron Probe Microanalysis
ERS	Elastic Recoil Spectrometry
HFS	Hydrogen Forward Scattering
HRS	Hydrogen Recoil Spectrometry
FRS	Forward Recoil Spectrometry
ERDA	Elastic Recoil Detection Analysis
ERD	Elastic Recoil Detection
PRD	Particle Recoil Detection
EXAFS	Extended X-Ray Absorption Fine Structure
SEXAFS	Surface Extended X-Ray Absorption Fine Structure
NEXAFS	Near-Edge X-Ray Absorption Fine Structure
XANES	X-Ray Absorption Near-Edge Structure
XAFS	X-Ray Absorption Fine Structure
FMR	Ferromagnetic Resonance
FTIR	See IR
FT Raman	See Raman
HREELS	See EELS
HRTEM	See TEM
GDMS	Glow Discharge Mass Spectrometry
GDQMS	Glow Discharge Mass Spectrometry using a Quadruple Mass Analyser
Gloquad	Manufacturer name
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
ICP	Inductively Coupled Plasma
LA-ICP-MS	Laser Ablation ICP-MS
ICP-Optical	Inductively Coupled Plasma Optical Emission
ICP	Inductively Coupled Plasma
IETS	Inelastic Electron Tunneling Spectroscopy
IR	Infrared (Spectroscopy)
FTIR	Fourier Transform Infra-Red (Spectroscopy)
GC-FTIR	Gas Chromatography FTIR
TGA-FTIR	Thermo Gravimetric Analysis FTIR
ATR	Attenuated Total Reflection

Various analytical techniques (Cont.)

RA	Reflection Absorption (Spectroscopy)
IRAS	Infrared Reflection Absorption Spectroscopy
ISS	Ion Scattering Spectrometry
LEIS	Low-Energy Ion Scattering
RCE	Resonance Charge Exchange
LEED	Low-Energy Electron Diffraction
LIMS	Laser Ionization Mass Spectrometry
LAMMA	Laser Microprobe Mass Analysis
LAMMS	Laser Microprobe Mass Spectrometry
LIMA	Laser Ionization Mass Analysis
NRMPI	Nonresonant Multi-Photon Ionization
MEISS	Medium-Energy Ion Scattering Spectrometry
MEIS	Medium-Energy Ion Scattering
MOKE	Magneto-Optic Kerr Rotation
SMOKE	Surface Magneto-Optic Kerr Rotation
NAA	Neutron Activation Analysis
INAA	Instrumental Neutron Activation Analysis
NEXAFS	Near Edge X-Ray Absorption Fine Structure
XANES	X-Ray Absorption Near Edge Structure
NIS	Neutron Inelastic Scattering
NMR	Nuclear Magnetic Resonance
MAS	Magic-Angle Spinning
NRA	Nuclear Reaction Analysis
OES	Optical Emission Spectroscopy
PAS	Photoacoustic Spectroscopy
PIXE	Particle Induced X-Ray Emission
HIXE	Hydrogen/Helium Induced X-ray Emission
PL	Photoluminescence
PLE	Photoluminescence Excitation
PR	Photoreflectance
EBER	Electron Beam Electroreflectance
RDS	Reflection Difference Spectroscopy
Raman	Raman Spectroscopy
FT Raman	Fourier Transform Raman Spectroscopy
RS	Raman Scattering
RRS	Resonant Raman Scattering
CARS	Coherent Anti-Stokes Raman Scattering

SERS	Surface Enhanced Raman Spectroscopy
RBS	Rutherford Backscattering Spectrometry
HEIS	High-Energy Ion Scattering
RHEED	Reflected High Energy Electron Diffraction
SREM	Scanning Reflection Electron Microscopy
SALI	Surface Analysis by Laser Ionization
PISIMS	Post-Ionization Secondary Ion Mass Spectrometry
MPNRPI	Multi-Photon Nonresonant Post Ionization
MRRPI	Multiphoton Resonant Post Ionization
RPI	Resonant Post Ionization
MPI	Multi-Photon Ionization
SPI	Single-Photon Ionization
SIRIS	Sputter-Initiated Resonance Ionization Spectroscopy
SARIS	Surface Analysis by Resonant Ionization Spectroscopy
TOFMS	Time-of-Flight Mass Spectrometer
SAM	See AES
SEM	Scanning Electron Microscopy
	Scanning Electron Microprobe
	Secondary Electron Miscroscopy
SE	Secondary Electron
BSE	Backscattered Electron
SEMPA	Secondary Electron Microscopy with Polarization Analysis
SFM	Scanning Force Microscopy
	Scanning Force Microscope
AFM	Atomic Force Microscopy
SPM	Scanning Probe Microscopy
SIMS	Secondary Ion Mass Spectrometry
Dynamic SIMS	Dynamic Secondary Ion Mass Spectrometry
Static SIMS	Static Secondary Ion Mass Spectrometry
Q-SIMS	SIMS using a Quadruple Mass Spectrometer
Magnetic SIMS	SIMS using a Magnetic Sector Mass Spectrometer
Sector SIMS	See Magnetic SIMS
TOF-SIMS	SIMS using Time-of-Flight Mass Spectrometer
PISIMS	Post Ionization SIMS
SNMS	Sputtered Neutrals Mass Spectrometry
	Secondary Neutrals Mass Spectrometry
SNMSd	Direct Bombardment Electron Gas SNMS
SSMS	Spark Source Mass Spectrometry
Spark Source	Spark Source Mass Spectrometry
STEM	See TEM
STM	Scanning Tunneling Microscopy

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Various analytical techniques (Cont.)

	Scanning Tunneling Microscope
SPM	Scanning Probe Microscopy
TEAS	Thermal Energy Atom Scattering
TEM	Transmission Electron Microscopy
	Transmission Electron Microscope
CTEM	Conventional Transmission Electron Microscopy
STEM	Scanning Transmission Electron Microscopy
HRTEM	High Resolution Transmission Electron Microscopy
SAD	Selected Area Diffraction
AEM	Analytical Electron Microscopy
CBED	Convergent Beam Electron Diffraction
LTEM	Lorentz Transmission Electron Microscopy
TLC	Thin Layer Chromatography
TSRLM	Tandem Scanning Reflected-Light Microscope
TSM	Tandem Scanning Reflected-Light Microscope
TXRF	See XRF
UPS	Ultraviolet Photoelectron Spectroscopy
	Ultraviolet Photoemission Spectroscopy
MPS	Molecular Photoelectron Spectroscopy
VASE	Variable Angle Spectroscopic Ellipsometry
WDS	Wavelength Dispersive (X-Ray) Spectroscopy
WDX	Wavelength Dispersive X-Ray Spectroscopy
XAS	X-Ray Absorption Spectroscopy
XPS	X-Ray Photoelectron Spectroscopy
	X-Ray Photoemission Spectroscopy
ESCA	Electron Spectroscopy for Chemical Analysis
XPD	X-Ray Photoelectron Diffraction
PHD	Photoelectron Diffraction
KE	Kinetic Energy
XRD	X-RayDiffraction
GIXD	Grazing Incidence X-Ray Diffraction
GIXRD	Grazing Incidence X-Ray Diffraction
DCD	Double Crystal Diffractometer
XRF	X-Ray Fluorescence
XFS	X-Ray Fluorescence Spectroscopy
TXRF	Total Reflection X-Ray Fluorescence
TRXFR	Total Reflection X-Ray Fluorescence
VPD-TXRF	Vapor Phase Decomposition Total X-Ray Fluorescence

Encyclopedia of materials characterization
C. R. Brundle, C. A. Evans, Jr., S. Wilson,
Butterworth-Heinemann 1992

Total 183 techniques

Nanotechnology ⇨

Nano-characterization

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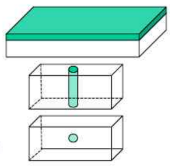
Nano-materials and analytic methods

1-dimensional : Quantum well, Thin films — Z ≈ nm

2-dimensional : Quantum wire, Nanotubes — X, Y ≈ nm

3-dimensional : Quantum dot, Nano-powders — X, Y, Z ≈ nm



Method	Source	Sampling	Depth (Z)
XPS	X-ray	Photoelectron	1-10 nm
AES	Electron	Auger electron	2-6 nm
SIMS	Ion	Secondary ion	5-30 nm
RBS	He ion	Scattered ion	2-20 nm
SEM	Electron	Secondary electron	10 nm
EPMA	Electron	X-ray	1 μm
TEM	Electron	Transmitted Electron	10 nm

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Objectives of Analytical Methods

- Identification : Elements or compounds with high sensitivity
- Quantification : Concentration of elements with high accuracy
- Localization : Identification and quantification in the small region

➢ Localization becomes an important factor in nano-materials

Classification of Analytic techniques

- Nano-characterization : Region of analysis in nano-scale
- Surface analysis : Information from the depth of about 5 nm
- Thin film analysis : Analysis for thin film and substrate (~ 1 μm)
- Bulk analysis : Composition and microstructure in macro scale

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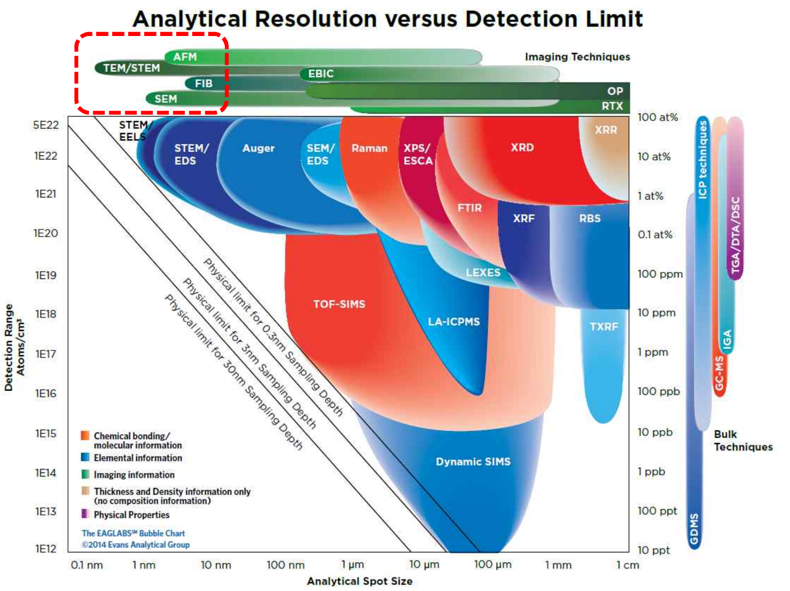
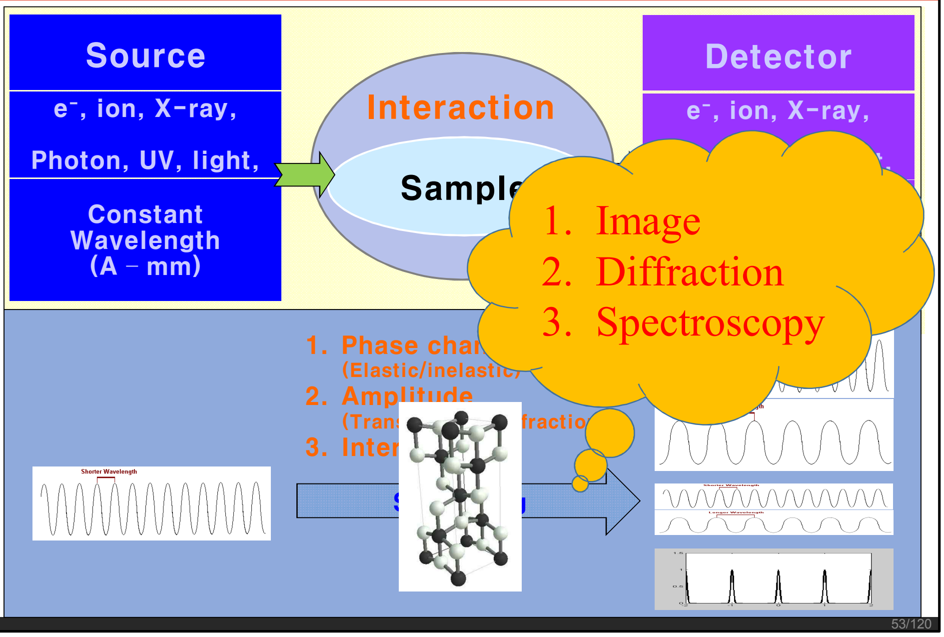
Analytical resolution and detection limit



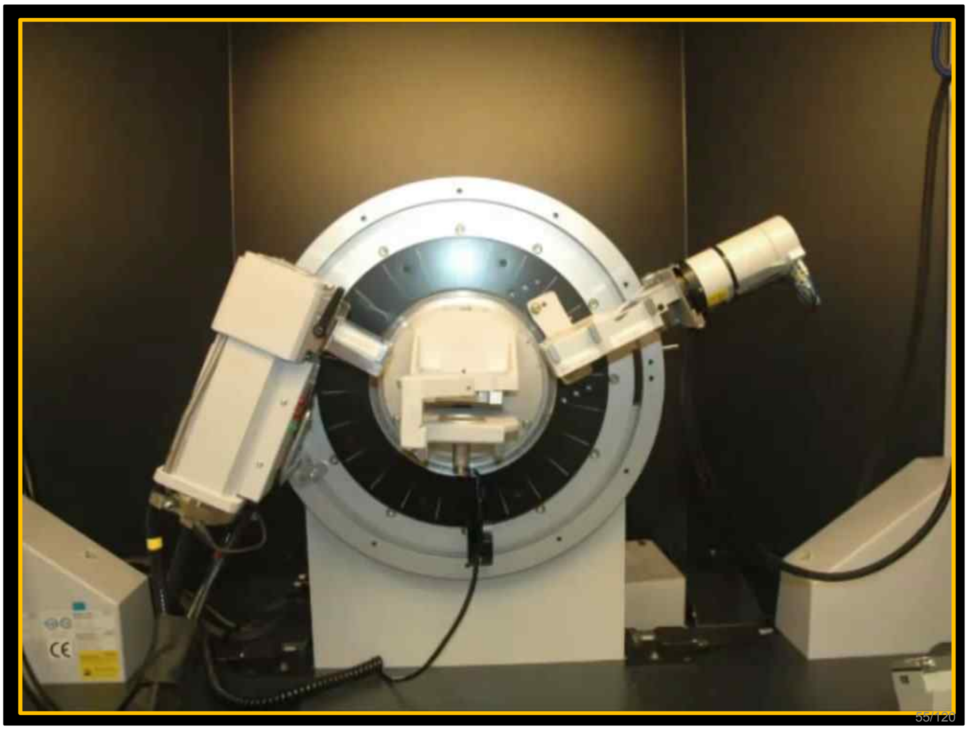
재료 분석장비의 간단한 원리

Common principle of analytical instruments



나노스케일 재료의 구조분석 장비

- X-ray diffractometer
- TEM (electron scattering & diffraction)
  - Spot pattern (SAD)
  - Ring pattern
  - Kikuchi pattern
  - CBED pattern
  - NED (Astar, Topspin)
  - HRTEM
- SEM
  - EBSD
- Tomography (FIB, SEM, TEM)
- Raman
- Synchrotron
  - X-ray



X-ray detector

(1) 사진작용	사진 film
(2) 이온화작용	전리함(Ion Chamber) GM 계수관(Geiger-Muller Counter, GMC) 비례계수관(Proportional Counter, PC) 위치민감형 비례계수관(Position Sensitive Proportional Counter, 반도체 검출기(Solid-State Detector, SSD)
(3) 형광작용	형광판 Scintillation 계수관(Scintillation Counter, SC) X선(X-Rays) TV CCD Image Plate, IP
(4) 광전도작용	PbO(X선 TV)

Detector of X-ray

On film

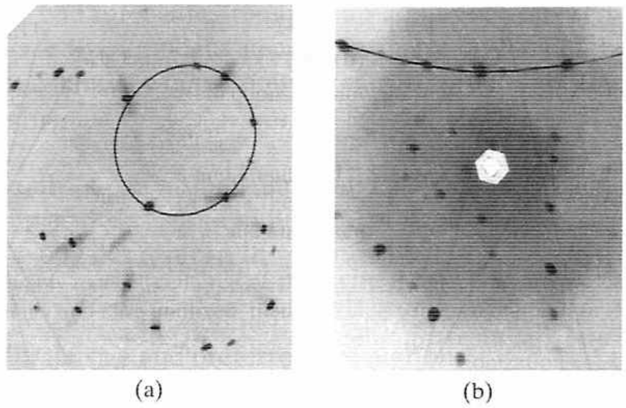
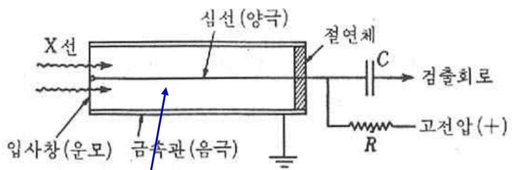


Fig 3-10. (a) Transmission and (b) back-reflection Laue patterns of an aluminum crystal (cubic). Tungsten radiation, 30KV, 19mA.

