The CERN Accelerator School

MAX IV LABORATORY

CERN Accelerator School

in collaboration with

MAX IV Laboratory

are organising a course on

Vacuum for Particle Accelerators

INDUSTRIAL VACUUM APPLICATIONS

- A VERY PERSONAL PERSPECTIVE

DR ANDREW CHEW

SATURDAY 10TH JUNE

EDWARDS

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CAS - VACUUM FOR PARTICLE ACCELERATORS

DRAFT PROGRAMME FOR VACUUM FOR PARTICLE ACCELERATORS
6-16 June, 2017, Lund, Sweden

Time	Tuesday 6 June	Wednesday 7 June	Thursday 8 June	Friday 9 June	Saturday 10 June	Sunday 11 June	Monday 12 June	Tuesday 13 June	Wednesday 14 June	Thursday 15 June	Friday 16 June
08:30 – 09:20	ARRIVAL DAY	Opening Talks	Materials & Properties IV: Outgassing P. Chiggiato	Getter Pumps E. Maccallini	Industrial Vacuum Applications	EXCURSION	Surface Characterisation R. Valizadeh	Transport to Max IV Lab	Controlling Particles/Dust in Vacuum Systems L. Lilje	Vacuum Design Aspects H. Reich-Sprenger	DEPARTURE DAY
09:30 – 10:20		Introduction to Machine Parameters P. Tavares	Vacuum Gauges I K. Jousten	Ion Pump Technology for Particle Accelerators M. Audi	Vacuum Gauges II K. Jousten		Interactions between Beams and Vacuum System Walls R. Cimino	**Seminar** Max IV Laboratory M. Grabski	Beam Induced Radioactivity & Radiation Hardness F. Cerutti	Manufacturing & Assembly for Vacuum Technology S. Mathot	
		COFFEE	COFFEE	COFFEE	COFFEE		COFFEE	COFFEE	COFFEE	COFFEE	
11:00 – 11:50		Fundamentals of Vacuum Technology E. Al Dmour	Mechanical Vacuum Pumps H. Barfuss	Introduction to Cryogenics S. Claudet	Beam Induced Desorption O. Malyshev		Surface Cleaning & Finishing M. Taborelli	**Seminar** ESS Spallation Source Vacuum System M. Juni Ferreira	Radiation Damage and its Consequence M. Brugger	The Real Life of Operation V. Baglin	
12:00 – 13:00		Impedance & Instabilities R. Wanzenberg	Computation for Vacuum System of Accelerators R. Kersevan	Cryo-pumping V. Baglin	Beam-Gas Interaction M. Ferro Luzzi		Thin-Film Coating P. Costa Pinto		Control & Diagnostic P. Gomes	Challenges for Vacuum Technology of Future Accelerators J. Jimenez	
		LUNCH	LUNCH	LUNCH	LUNCH		LUNCH	LUNCH	LUNCH	LUNCH	
14:30 – 15:20		Materials & Properties I: Introduction S. Sgobba	Tutorial	Tutorial	Tutorial		Tutorial	Visit to Max IV 15:30	Tutorial	Tutorial Work	
15:30 – 16:20		Materials & Properties II: Thermal & Electrical Characteristics S. Calatroni						15:30 Visit to ESS		Closeout	
		TEA	TEA	TEA	TEA		TEA		TEA	TEA	
17:00 – 17:50		Materials & Properties III: Mechanical Behaviour C. Garion	Tutorial Work	Tutorial Work	Tutorial Work		Tutorial Work		Tutorial Work	Closing Remarks	
19:30	Buffet	**Dinner**	**Dinner**	**Dinner**	**Dinner**	**Dinner**	**Dinner**	**Dinner**	**Dinner**	**Special Dinner**	

ABSTRACT

- *The market segmentation of the vacuum industry includes a wide range of applications; from microelectronics processing to food packaging, to the ‘Analytical’ sector*

- *As well as giving an overview of the vacuum industry, we will focus on some specific examples including semiconductor manufacturing, metallurgy and the historical evolution of vacuum pump requirements in Liquid Chromatography Mass Spectrometry.*

- *This will be discussed in relation a wide range of factors including; applicable pump type, crucial characteristics and communications protocols. Future trends will be discussed*