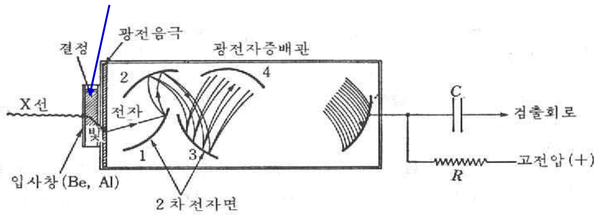
Proportional Counter

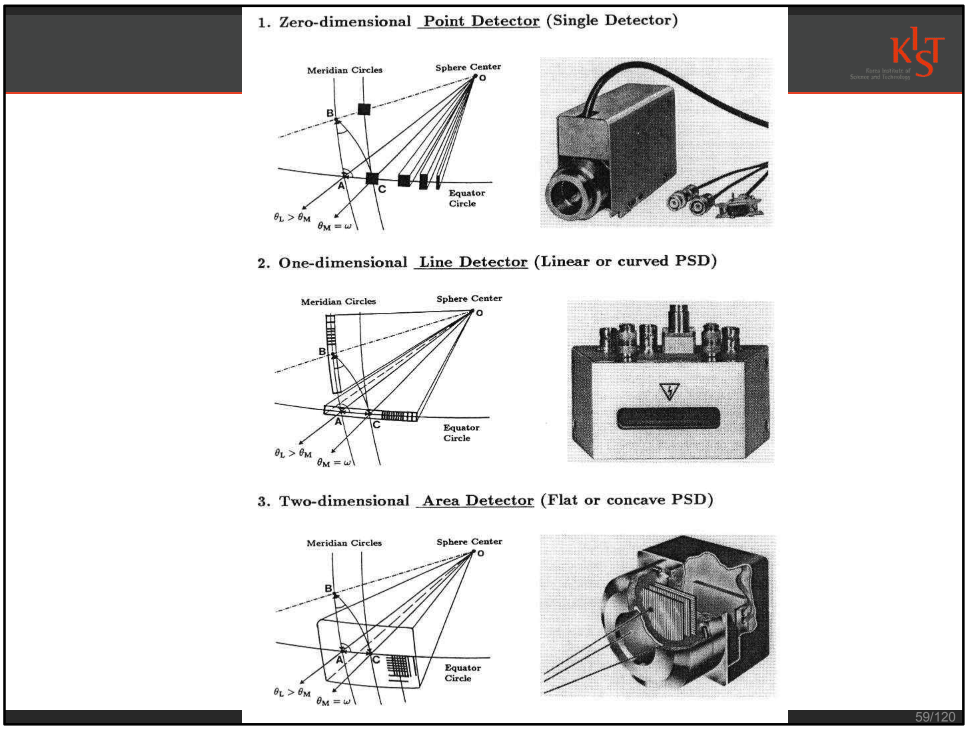


불활성가스(Ar, Kr, Xe 등) + (에테르, 알콜, Br_2, Cl_2)

Tl첨가 NaI 단결정의 형광작용

Scintillation Counter




1. Zero-dimensional Point Detector (Single Detector)
Meridian Circles
Sphere Center
Equator Circle
$\theta_L > \theta_M$
$\theta_M = \omega$
2. One-dimensional Line Detector (Linear or curved PSD)
Meridian Circles
Sphere Center
Equator Circle
$\theta_L > \theta_M$
$\theta_M = \omega$
3. Two-dimensional Area Detector (Flat or concave PSD)
Meridian Circles
Sphere Center
Equator Circle
$\theta_L > \theta_M$
$\theta_M = \omega$
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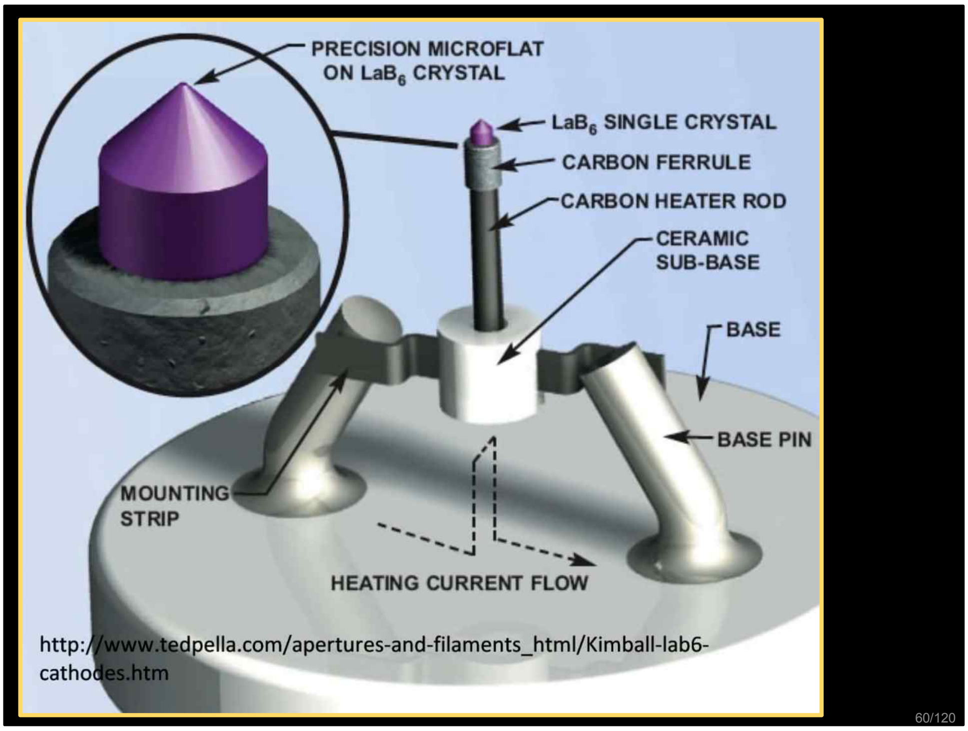
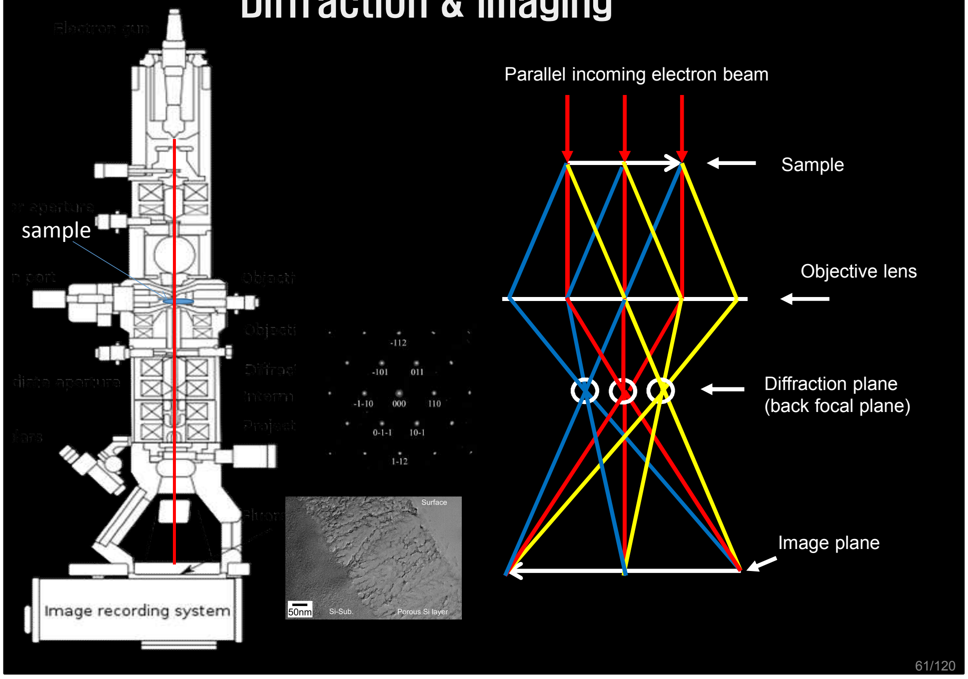

PRECISION MICROFLAT ON LaB_6 CRYSTAL
LaB_6 SINGLE CRYSTAL
CARBON FERRULE
CARBON HEATER ROD
CERAMIC SUB-BASE
BASE
BASE PIN
MOUNTING STRIP
HEATING CURRENT FLOW
http://www.tedpella.com/apertures-and-filaments_html/Kimball-lab6-cathodes.htm
60/120

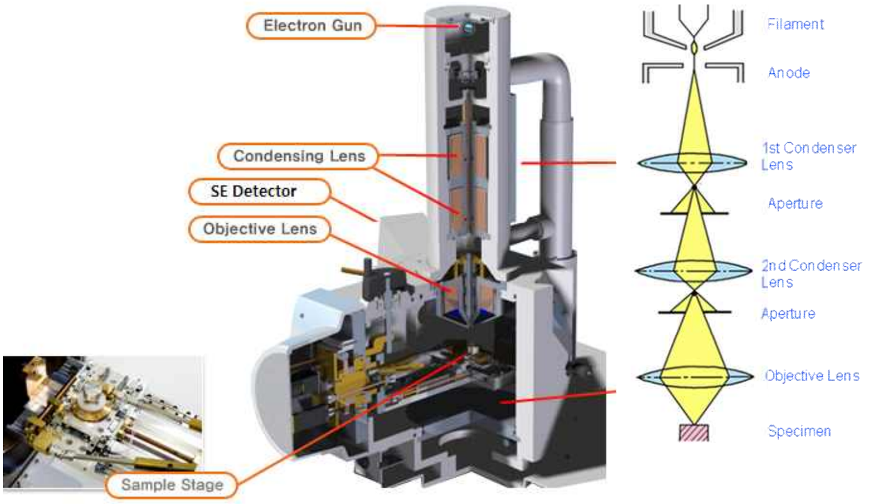
Diffraction & imaging



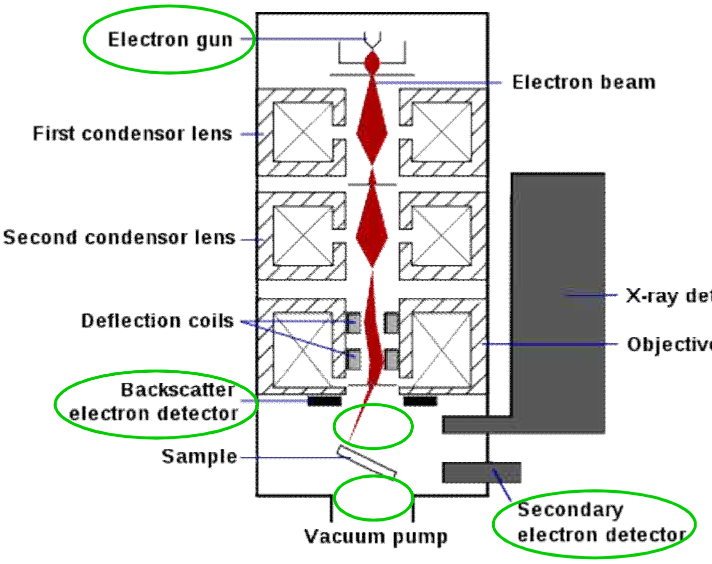
Macro 구조분석 예들…

NanoSEM(Nova600)

Ray diagram of SEM



Ray diagram of SEM



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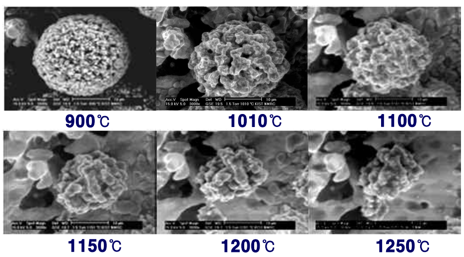
Scanning Electron Microscopes

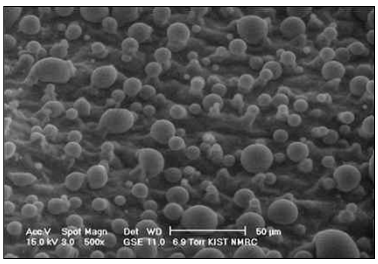
- Nano SEM
- FE-SEM
- E-SEM
- EPMA

FEI XL-30 FEG ESEM

- ✓ 0.2 - 30 kV, 2 nm resolution
- ✓ 10 – 500,000x
- ✓ GSED, SE, BSE detector
- ✓ 10 – 10^{-8} torr
- ✓ Cathodoluminescence (180-850 nm)
- ✓ Heating stage (1500° C)
- ✓ Cooling stage (-30° C)
- ✓ Electron Backscatter Diffraction
- ✓ EDXS for chemical analysis



In-situ heating of WC-Co



Water condensation on Lotus leaf

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Dualbeam Focused Ion Beam

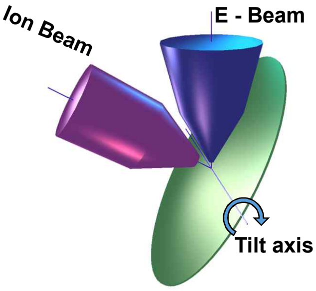
FIB (Nova 600)

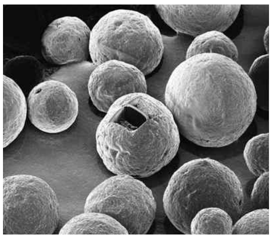
FIB (Helios)

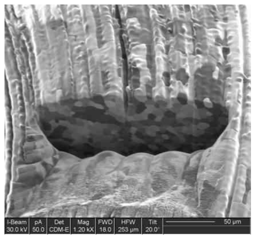
FIB (Quanta 3D)

FEI Nova NanoLab 600

- ✓ FEG e-beam
- ✓ Ga+ ion beam
- ✓ Image resolution : 1 nm
- ✓ 5 - 30 kV, 250 - 1 Mx
- ✓ e-beam size : 0.3 nm and up
- ✓ Ion beam size : 5 - 500 nm
- ✓ Simultaneous milling / imaging

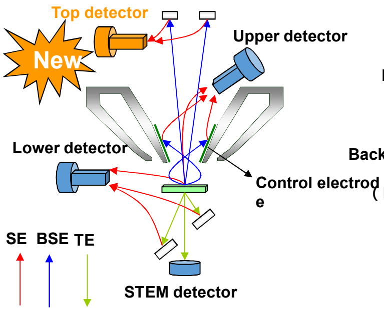


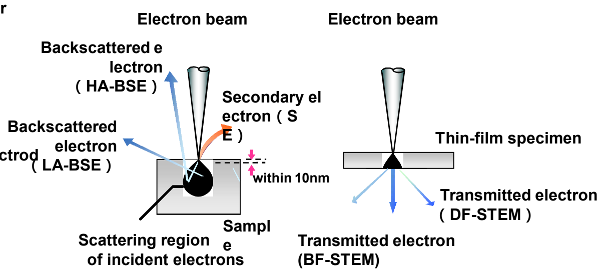




67/120

Top detector to obtain compositional/diffraction contrast of topmost surface

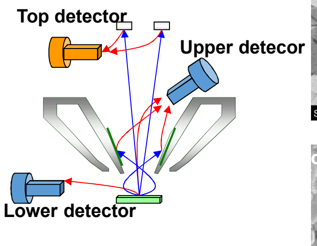


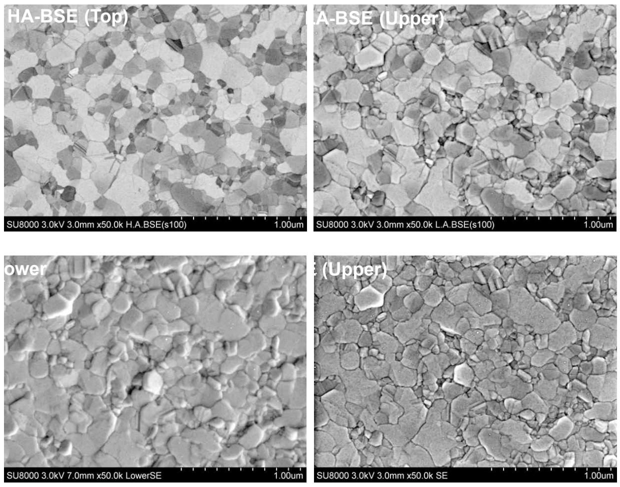


Signal	Abbrev.	Detector	Included information
Backscattered electron	HA-BSE	Top	Compositional + Crystal
Backscattered electron	LA-BSE	Upper	Compositional + Crystal +Topographical (with Charge reduction)
Secondary electron	SE	Upper	surface (incl. Voltage contrast)
Secondary electron	Lower	Lower	Topographical
Transmitted electron	BF-STEM	STEM	Internal + Crystal
Transmitted electron	DF-STEM	Lower	Internal + Compositional

Enhanced signal detection performance

Different contrast from the same field of view for different purpose

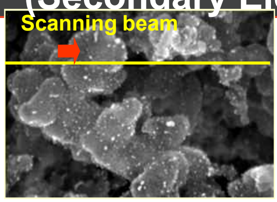


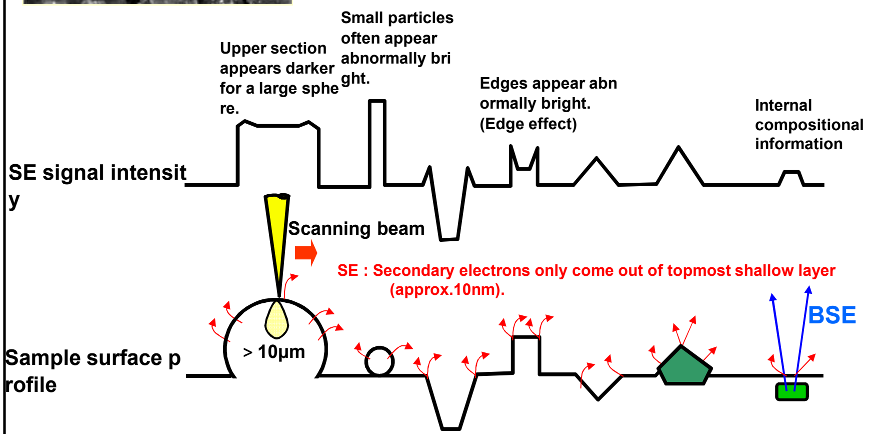


Sample : Surface of Au plating

Signal (Detector)	Included information
HA-BSE (Top)	Compositional + Crystal
LA-BSE (Upper)	Compositional + Crystal + Topographical (with Charge reduction)
SE (Upper)	Topmost surface (Incl. Voltage contrast)
Lower SE (Lower)	Topographical

Review of SEM basic (Secondary Electron excitation volume)





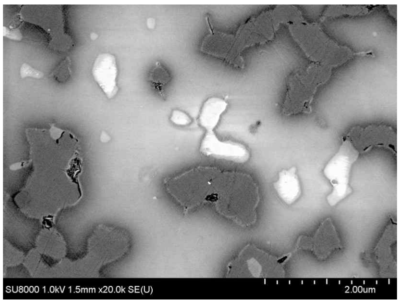
Charge reduction with LA-BSE

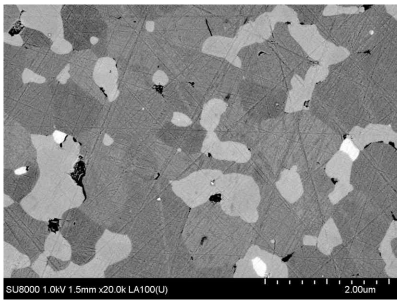
For engineers pursuing advanced technologies・・・

From high voltage imaging to low voltage imaging

Advantage

Reduction of local charging contrast using LA-BSE





Vacc :1kV
Imaging mode: SE

Vacc : 1kV
Imaging mode : LA-BSE

Sample : AlTiC
(Nonconductive sample)

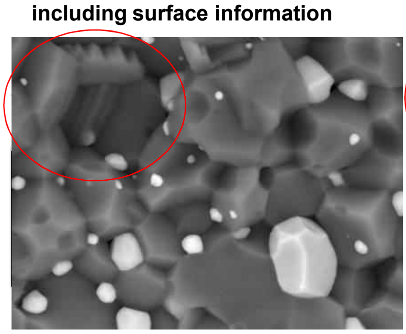
Low acceleration voltage BSE image

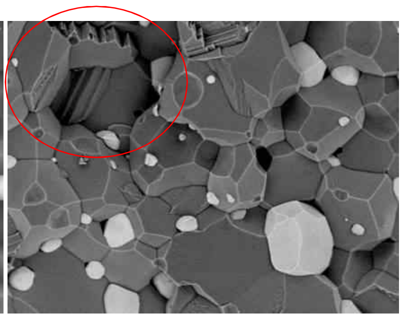
For engineers pursuing advanced technologies・・・

From high voltage imaging to low voltage imaging

Advantage

・ Small interaction volume contributes to the high resolution BSE image including surface information





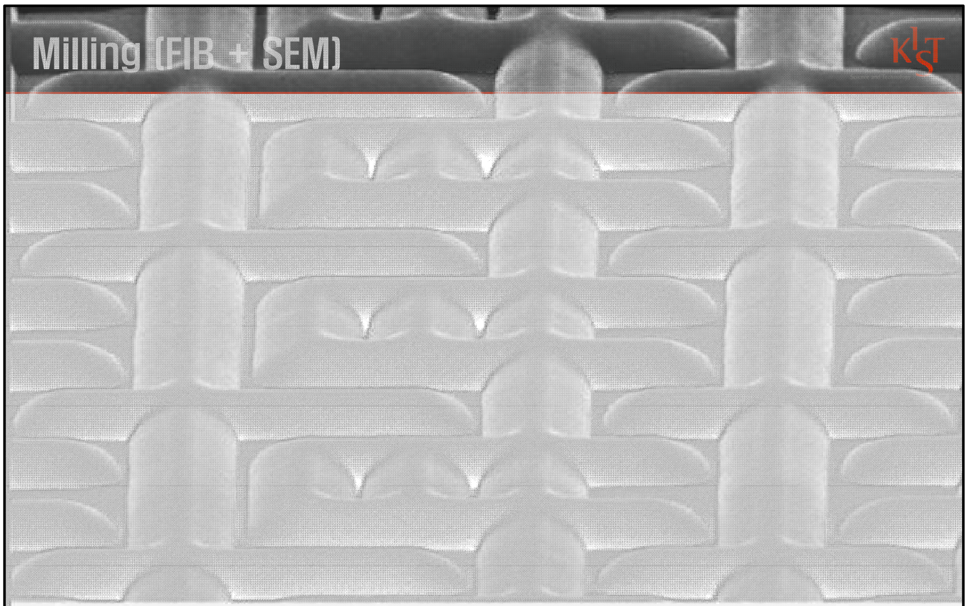
Monte Carlo simulation
incident Volume (Si)

Sample : Ni-Al alloy

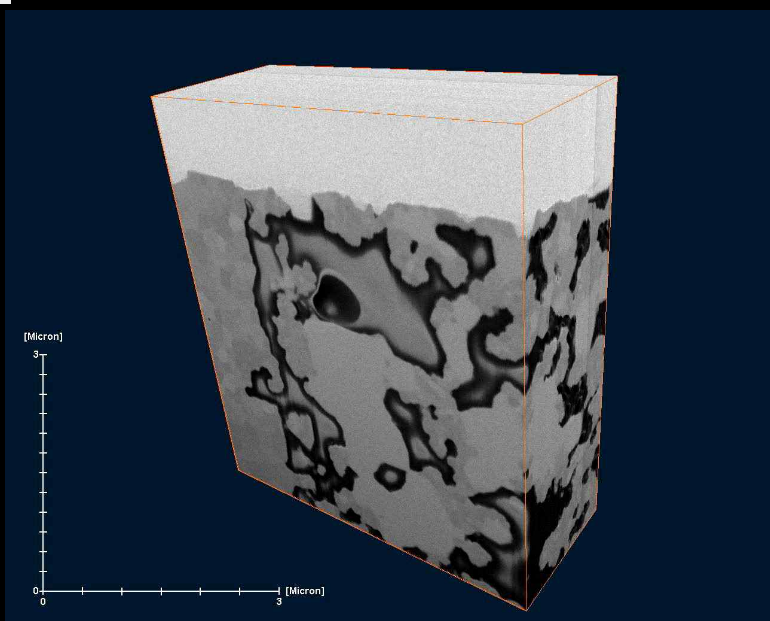
Vacc :10kV
Imaging mode: BSE

Vacc : 1kV
Imaging mode : BSE

Milling (FIB + SEM)



3D_2

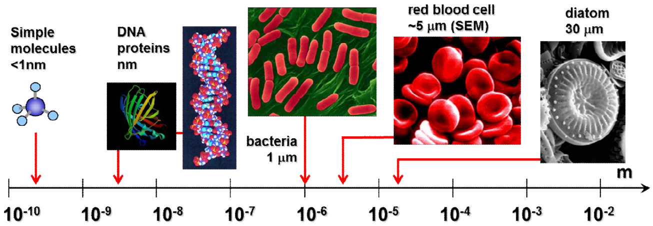


Nano 구조분석 예들…

Nano-characterization, Micron to Nano

- Identification and quantification in the nanometer region
  - Building blocks / electronic structures
  - Arrangement of building blocks
  - Mechanical response / chemical reaction etc.

- Chemical and Physical properties.
  - How the material "behaves" at the nano-scale!



Analytical TEM | DualBeam FIB | Analytical SEM

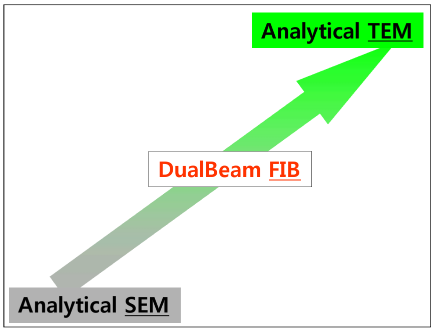
Higher resolution ← → Larger field of view

Nano-characterization, Micron to Nano

Crystal structure
Nanostructure
Chemistry

Information ↕

Morphology
Chemistry

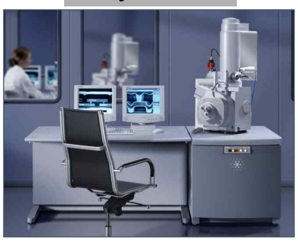


Requirements

➢ Imaging resolution	nm	↔	Å
➢ Analytical resolution	µm	↔	nm
➢ Sample size	150 mm	↔	10 µm
➢ Sample preparation	Bulk	↔	Foil
➢ Contrast mechanism	Topography	↔	Diffraction
➢ Dimensions	Projection	↔	Tomography

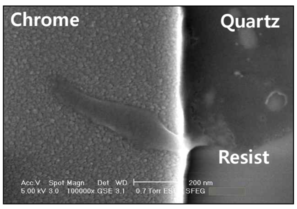
Microscopes for Nano-Analysis

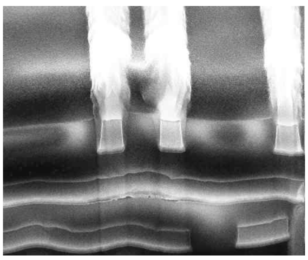
Analytical SEM

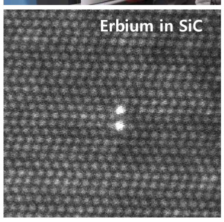


DualBeam FIB

Analytical TEM



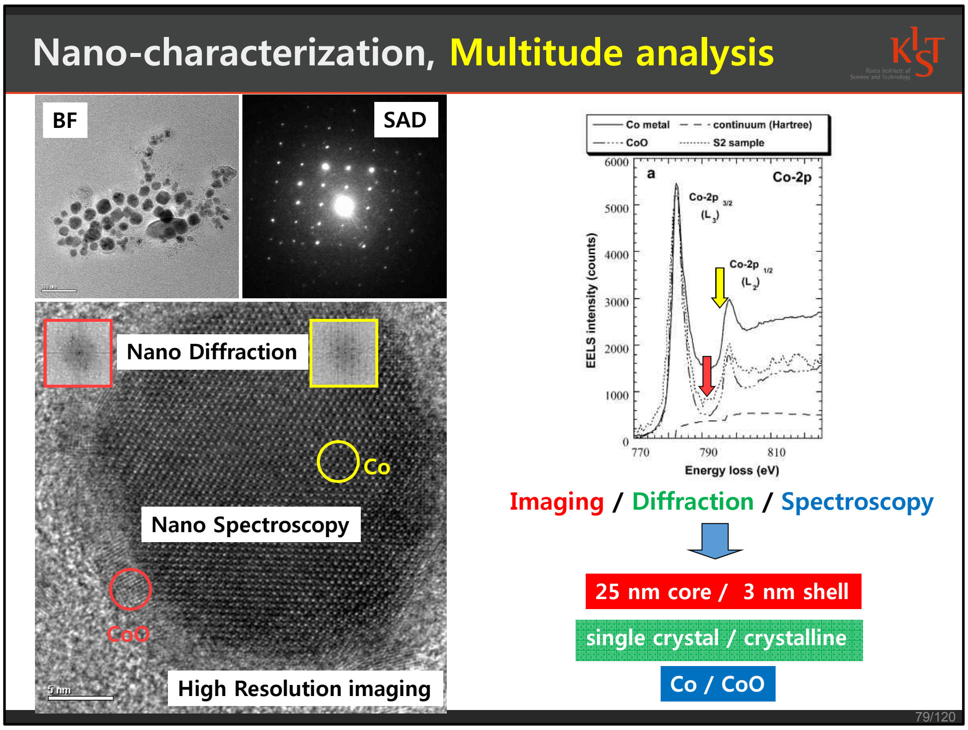


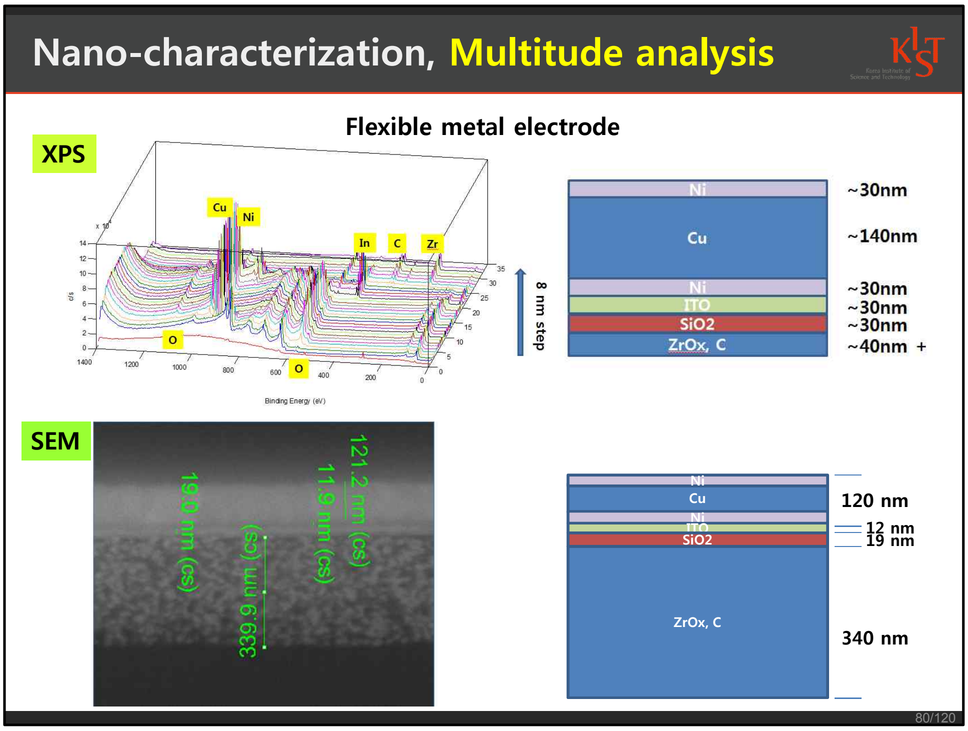


Large area surface imaging

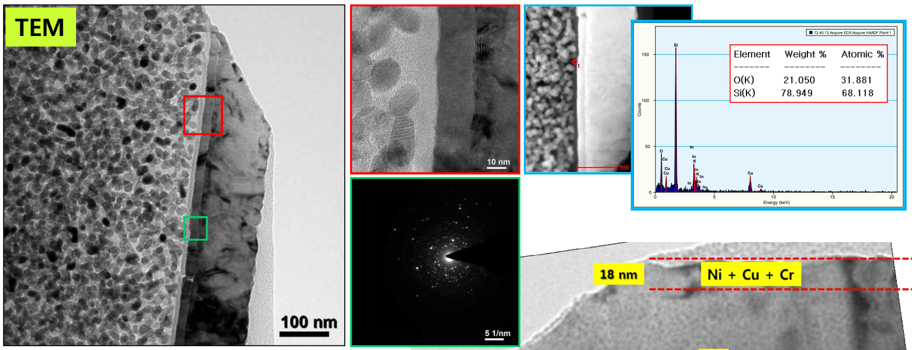
Large area sub-surface imaging

Small area internal imaging

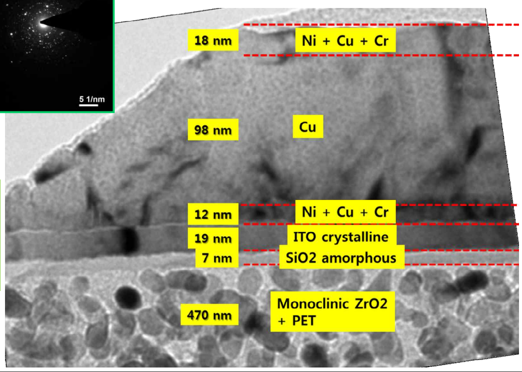

Nano-characterization, Multitude analysis
KIST
BF
SAD
Nano Diffraction
Co
Nano Spectroscopy
CoO
5 nm
High Resolution imaging
Co metal
CoO
continuum (Hartree)
S2 sample
a
Co-2p
Co-2p 3/2 (L3)
Co-2p 1/2 (L2)
EELS intensity (counts)
Energy loss (eV)
Imaging / Diffraction / Spectroscopy
25 nm core / 3 nm shell
single crystal / crystalline
Co / CoO
79/120


Nano-characterization, Multitude analysis
KIST
Flexible metal electrode
XPS
Cu
Ni
In
C
Zr
O
Binding Energy (eV)
8 nm step
Ni
Cu
Ni
ITO
SiO2
ZrOx, C
~30nm
~140nm
~30nm
~30nm
~30nm
~40nm +
SEM
19.0 nm (cs)
339.9 nm (cs)
11.9 nm (cs)
121.2 nm (cs)
Ni
Cu
Ni
ITO
SiO2
ZrOx, C
120 nm
12 nm
19 nm
340 nm
80/120