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CONTENTS

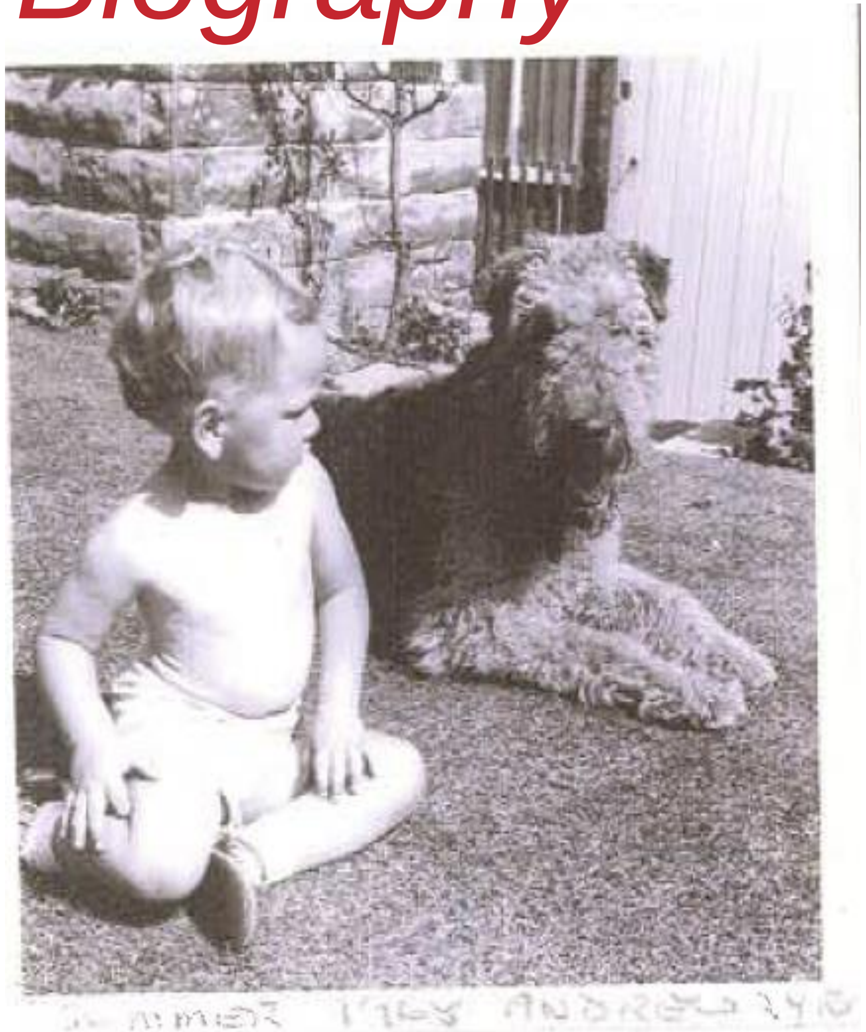
FIRSTLY……

EXPERIMENT ON CHEW'S SECOND THEOREM

WE SHALL RETURN TO THIS LATER

EDWARDS

Biography



1968

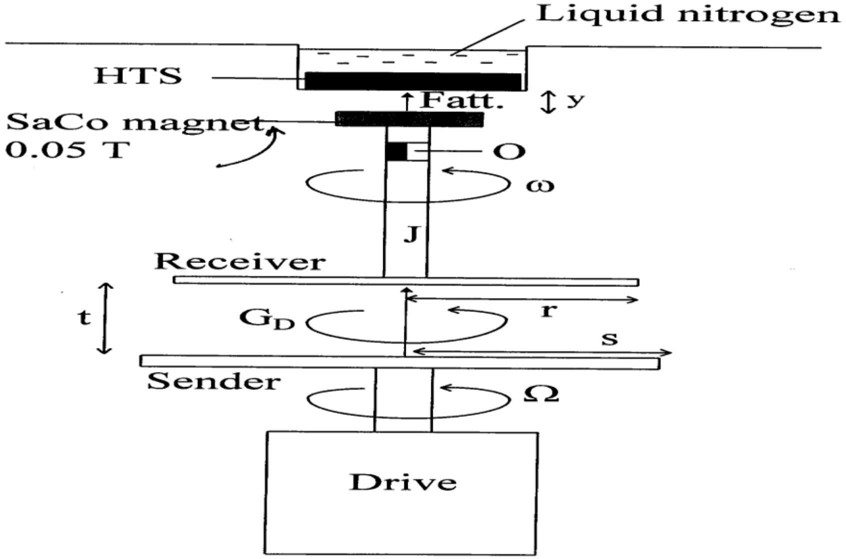
1986

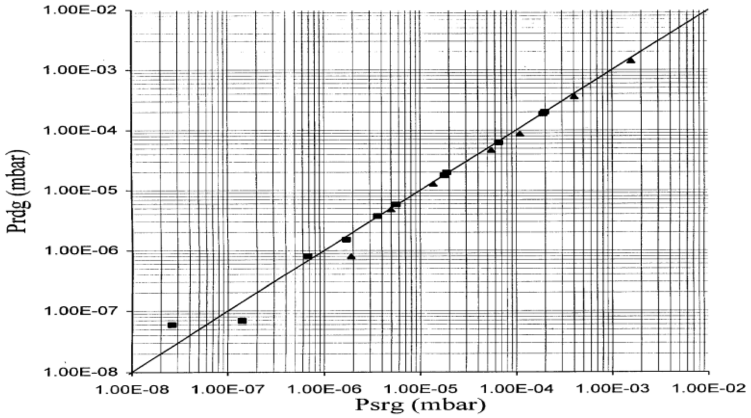
1995

EDWARDS

SHORT BIOGRAPHY - ROTATING DISC GAUGE

Measures molecular torque developed between coaxial discs direct





1989-1995

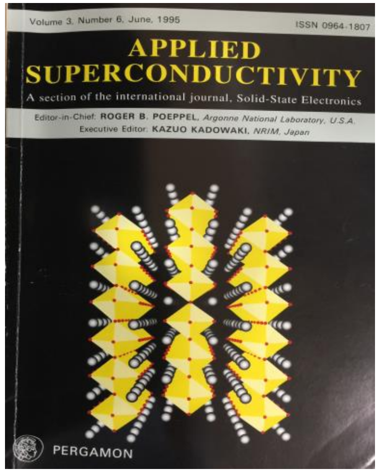
$$I\dot{\omega} = G_D - G_I - G_M - G_E$$

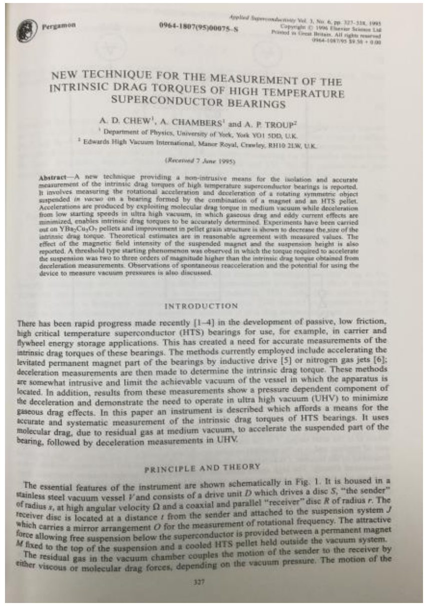
G_D ~ pressure

G_I suspension asymmetries

G_M molecular drag

G_E Eddy current drag




Pergamon 0964-1807(95)00075-S

Applied Superconductivity Vol. 3, No. 6, pp. 327-338, 1995. Copyright © 1996 Elsevier Science Ltd. Printed in Great Britain. All rights reserved.

NEW TECHNIQUE FOR THE MEASUREMENT OF THE INTRINSIC DRAG TORQUES OF HIGH TEMPERATURE SUPERCONDUCTOR BEARINGS

A. D. CHEW[1], A. CHAMBERS[1] and A. P. TROUP[2]

[1] Department of Physics, University of York, York YO1 5DD, U.K.

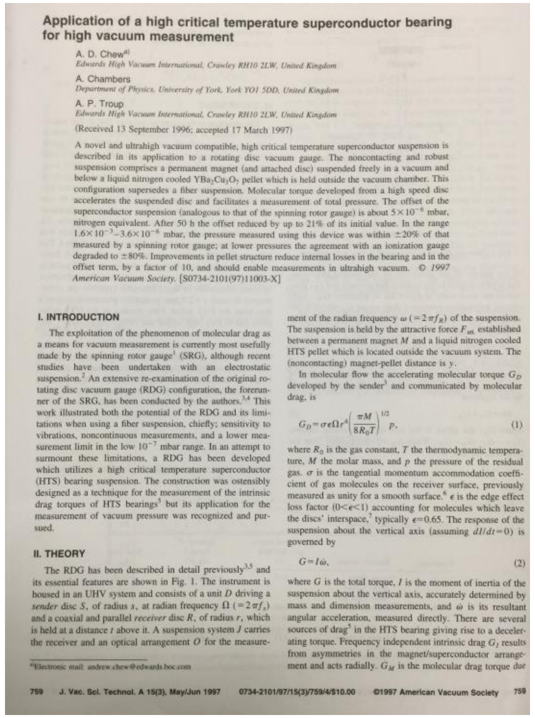
[2] Edwards High Vacuum International, Manor Royal, Crawley, RH10 2LW, U.K.