Nano-characterization, Multitude analysis

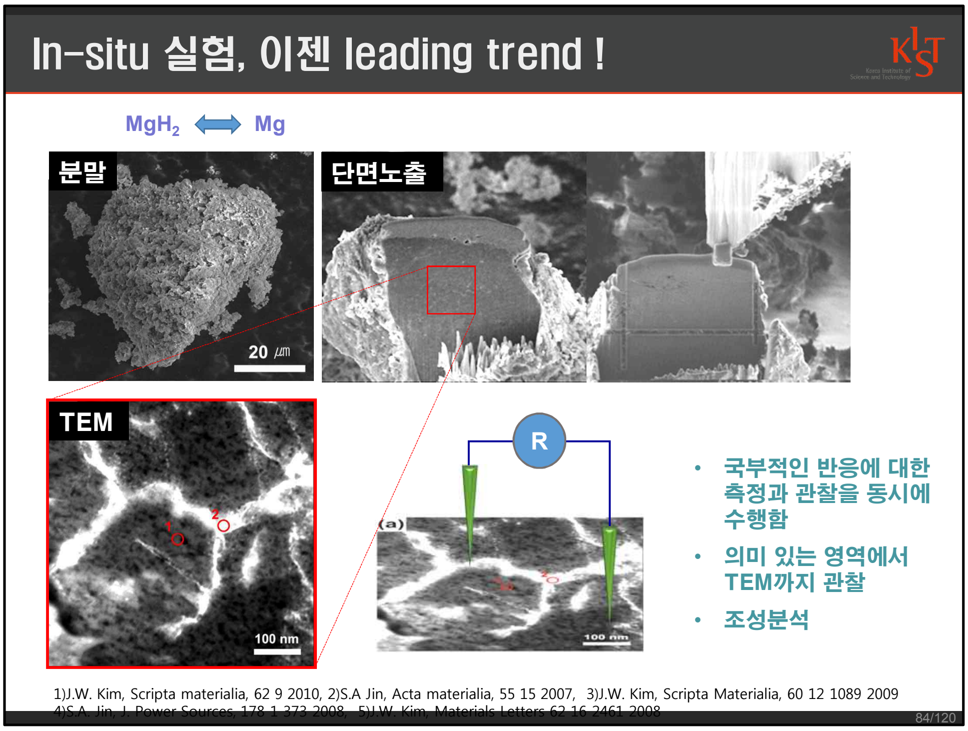


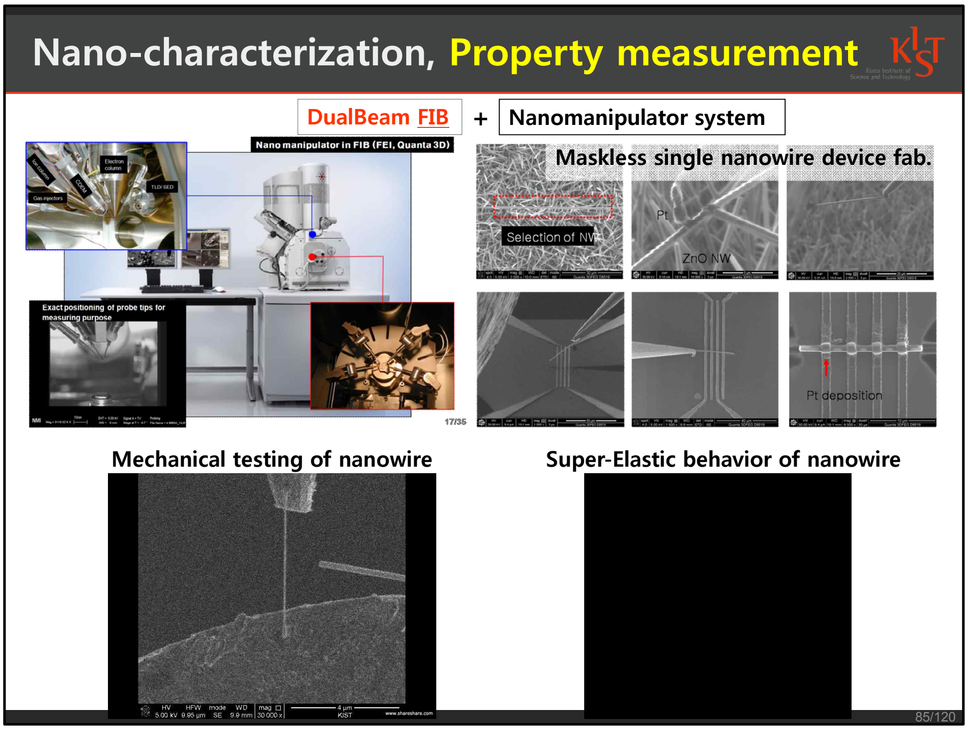
영상법 : 미세구조 관찰 (영상분해능 ~ 0.1 nm)
회절법 : 결정구조 분석 (공간분해능 ~ 0.1 nm)
분광법 : 화학조성 분석 (공간분해능 ~ 0.1 nm)

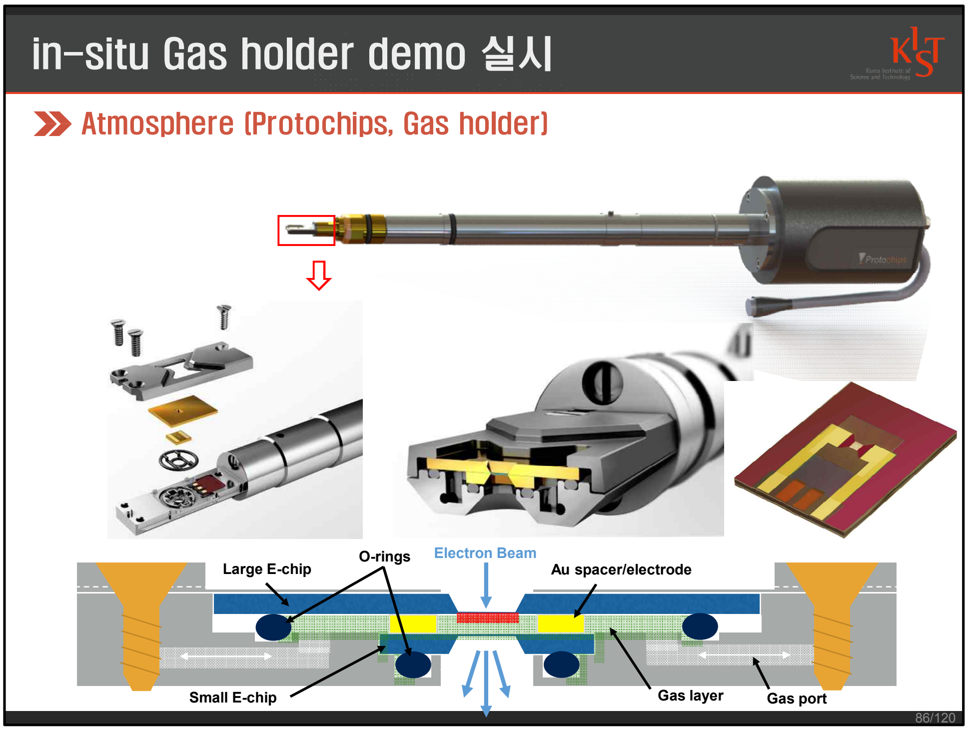


In-situ TEM
(gas, liquid, T, P)

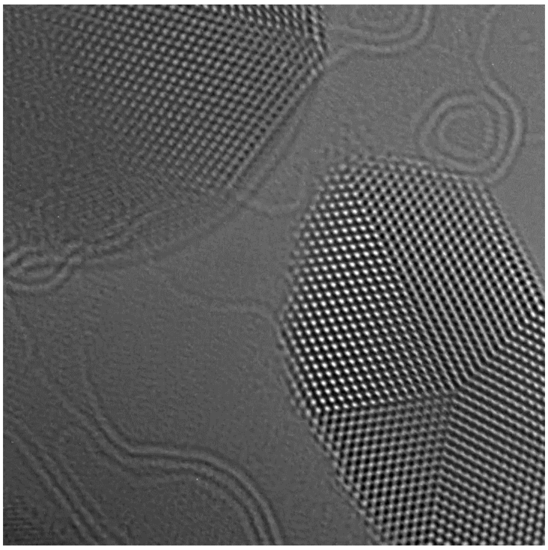

In-situ 실험, 이젠 leading trend !
Kinetics
Cooling & heating
스펙트럼
EDX
광학
CL
e⁻
전기적 특성 측정과 구조분석을 동시에 수행하여
하나의 시료로부터 종합적인 정보를 추출함
Heating & Cooling
기계적특성
Nano probe
구조분석
FIB
TEM
5.1 Å
5 nm
전기적특성
소자제작
전기특성
I-V
83 / 93
83/120


In-situ 실험, 이젠 leading trend !
MgH2 ⟷ Mg
분말
20 ㎛
단면노출
TEM
100 nm
R
(a)
• 국부적인 반응에 대한 측정과 관찰을 동시에 수행함
• 의미 있는 영역에서 TEM까지 관찰
• 조성분석
1)J.W. Kim, Scripta materialia, 62 9 2010, 2)S.A Jin, Acta materialia, 55 15 2007, 3)J.W. Kim, Scripta Materialia, 60 12 1089 2009
4)S.A. Jin, J. Power Sources, 178 1 373 2008, 5)J.W. Kim, Materials Letters 62 16 2461 2008
84/120


Nano-characterization, Property measurement
KIST
DualBeam FIB
+
Nanomanipulator system
Nano manipulator in FIB (FEI, Quanta 3D)
Exact positioning of probe tips for measuring purpose
Maskless single nanowire device fab.
Selection of NW
Pt
ZnO NW
Pt deposition
Mechanical testing of nanowire
Super-Elastic behavior of nanowire
85/120


in-situ Gas holder demo 실시
KIST
Atmosphere (Protochips, Gas holder)
Large E-chip
O-rings
Electron Beam
Au spacer/electrode
Small E-chip
Gas layer
Gas port
86/120

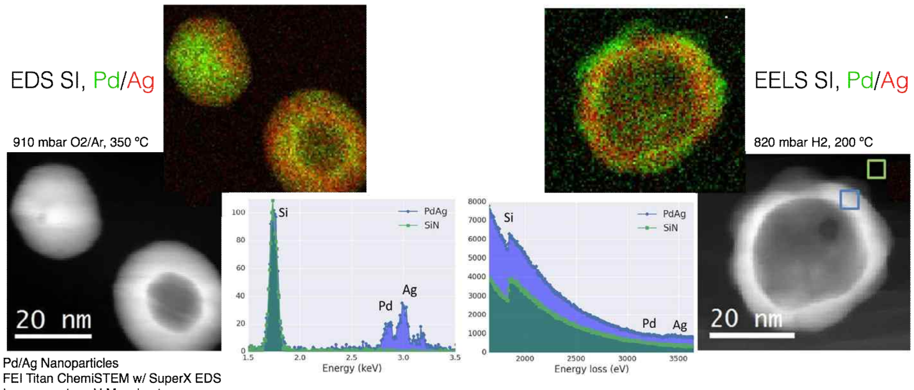
In-situ heating



Surface change of Au nanoparticles at 600℃

https://www.youtube.com/watch?v=Jtq2Qy-UKx0 , from Proto chips

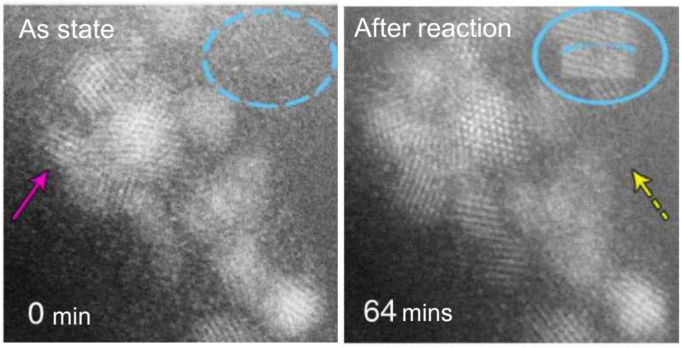
EDS & EELS analysis at specific pressure and temperature

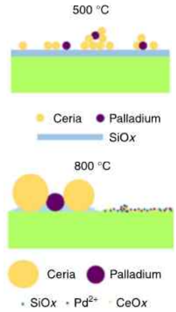


Pd/Ag Nanoparticles
FEI Titan ChemiSTEM w/ SuperX EDS
Image courtesy U Manchester

CASE-2 : Methane combustion catalysts

- **Solution:** Atmosphere system with 150 Torr O_2 to mimic calcination conditions
- **Results:** Confirmed the formation of the two distinct structures – larger nanoparticles and highly dispersed atomic-scale clusters possibly stabilized by silicon.

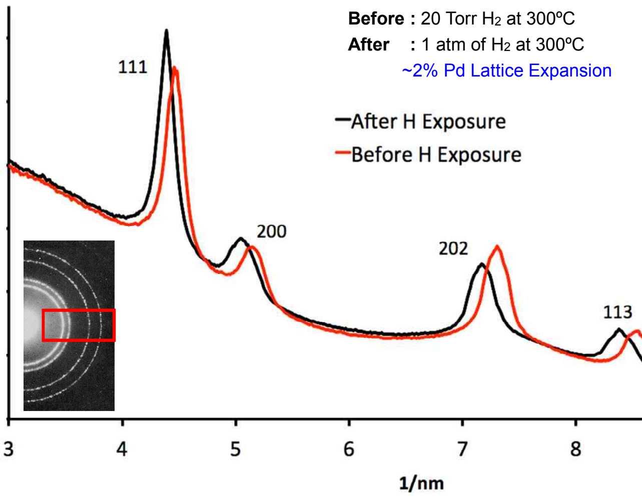


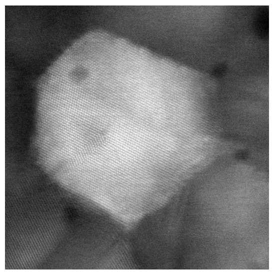


Pd@CeO_2 At 150 Torr O_2, 500 °C

Zhang, Shuyi, et al. Nature communications 6 (2015). 7778-

Case-3 : Hydrogen absorption in palladium



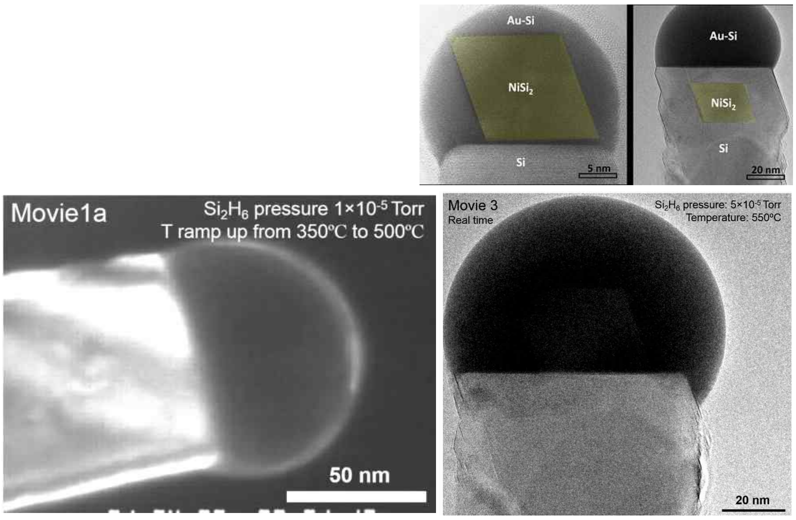


Courtesy Univ of Manchester
& Karlsruhe Inst of Tech
FEI Titan

Protochips Application notes. AG80.3

New Capabilities for new science

Static → Dynamic



Synthesis of nanostructures in nanowires using sequential catalyst reactions
F. Panciera, Y.-C. Chou, M. C. Reuter, D. Zakharov, E. A. Stach, S. Hofmann and F. M. Ross
NATURE MATERIALS, 14 , 820-826, 2015

91/120

제언

- 2017년 국가연구장비 현황
- SEM과 TEM의 주요 기능에 바탕을 둔 주변 장비
  - ion miller
  - cp
  - in-situ TEM (Protochips, Dens)
  - in-situ SEM
  - Air SEM
  - Plasma cleaner
  - SEM-groove box 연결
- 전자현미경의 진화를 위한 진공기술
  (조인트, 프랜지, 펌프, 피드쓰루, 디텍터, 노이즈)

92/120

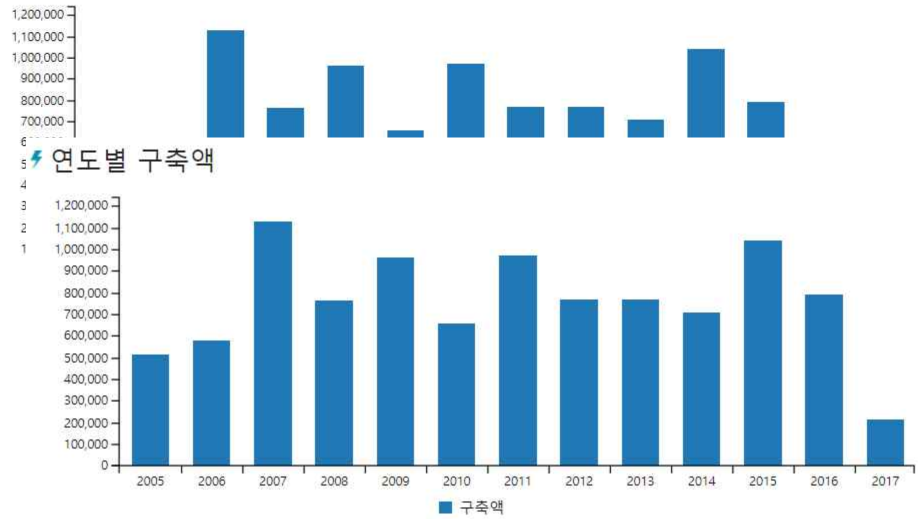
보조자료

94/120

2017년 국가연구장비 현황

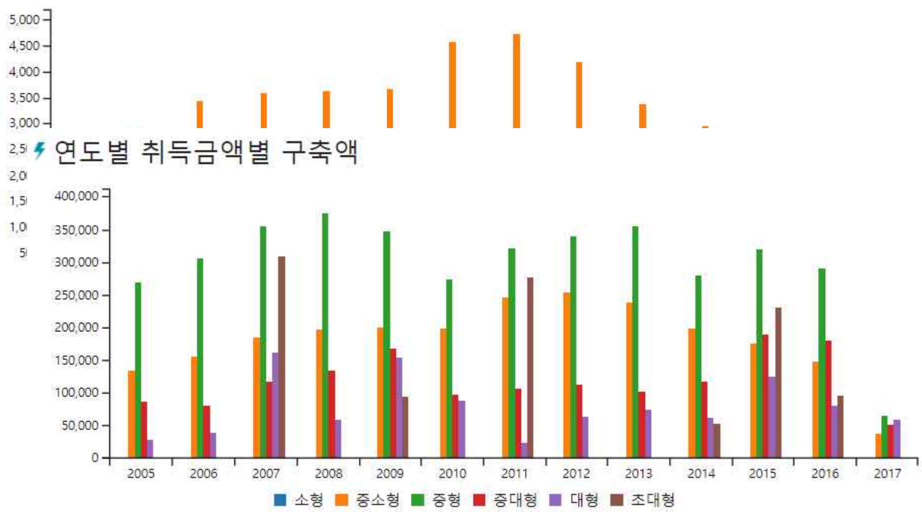
연도별 구축액

연도별 구축액



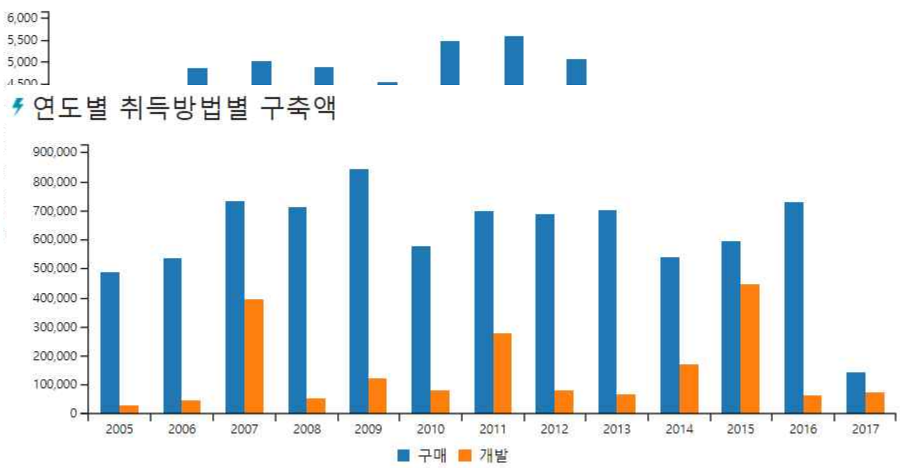
연도별 취득금액별 구축액

연도별 취득금액별 구축수



연도별 취득방법별 구축액

연도별 취득방법별 구축수



연도별 국산/외산별 구축액

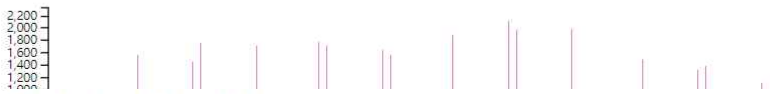
연도별 국산/외산별 구축수

연도별 국산/외산별 구축액

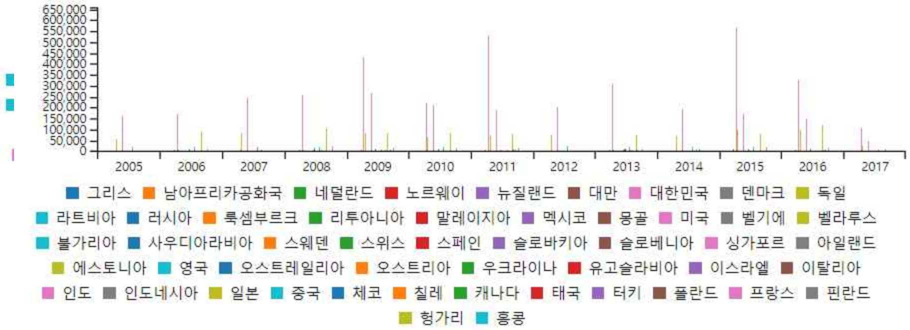
99/120

연도별 제작국가별 구축액

연도별 제작국가별 구축수

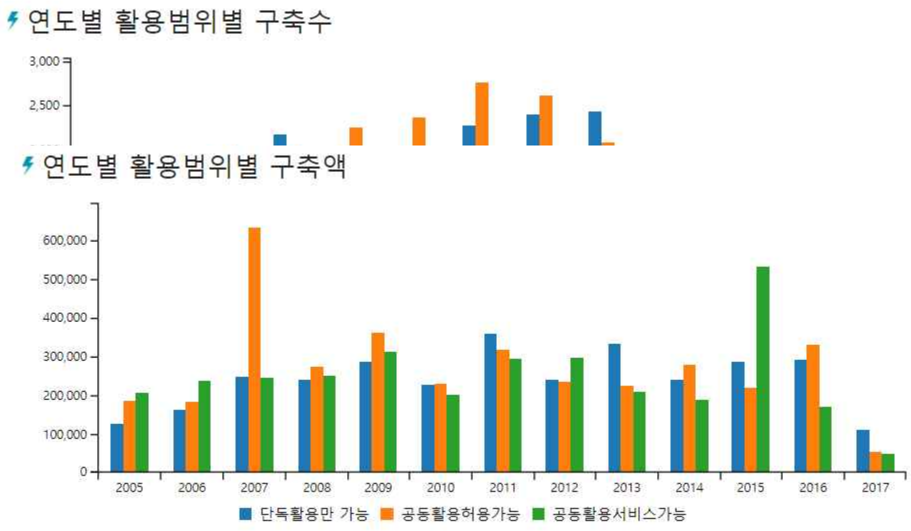


연도별 제작국가별 구축액

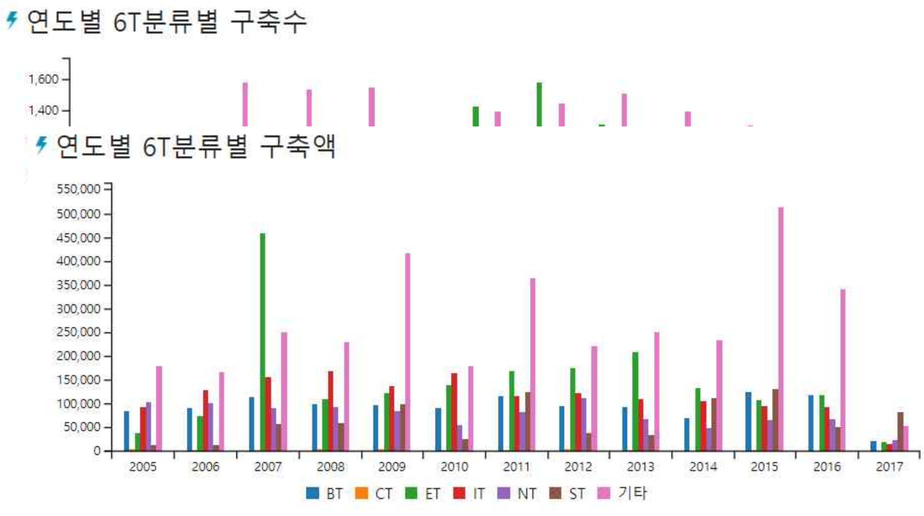


100/120

연도별 활용범위별 구축액



연도별 6T 분류별 구축액

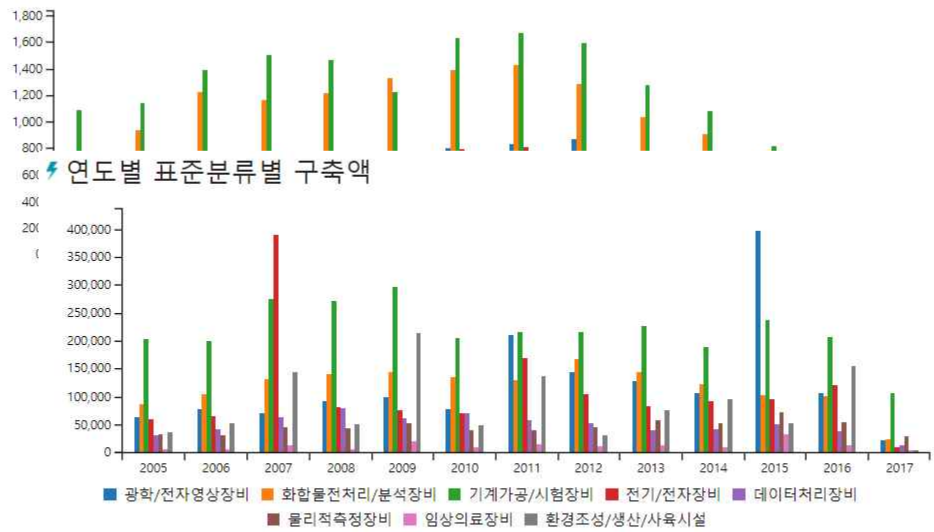


연도별 표준 분류별 구축액

KIST

연도별 표준분류별 구축수

연도별 표준분류별 구축액

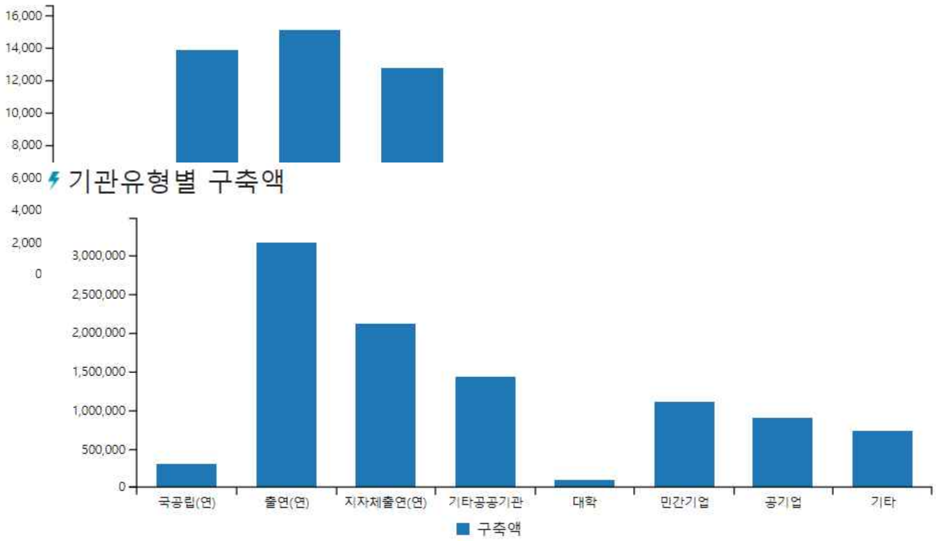


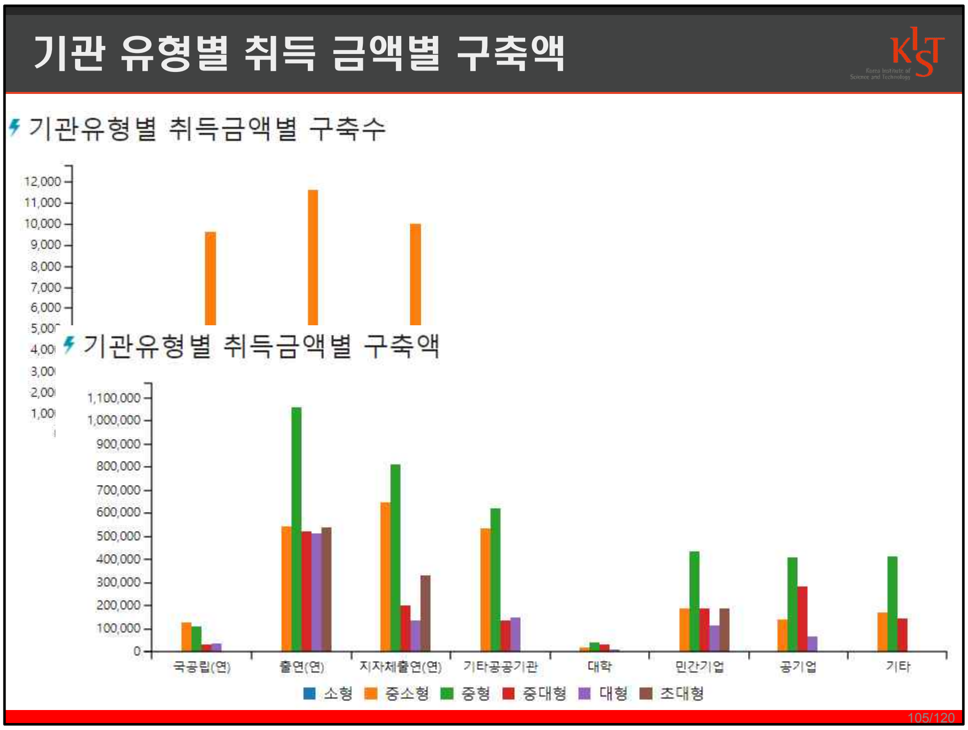
기관 유형별 구축액

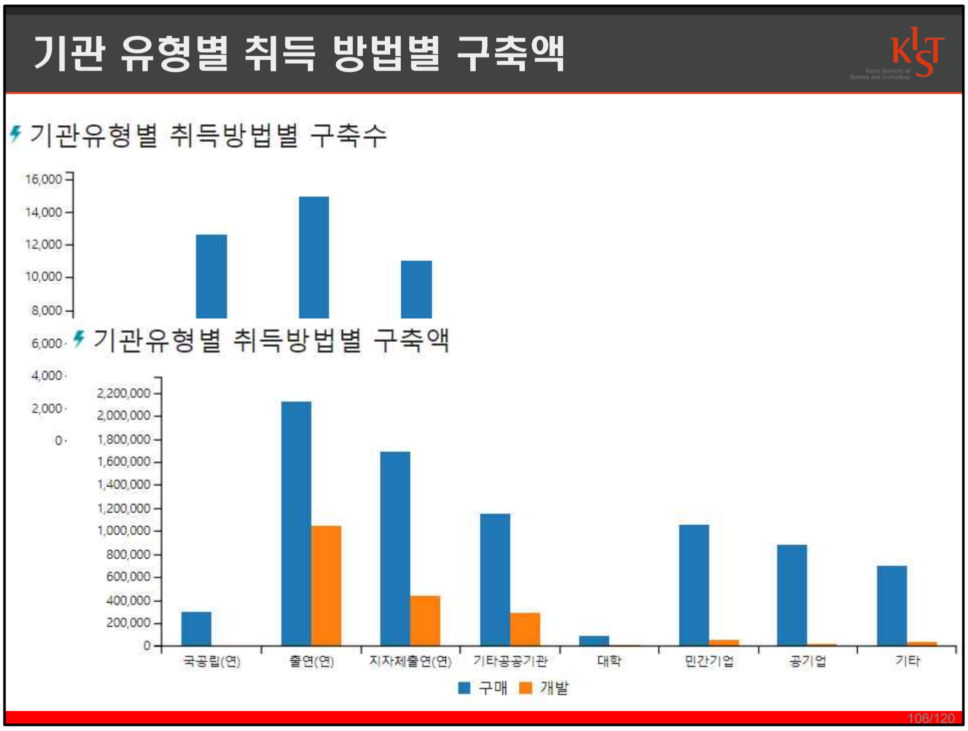
KIST

기관유형별 구축수

기관유형별 구축액

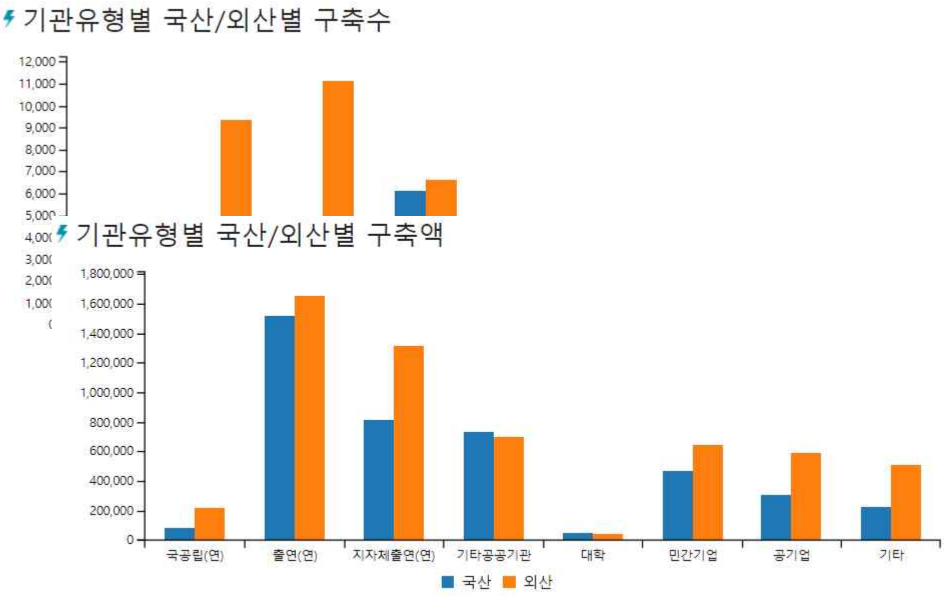



기관 유형별 취득 금액별 구축액
기관유형별 취득금액별 구축수
12,000
11,000
10,000
9,000
8,000
7,000
6,000
기관유형별 취득금액별 구축액
1,100,000
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
국공립(연)
출연(연)
지자체출연(연)
기타공공기관
대학
민간기업
공기업
기타
소형
중소형
중형
중대형
대형
초대형
105/120


기관 유형별 취득 방법별 구축액
기관유형별 취득방법별 구축수
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
기관유형별 취득방법별 구축액
2,200,000
2,000,000
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
국공립(연)
출연(연)
지자체출연(연)
기타공공기관
대학
민간기업
공기업
기타
구매
개발
106/120