(Received 7 June 1995)

Abstract—A new technique providing a non-intrusive means for the isolation and accurate measurement of the intrinsic drag torques of high temperature superconductor bearings is reported. It involves measuring the rotational acceleration and deceleration of a rotating symmetric object suspended *in vacuo* on a bearing formed by the combination of a magnet and an HTS pellet. Accelerations are produced by exploiting molecular drag torque in medium vacuum while deceleration from low starting speeds in ultra high vacuum, in which gaseous drag and eddy current effects are minimized, enables intrinsic drag torques to be accurately determined. Experiments have been carried out on $YBa_2Cu_3O_7$ pellets and improvement in pellet grain structure is shown to decrease the size of the intrinsic drag torque. Theoretical estimates are in reasonable agreement with measured values. The effect of the magnetic field intensity of the suspended magnet and the suspension height is also reported. A threshold type starting phenomenon was observed in which the torque required to accelerate the suspension was two to three orders of magnitude higher than the intrinsic drag torque obtained from deceleration measurements. Observations of spontaneous reacceleration and the potential for using the device to measure vacuum pressures is also discussed.

INTRODUCTION

There has been rapid progress made recently [1–4] in the development of passive, low friction, high critical temperature superconductor (HTS) bearings for use, for example, in carrier and flywheel energy storage applications. This has created a need for accurate measurements of the intrinsic drag torques of these bearings. The methods currently employed include accelerating the …


Application of a high critical temperature superconductor bearing for high vacuum measurement

A. D. Chew[a]
Edwards High Vacuum International, Crawley RH10 2LW, United Kingdom

A. Chambers
Department of Physics, University of York, York YO1 5DD, United Kingdom

A. P. Troup
Edwards High Vacuum International, Crawley RH10 2LW, United Kingdom

(Received 13 September 1996; accepted 17 March 1997)

A novel and ultrahigh vacuum compatible, high critical temperature superconductor suspension is described in its application to a rotating disc vacuum gauge. The noncontacting and robust suspension comprises a permanent magnet (and attached disc) suspended freely in a vacuum and below a liquid nitrogen cooled $YBa_2Cu_3O_7$ pellet which is held outside the vacuum chamber. This configuration supersedes a fiber suspension. Molecular torque developed from a high speed disc accelerates the suspended disc and facilitates a measurement of total pressure. The offset of the superconductor suspension (analogous to that of the spinning rotor gauge) is about 5×10^{-6} mbar, nitrogen equivalent. After 50 h the offset reduced by up to 21% of its initial value. In the range 1.6×10^{-3}–3.6×10^{-6} mbar, the pressure measured using this device was within ±20% of that measured by a spinning rotor gauge; at lower pressures the agreement with an ionization gauge degraded to ±80%. Improvements in pellet structure reduce internal losses in the bearing and in the offset term, by a factor of 10, and should enable measurements in ultrahigh vacuum. © *1997 American Vacuum Society.* [S0734-2101(97)11003-X]

I. INTRODUCTION

The exploitation of the phenomenon of molecular drag as a means for vacuum measurement is currently most usefully made by the spinning rotor gauge[1] (SRG), although recent …

759 J. Vac. Sci. Technol. A 15(3), May/Jun 1997 0734-2101/97/15(3)/759/4/$10.00 ©1997 American Vacuum Society 759

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INDUSTRIAL VACUUM APPLICATIONS – DICTIONARY DEFINITIONS

Industrial
ADJECTIVE

relating to or characterized by industry

Synonyms: manufacturing, factory, commercial, business, trade

Vacuum
NOUN

1. a region containing no matter; free space
2. a region in which gas is present at a low pressure
3. the degree of exhaustion of gas within an enclosed space: a high vacuum, a perfect vacuum

any region below atmospheric pressure

Synonyms: empty space, emptiness, void, nothingness, vacuity, vacancy, voidness, nihility

Dictionaries are not always very good

Applications
NOUN

the special use or purpose to which something is put:

Synonyms: utilization, aptitude, suitability, pertinence, solicitation, petition, assiduity, industry, persistence, perseverance

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THE VACUUM MARKET SEGMENTATION - ISVT

International Statistics on Vacuum Technology
JVIA (Japan Vacuum Industry Association)
AVEM (Association of Vacuum Equipment Manufacturers)
EVTA (European Vacuum Technology Association)
in co-operation with
SEMI (Semiconductor Equipment and Materials)

Vacuum Market Segmentation

Rough Vacuum	Process Vacuum	Industrial Vacuum	Semiconductor Process Vacuum	Thin Film Deposition (non-Semiconductor)	Solar	Instrumentation Manufacturers	R&D
Markets – Packaging (except food) – Central Vacuum – Printing and Paper Handling – Pick and Place – Conveying – Moulding – Air sampling – Medical	Markets – Chemical (Bulk, Fine,...) – Petrochemical – Pharmaceutical – Plastics (Extrusion,...) – Food – Beverage – Textile – Paper – Ceramics – Freeze drying – Energy (Wind, Nuclear, Stream Turbines,...) – Central Vacuum (Batteries,...)	Markets – Vacuum Metallurgy (Metal Degassing, Melting, Re-melting, E-beam welding, casting,...) – Vacuum Heat Treatment (Brazing, Carburising, Nitriding, Quenching,...) – Laser Technology – Electron Tubes – TV Tubes – Lamps and Bulbs – Industrial leak detection – Refrigeration and Air Conditioning – Automotive (Dehydration, Charging and Test) – Electrical (Encapsulation,..)	Markets – Silicon Semiconductor – Compound Semiconductor (LEDs,...) – TFT-LCD Displays – MEMS – Crystal Pulling *Please note: Above includes both Process Equipment Manufacturers and End Users for PVD, CVD, Etching, Ion Implantation, MBE*	Markets – Glass/Web/Optical Coating – Optical Data Storage (CD, DVD, Hi Def Disk,..) – Magnetic Data Storage (HDD) – Thin Film Heads – Surface Coating (wear protection, decorative, ..) – Display Coatings (OLED, FED, PDP, SED,...)	Markets – Photovoltaic Solar (c-Si & Thin-Film Deposition, Laminating,...) – Thermal Solar (Water Heaters,...) – Crystal Growth (Re-melt, ...)	Markets – Mass Spectrometers – Electron Microscopes – Metrology/ Inspection/ Defect Review systems for Semiconductor including Focused Ion Beam systems and Electron Beam systems – Surface Analysis – Gas Analysis – X-Ray Analysis – MRI and NMR – Sample preperation (Driers, Centrifuges, Concentrators,...) – Leak Detectors	Markets – Universities – Government Labs – Scientific Research Laboratories – Space Simulation
Typical operating pressure (mbar)							
> 1	> 10^{-2}	10^{-2} - 10^{-6}	1 - 10^{-8}	10^{-3} - 10^{-8}		10^{-6} - 10^{-10}	10^{-2} - 10^{-11}

PVD:	Physical Vapour Deposition	CD:	Compact Disk
CVD:	Chemical Vapour Deposition	DVD:	Digital Video Disk
MBE:	Molecular Beam Epitaxy	OLED:	Organic Light Emitting Diode (or OELD: Organic Electro Luminescent Display)
MEMS:	Micro Electro Mechanical Systems	FED:	Field Emission Display
TFT-LCD:	Thin-Film Transistor Liquid Crystal Display	PDP:	Plasma Display Panel
SED:	Surface Emission Display	MRI:	Magnetic Resonance Imaging
HDD:	Hard Disk Drive	NMR:	Nuclear Magnetic Resonance

This Vacuum Market Segmentation Chart was developed by the Working Group of the International Statistics on Vacuum Technology Program (ISVT), and is published with their permission. Organisations that participate in the program are the Association of Vacuum Equipment Manufacturers International (AVEM), the Japan Vacuum Industry Association (JVIA), the European Vacuum Technology Association (EVTA), and the Semiconductor Equipment and Materials International (SEMI).

Version 2010.0, Hangzhou, China, September 24th 2009

ISVT PARTICIPATING COMPANIES

International Statistics on Vacuum Technology
JVIA (Japan Vacuum Industry Association)
AVEM (Association of Vacuum Equipment Manufacturers)
EVTA (European Vacuum Technology Association)
in co-operation with
SEMI (Semiconductor Equipment and Materials)

ISVT 2016 Participating companies

AVEM		JVIA		EVTA	
1	A&N	1	Anest Iwata	1	Aerzener Maschinenfabrik
2	Brooks Automation	2	Anlet	2	Agilent Technologies
3	DigiVac	3	Canon Anelva	3	Edwards
4	Drivac	4	Choshu Industry	4	GD Deutschland
5	GD Welch Technology	5	Cosmotec	5	GD Nash
6	GNB	6	Diavac	6	Gebr. Becker
7	Lesker	7	Ebara	7	Körting
8	Inficon	8	Fuji Technology	8	Oerlikon Leybold Vacuum
9	Mass-Vac	9	Green Tec	9	Pfeiffer Vacuum
10	Rocky Brook Associates	10	Hakuto	10	PIAB
11	Shi-APD Cryo	11	Hitachizosen	11	Robuschi
12	Teledyne Hastings Instruments	12	Irie Koken	12	Sterling Fluid Systems
13	Televac	13	Jeol	13	VACOM
14	Tuthill Vacuum Systems	14	Kashiyama		
15	U-C Components	15	Matumura Oil Research		
16	Vacuum Research Corporation	16	Mitsubishi Cable Industries		
17	Verity Instruments	17	Musashino Engineering		
		18	Neis		
		19	Okano Works		
		20	Optorun		
		21	Osaka Rasenkan Kogyo		
		22	Osaka Vacuum		
		23	Rigaku		
		24	Sato Vac		
		25	Shibaura Eletec		
		26	Shimadzu		
		27	Shimadzu Emit		
		28	Shinko Seiki		
		29	Shinmaywa Industries		
		30	SMC		
		31	Sumitomo Heavy Industries		
		32	Taiko Kikai Industries		
		33	Taisei Kinzoku Kogyosho		
		34	Tokyo Electronics		
		35	Toyama		
		36	Ulvac Cryogenics		
		37	Ulvac Kiko		
		38	Ulvac Tecno		
		39	Ulvac		
		40	V Tex		
		41	Wakaida Science		