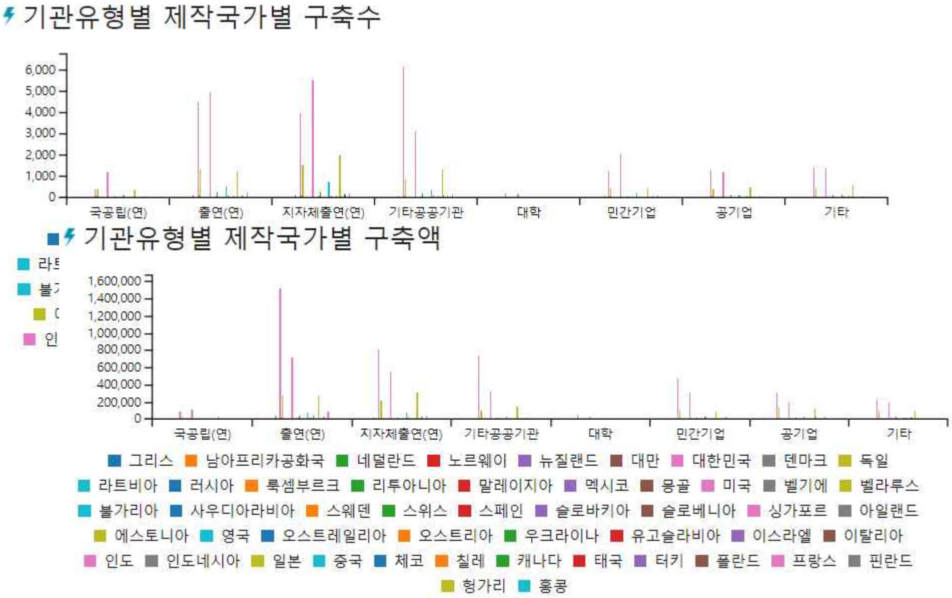
기관 유형별 국산/외산별 구축액

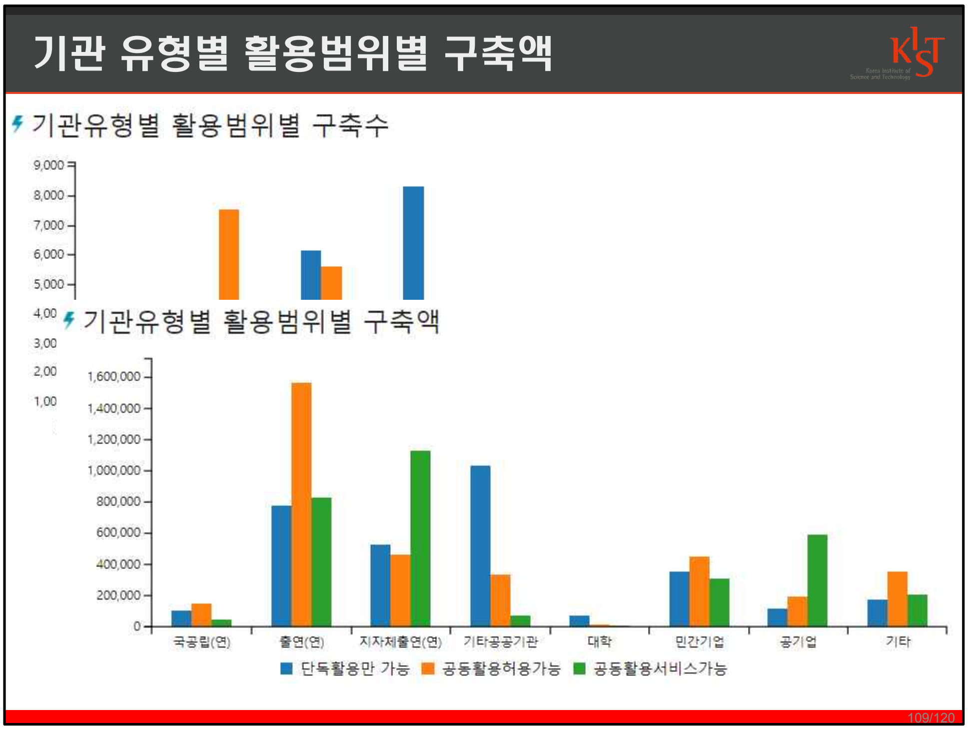
KIST

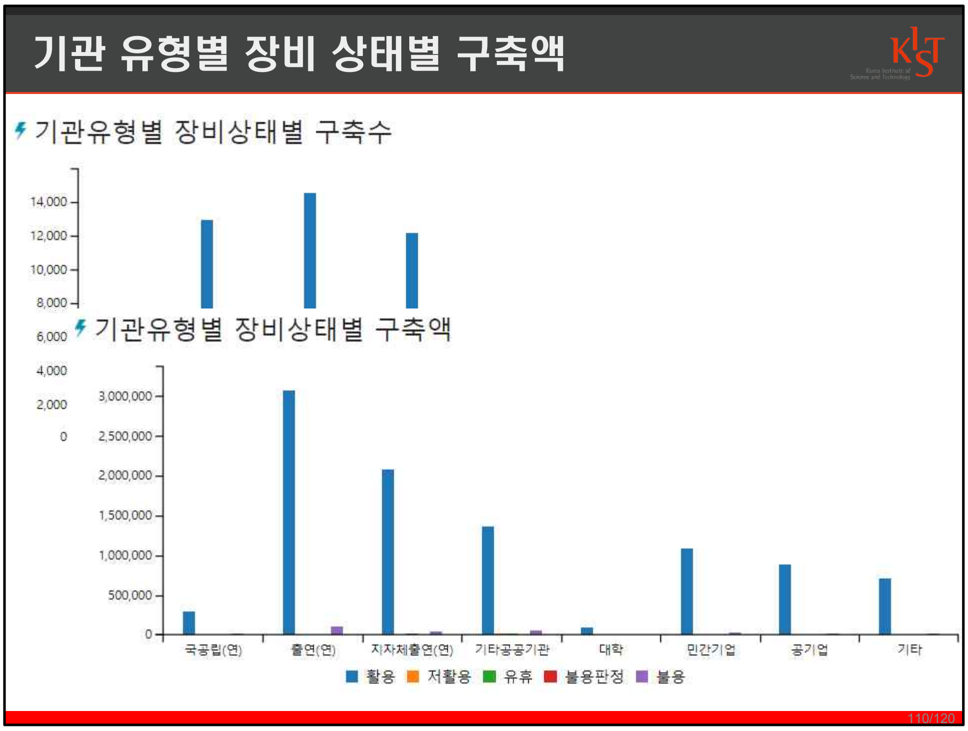


기관 유형별 제작 국가별 구축액

KIST

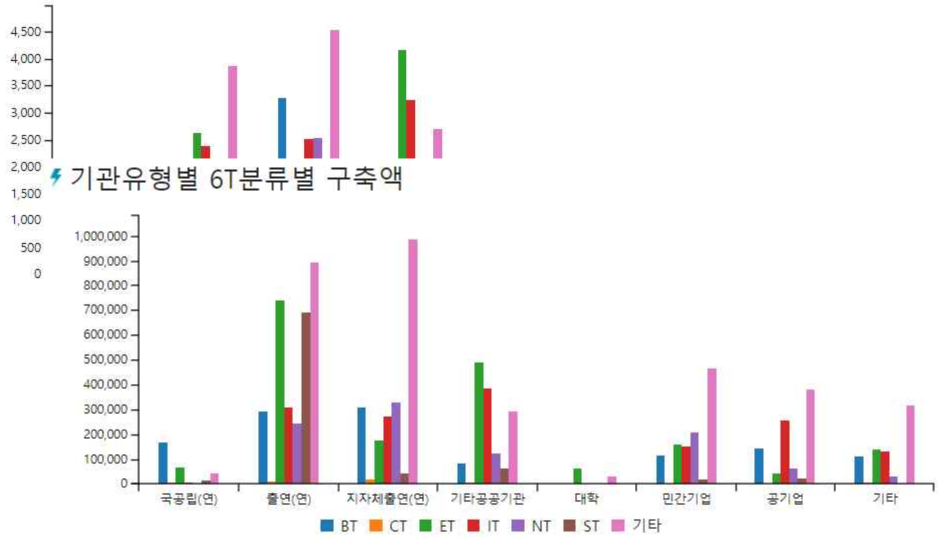



기관 유형별 활용범위별 구축액
기관유형별 활용범위별 구축수
9,000
8,000
7,000
6,000
5,000
기관유형별 활용범위별 구축액
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
국공립(연)
출연(연)
지자체출연(연)
기타공공기관
대학
민간기업
공기업
기타
단독활용만 가능
공동활용허용가능
공동활용서비스가능
109/120


기관 유형별 장비 상태별 구축액
기관유형별 장비상태별 구축수
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
기관유형별 장비상태별 구축액
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
국공립(연)
출연(연)
지자체출연(연)
기타공공기관
대학
민간기업
공기업
기타
활용
저활용
유휴
불용판정
불용
110/120

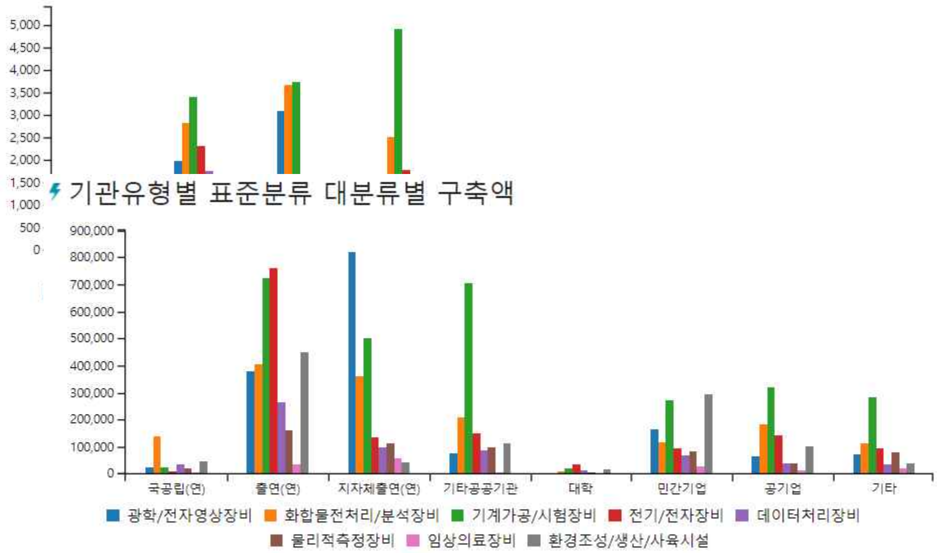
기관 유형별 6T 분류별 구축액

기관유형별 6T분류별 구축수

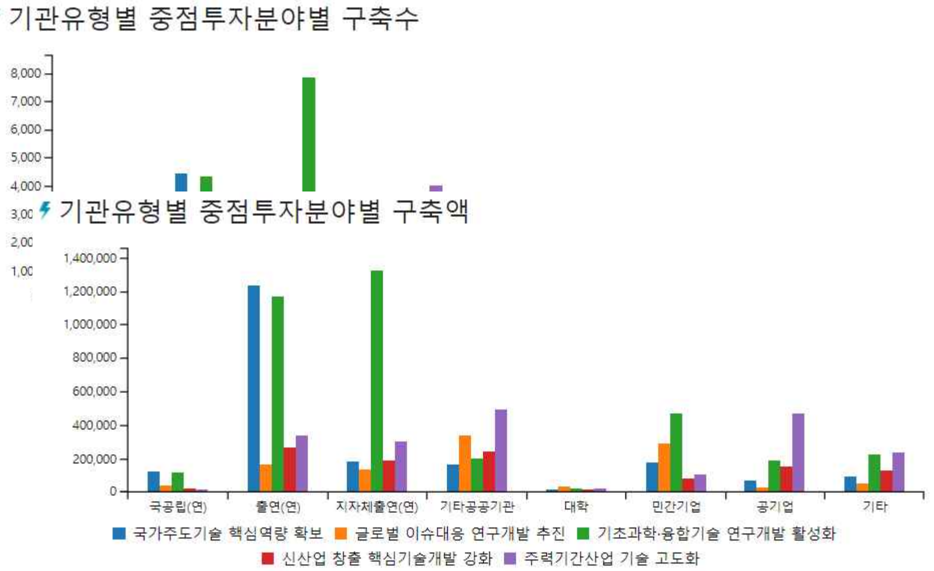


기관 유형별 표준분류 대분별 구축액

기관유형별 표준분류 대분류별 구축수



기관 유형별 중점투자 분야별 구축액



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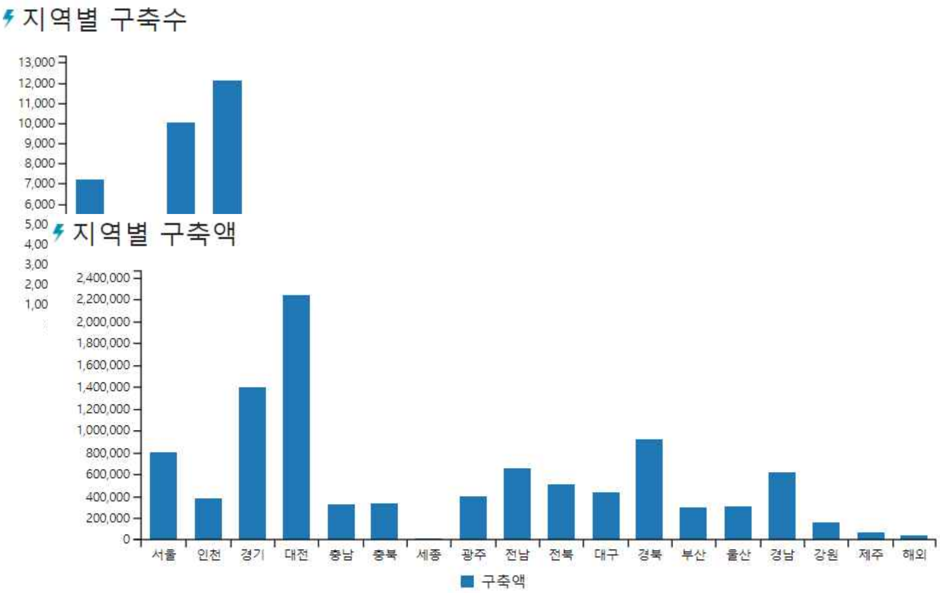
지역별 구축액



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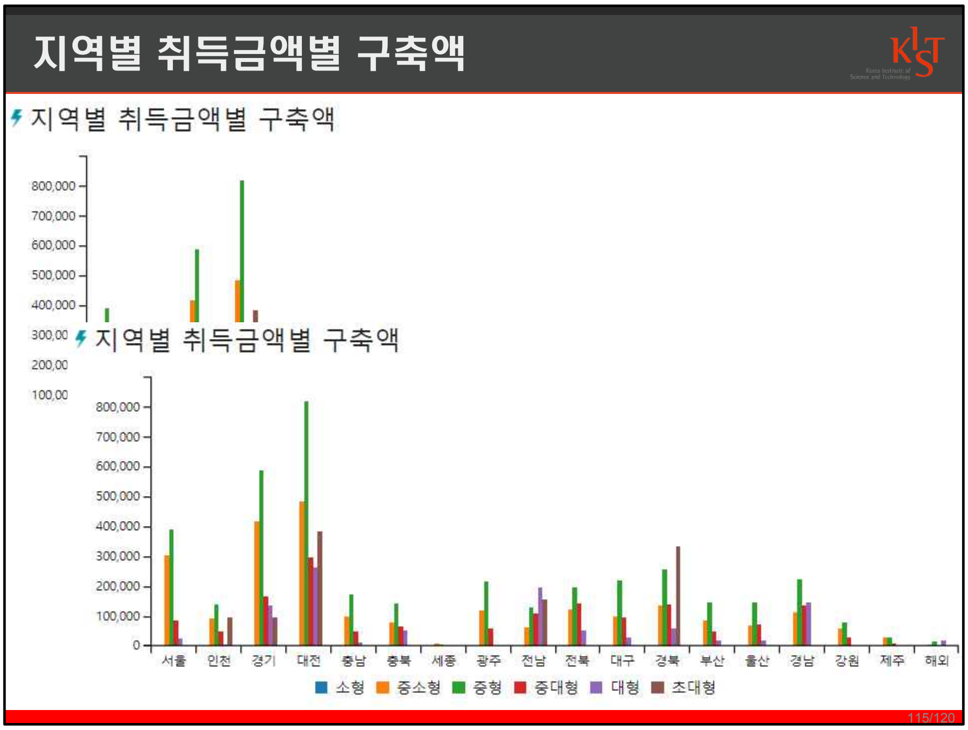
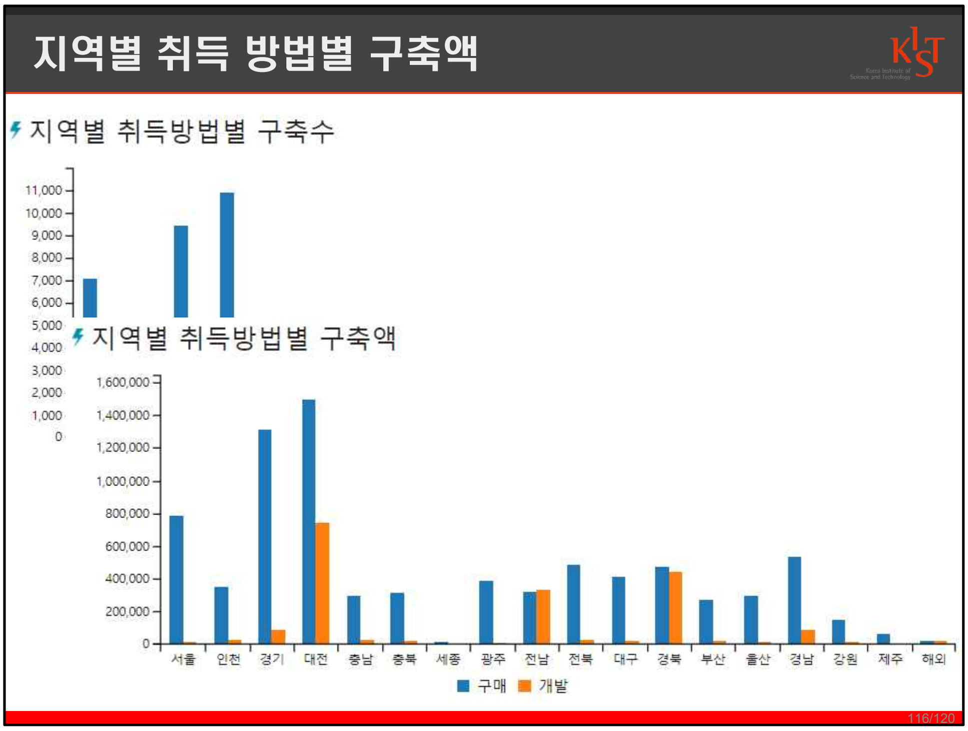
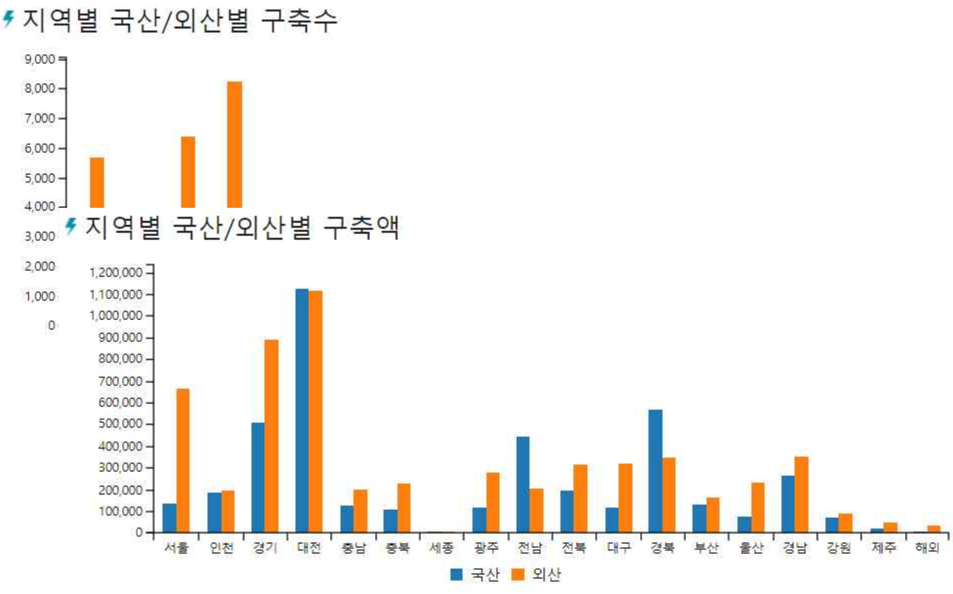
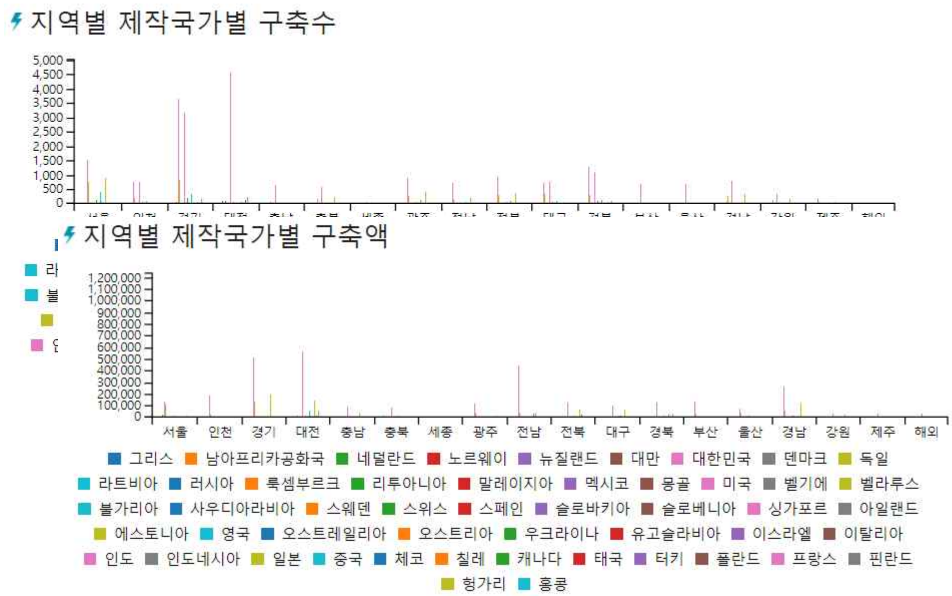

지역별 취득금액별 구축액
지역별 취득금액별 구축액
800,000
700,000
600,000
500,000
400,000
지역별 취득금액별 구축액
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
서울 인천 경기 대전 충남 충북 세종 광주 전남 전북 대구 경북 부산 울산 경남 강원 제주 해외
소형 중소형 중형 중대형 대형 초대형
115/120

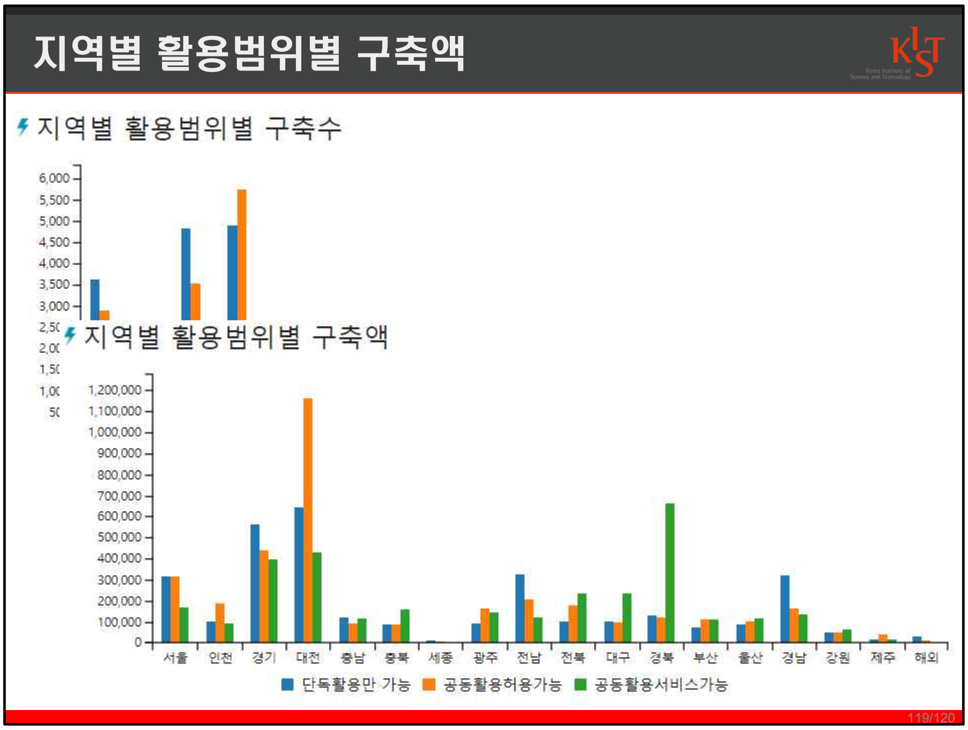

지역별 취득 방법별 구축액
지역별 취득방법별 구축수
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
지역별 취득방법별 구축액
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
서울 인천 경기 대전 충남 충북 세종 광주 전남 전북 대구 경북 부산 울산 경남 강원 제주 해외
구매 개발
116/120

지역별 국산/외산별 구축액

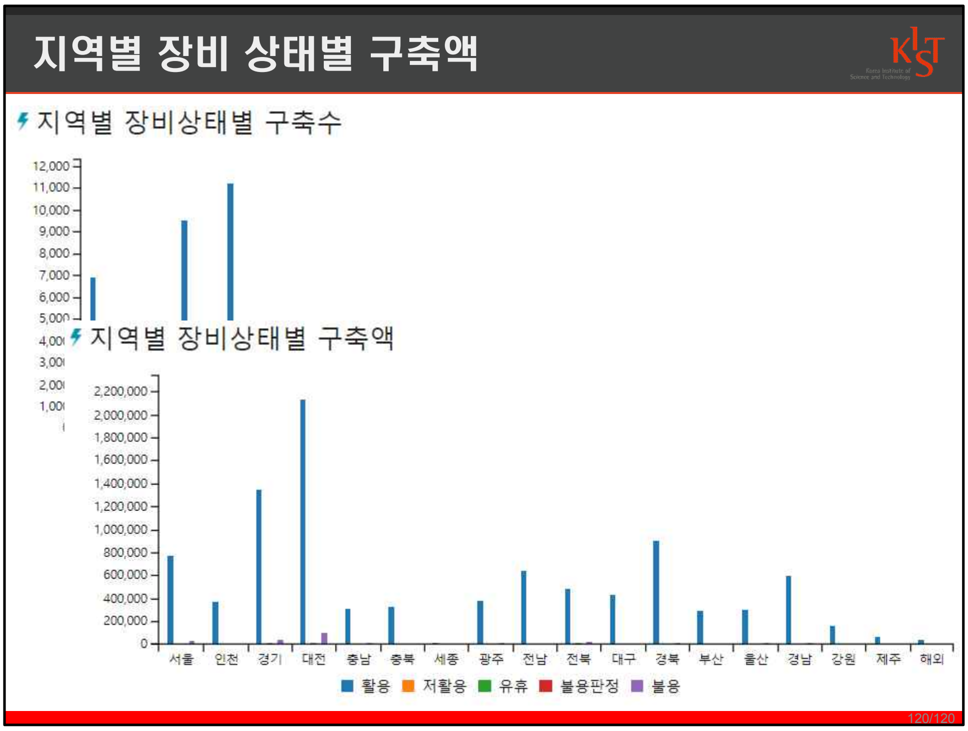


지역별 제작 국가별 구축액





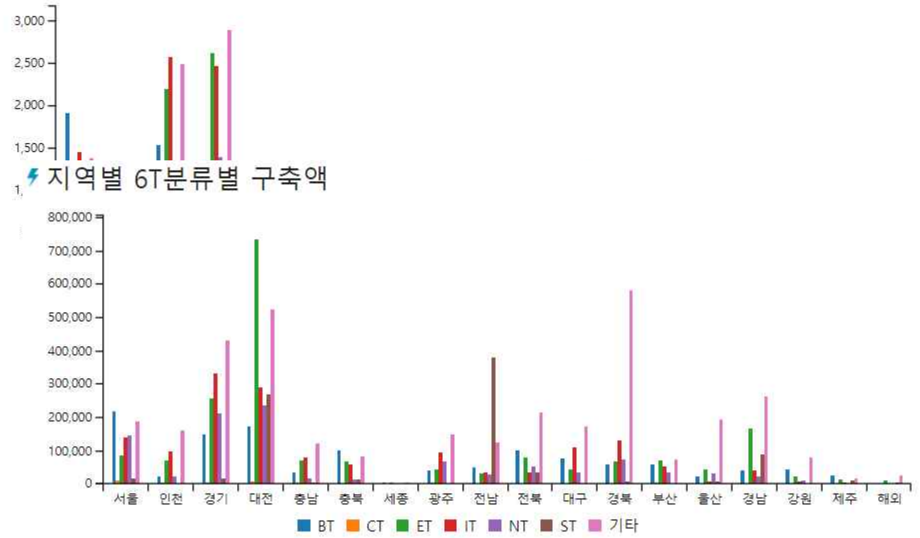
지역별 활용범위별 구축액
KIST
지역별 활용범위별 구축수
지역별 활용범위별 구축액
서울 인천 경기 대전 충남 충북 세종 광주 전남 전북 대구 경북 부산 울산 경남 강원 제주 해외
단독활용만 가능
공동활용허용가능
공동활용서비스가능
119/120



지역별 장비 상태별 구축액
KIST
지역별 장비상태별 구축수
지역별 장비상태별 구축액
서울 인천 경기 대전 충남 충북 세종 광주 전남 전북 대구 경북 부산 울산 경남 강원 제주 해외
활용
저활용
유휴
불용판정
불용
120/120

지역별 6T 분류별 추축액

지역별 6T분류별 구축수



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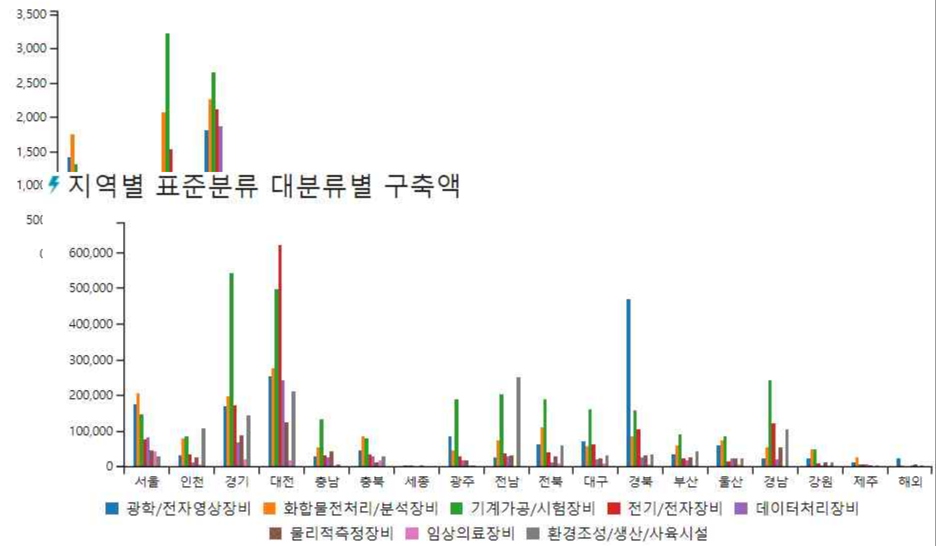
지역별 표준분류 대분류별 구축액

지역별 표준분류 대분류별 구축수



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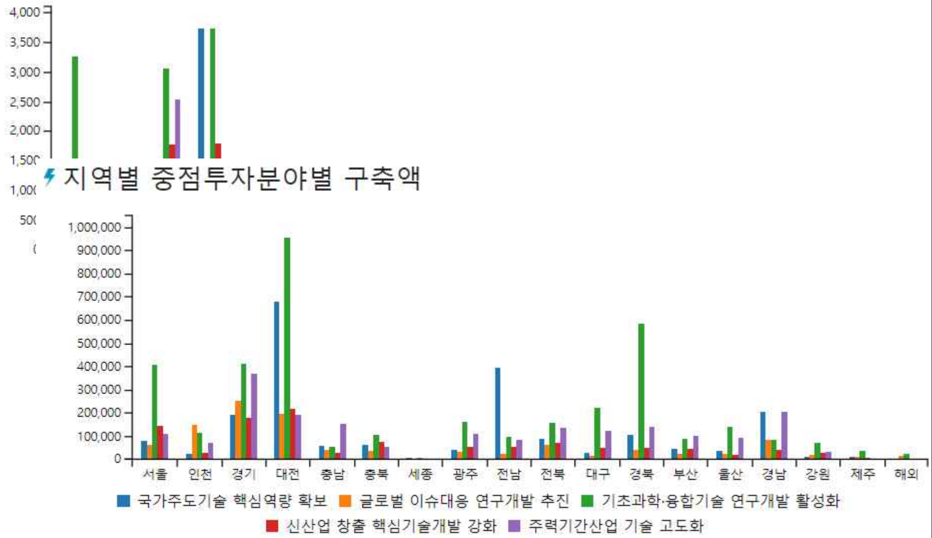
지역별 중점 투자 분야별 구축액