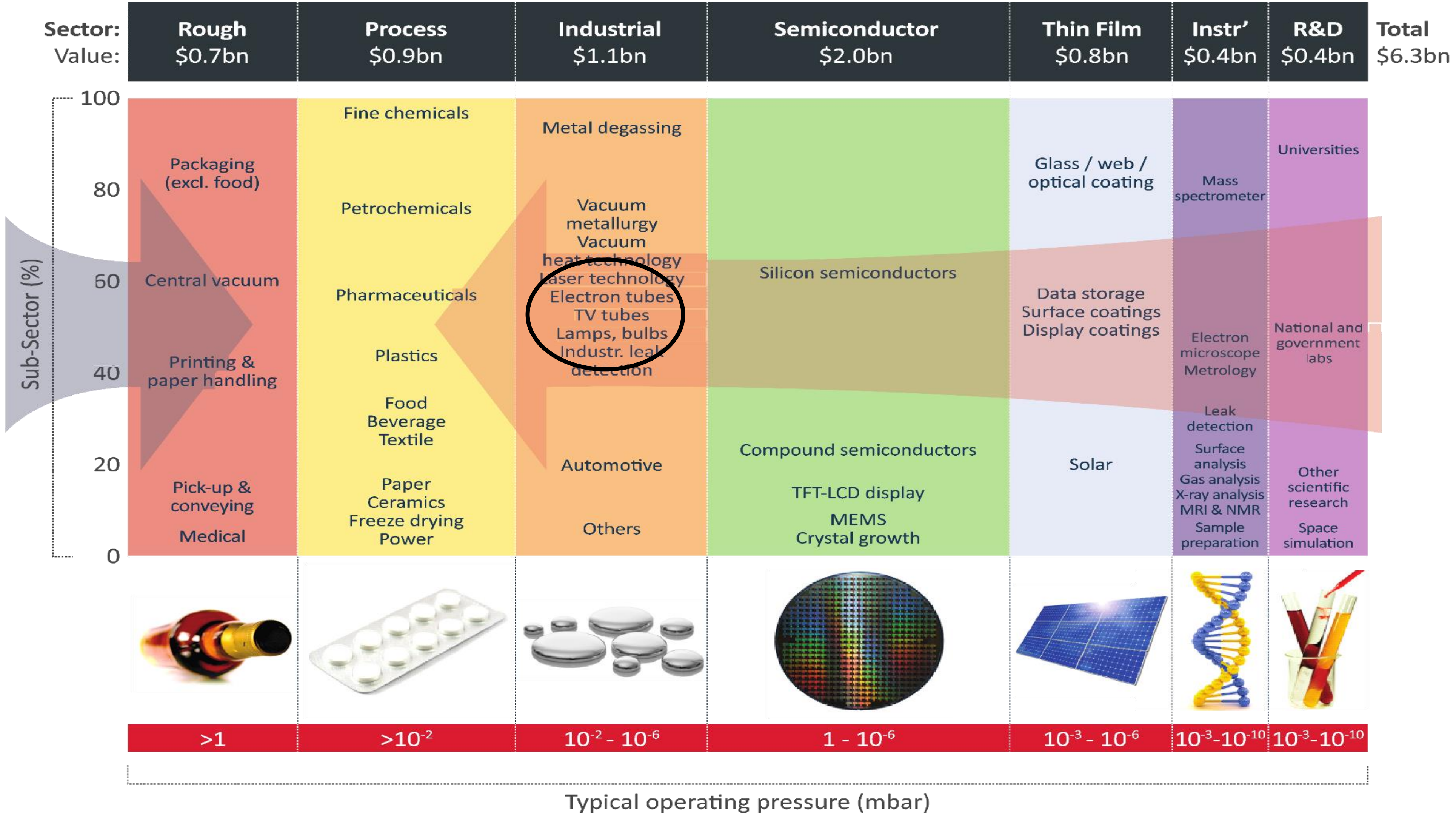
Ulrike Mätje 2016-10-13

Not all suppliers participate

EDWARDS

THE VACUUM WORLD

Dynamic range = 15 orders!!



Source: ISVT and Atlas Copco

HOW DOES THIS MARKET COMPARE?

Vacuum @ $9B

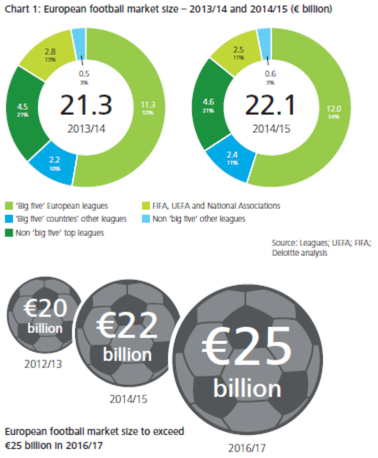
European football ~$30B

Oil ~ $2,000B

Scotch Whiskey ~ $3B

Automotive ~ $620B

Film Box Office ~ $38B



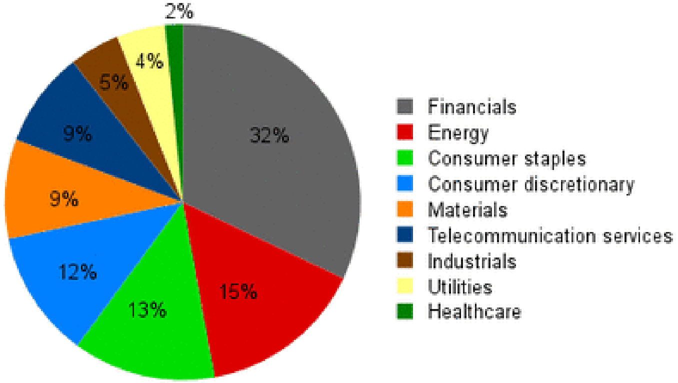
https://www2.deloitte.com/content/dam/Deloitte/uk/Documents/sports-business-group/deloitte-uk-annual-review-of-football-finance-2016.pdf

https://en.wikipedia.org/wiki/List_of_countries_by_GDP_(nominal)

Global GDP = ~$75,000,000M

Agriculture	Industrial	Services
6%	31%	64%

https://en.wikipedia.org/wiki/List_of_countries_by_GDP_sector_composition

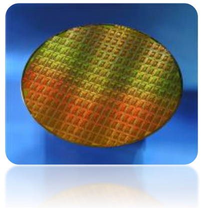


Source: iShares.

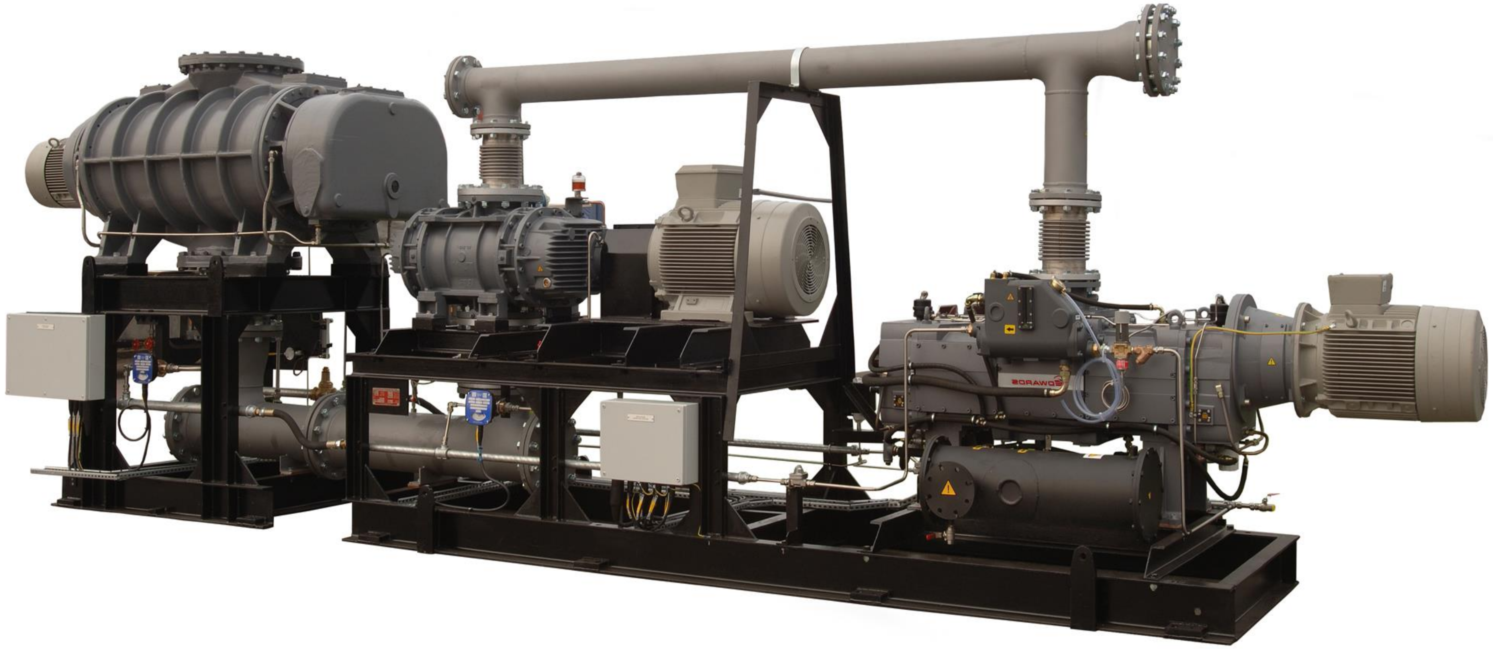
https://www.statista.com/topics/964/film/