지역별 중점투자분야별 구축수

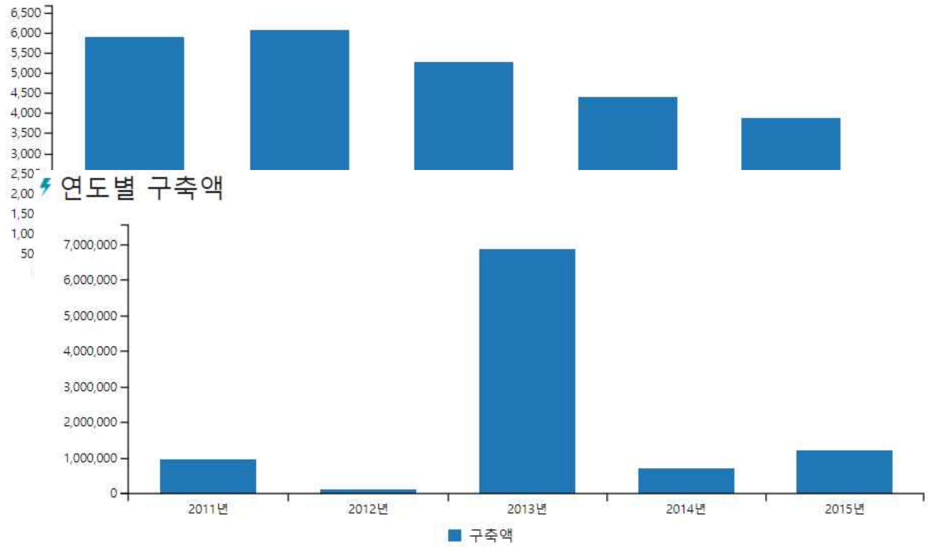
지역별 중점투자분야별 구축액

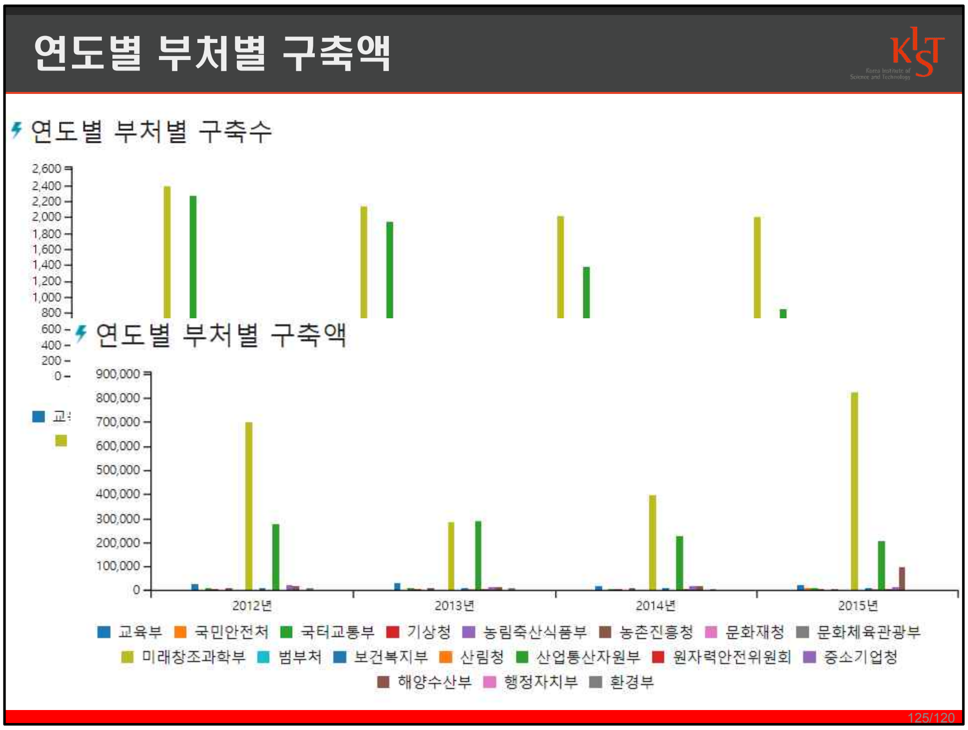


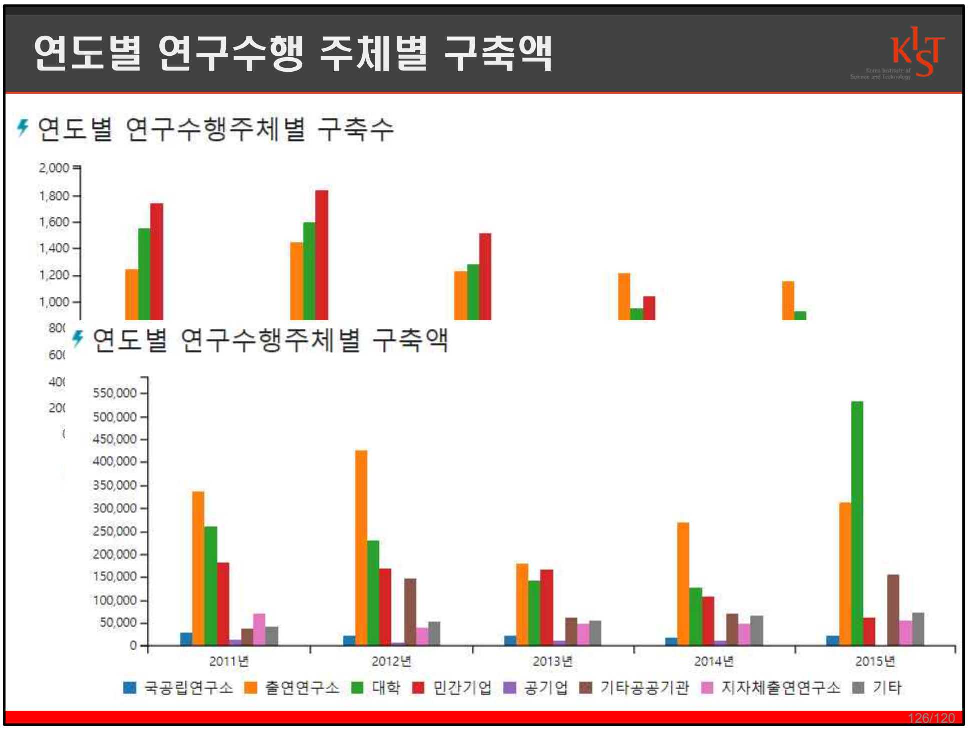
연도별 구축액

연도별 구축수

연도별 구축액

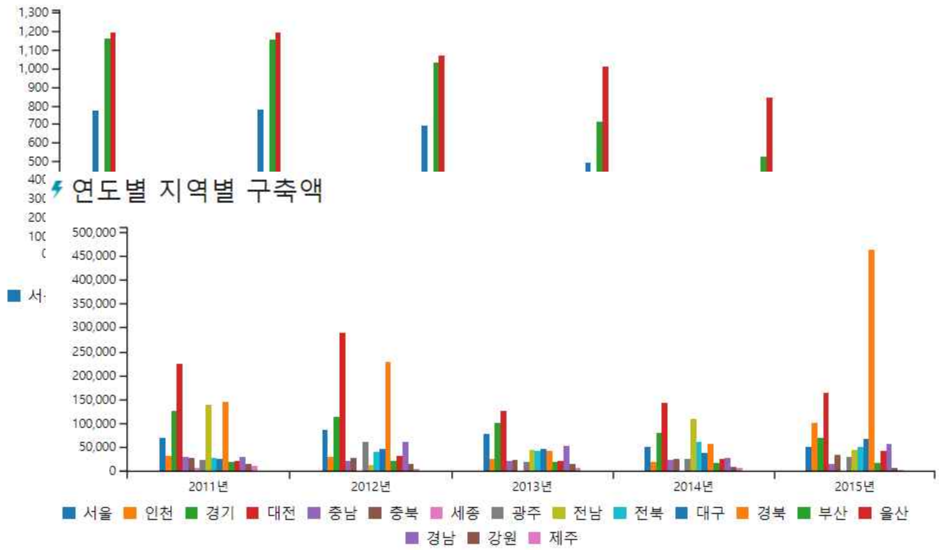



연도별 부처별 구축액
연도별 부처별 구축수
연도별 부처별 구축액
2012년
2013년
2014년
2015년
교육부
국민안전처
국토교통부
기상청
농림축산식품부
농촌진흥청
문화재청
문화체육관광부
미래창조과학부
법부처
보건복지부
산림청
산업통산자원부
원자력안전위원회
중소기업청
해양수산부
행정자치부
환경부
125/120


연도별 연구수행 주체별 구축액
연도별 연구수행주체별 구축수
연도별 연구수행주체별 구축액
2011년
2012년
2013년
2014년
2015년
국공립연구소
출연연구소
대학
민간기업
공기업
기타공공기관
지자체출연연구소
기타
126/120

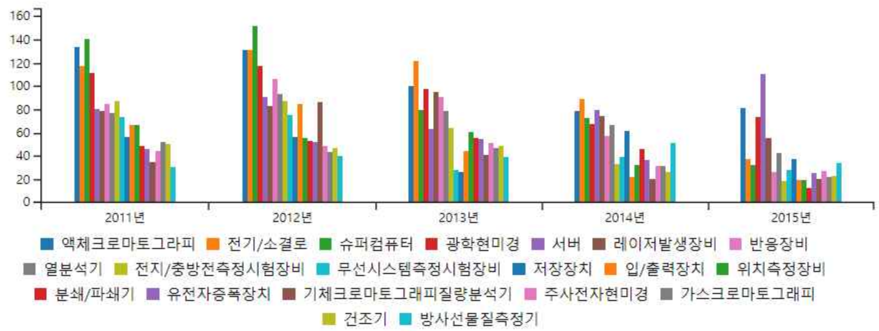
연도별 지역별 구축액

연도별 지역별 구축수

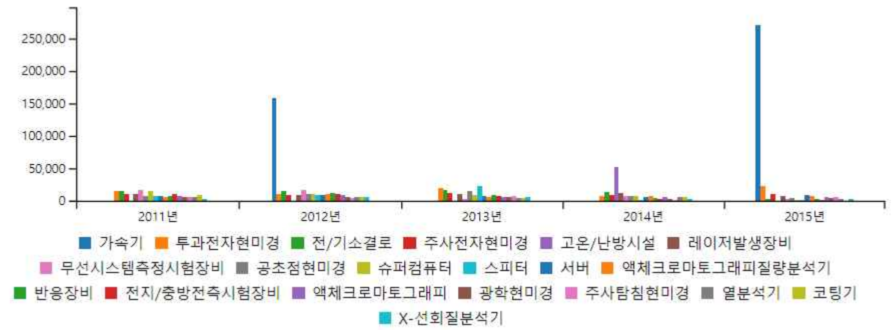


연도별 20대 투자상위 연구시설장비 구축수

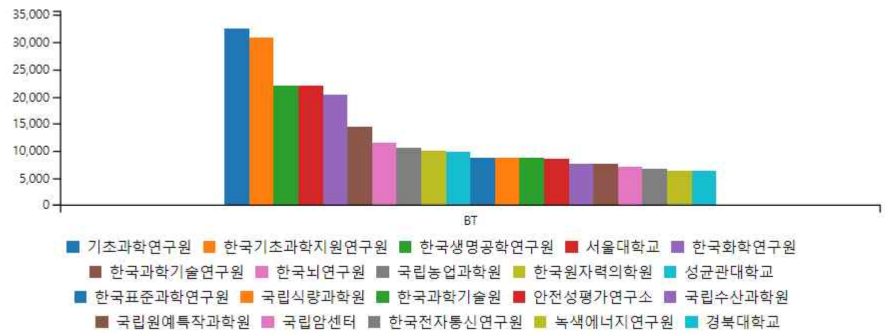
연도별 20대 투자상위 연구시설장비 구축수



연도별 20대 투자상위 연구시설장비 구축액

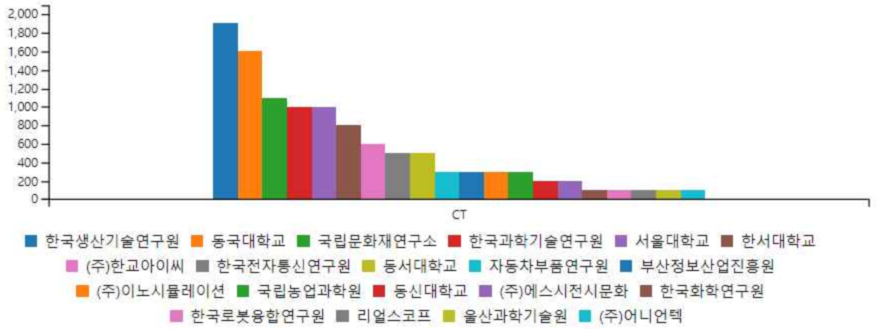


연도별 BT 분야 20대 투자상위 연구기관 구축액



연도별 CT 분야 20대 투자상위 연구기관 구축액

연도별 CT분야 20대 투자상위 연구기관 구축액

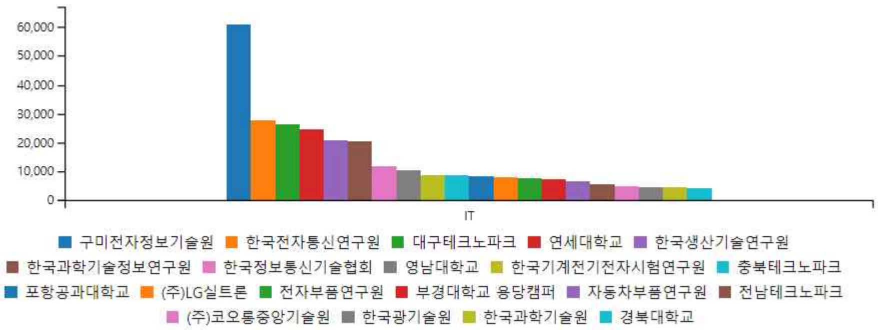


연도별 ET 분야 20대 투자상위 연구기관 구축액

연도별 ET분야 20대 투자상위 연구기관 구축액

연도별 IT 분야 20대 투자상위 연구기관 구축액

연도별 IT분야 20대 투자상위 연구기관 구축액



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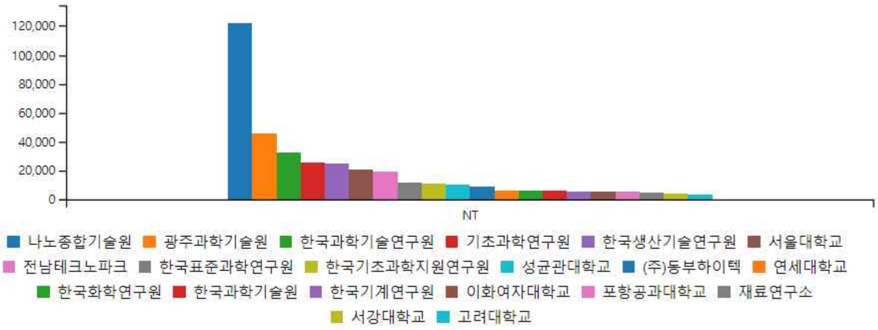
연도별 NT 분야 20대 투자상위 연구기관 구축액

연도별 NT분야 20대 투자상위 연구기관 구축액



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연도별 ST 분야 20대 투자상위 연구기관 구축액

연도별 ST분야 20대 투자상위 연구기관 구축액

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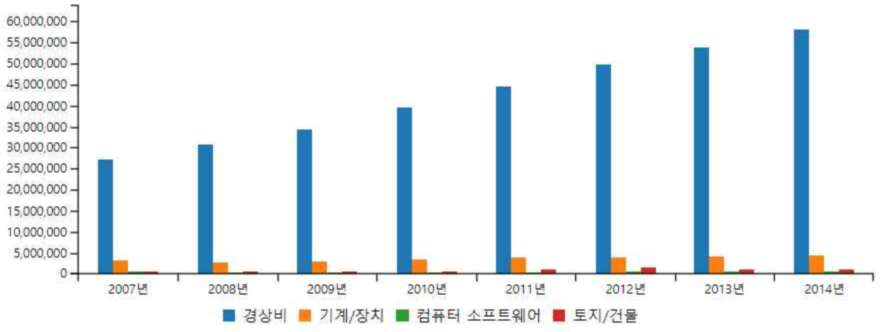
연도별 자본적 지출 추이별 구축액

연도별 자본적 지출 추이별 구축액



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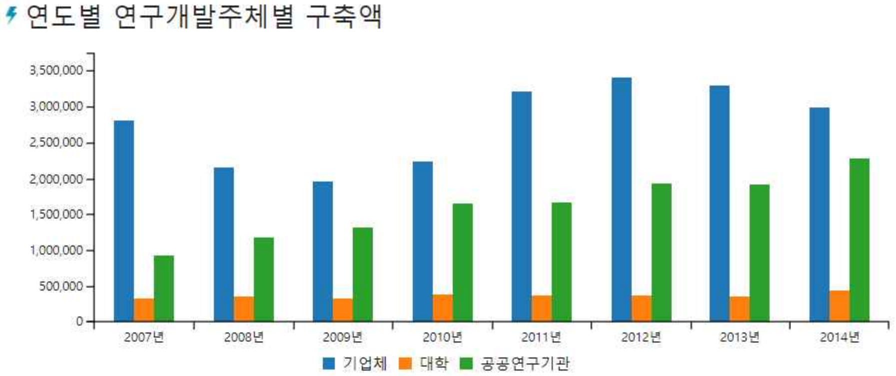
연도별 연구개발주체별 구축액



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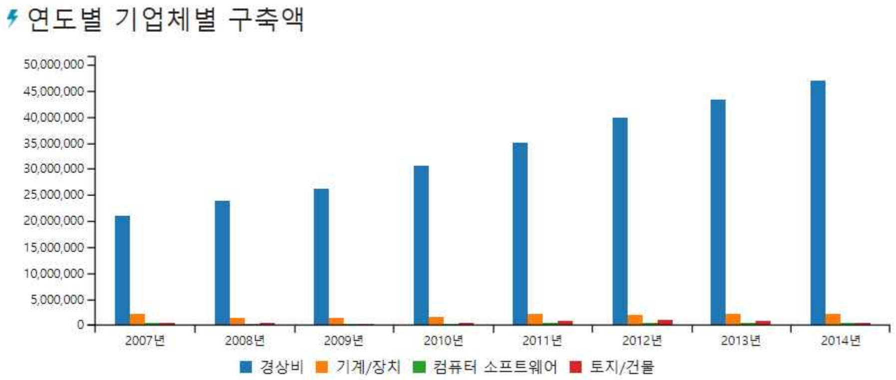
연도별 기업체별 구축액



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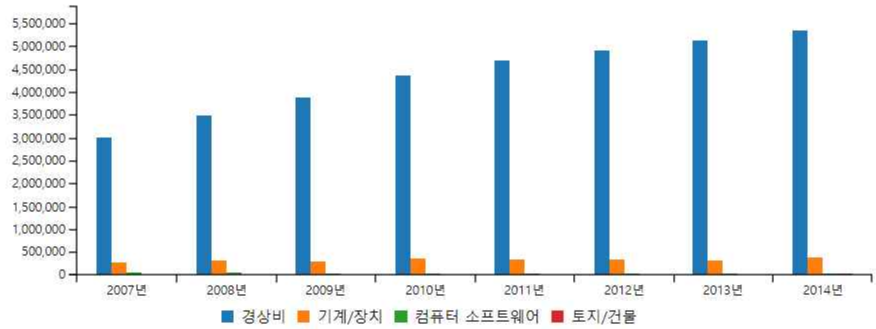
연도별 대학별 구축액

연도별 대학별 구축액



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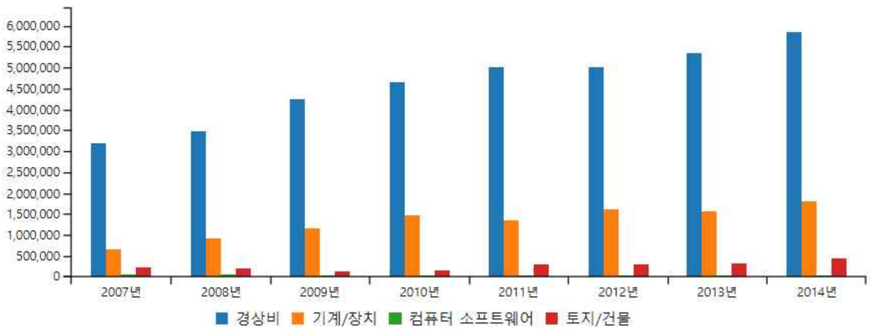
연도별 공공연구기관별 구축액

연도별 공공연구기관별 구축액



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연도별 장비수

취득년도 \ 장비구분	구매장비	개발장비	연구시설	Totals
2005	3,573	66	23	3,662
2006	4,038	60	22	4,120
2007	4,820	112	32	4,964
2008	4,986	152	29	5,167
2009	4,843	222	33	5,098
2010	4,507	308	39	4,854
2011	5,441	437	38	5,916
2012	5,540	487	46	6,073
2013	5,019	452	40	5,511
2014	4,001	418	48	4,467
2015	3,634	446	82	4,162
2016	3,104	241	109	3,454
2017	824	26	16	866
Totals	54,330	3,427	557	58,314

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연도별 장비 구축액

취득년도 \ 장비구분	구매장비	개발장비	연구시설	Totals
2005	480,694,562,254	28,214,871,628	7,054,017,033	515,963,450,915
2006	537,588,817,852	19,582,792,660	21,170,699,680	578,342,310,192
2007	704,003,482,751	382,159,125,692	41,118,012,803	1,127,280,621,246
2008	696,163,547,951	39,125,353,919	27,919,277,170	763,208,179,040
2009	736,972,996,509	48,747,918,573	175,375,395,042	961,096,310,124
2010	569,153,953,728	78,578,296,308	8,946,939,932	656,679,189,968
2011	691,541,165,003	269,191,657,828	10,699,286,575	971,432,109,406
2012	680,970,941,804	77,127,481,179	10,709,554,696	768,807,977,679
2013	696,368,580,754	65,037,018,599	5,882,372,778	767,287,972,131
2014	528,605,661,284	86,816,677,960	92,621,072,369	708,043,411,613
2015	580,360,338,645	415,321,150,604	43,074,293,983	1,038,755,783,232
2016	581,869,381,223	55,133,984,290	154,765,088,991	791,768,454,504
2017	136,970,262,704	70,396,621,225	4,757,773,403	212,124,657,332
Totals	7,621,263,692,462	1,635,432,950,465	604,093,784,455	9,860,790,427,382

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