APPLICATIONS….OVER THE YEARS

https://en.wikipedia.org/wiki/Electron_microscope



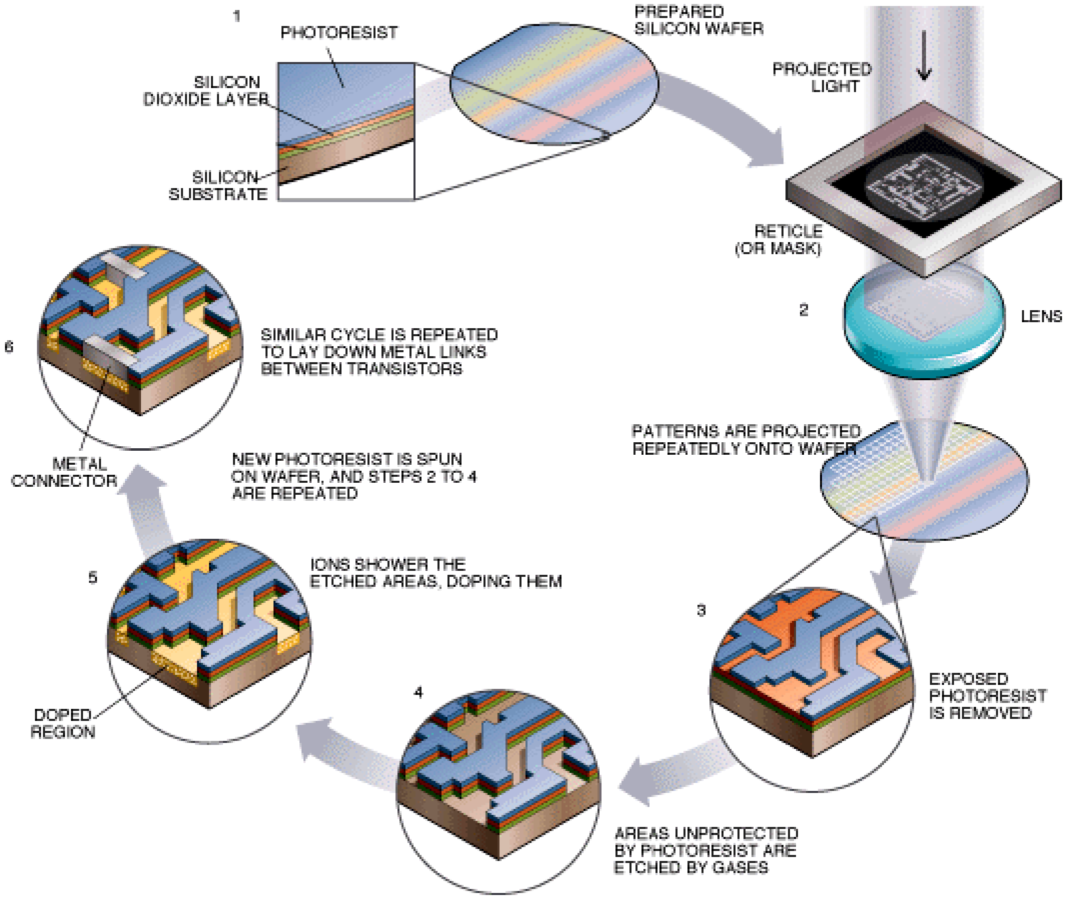
VACUUM PUMPS: FROM VERY SMALL TO VERY BIG



SOME APPLICATIONS EXAMPLES

- Microelectronics
- Steel
- Liquid Chromatography Mass Spectroscopy
- CPI
- Food
- Microscopy
- Sterilization

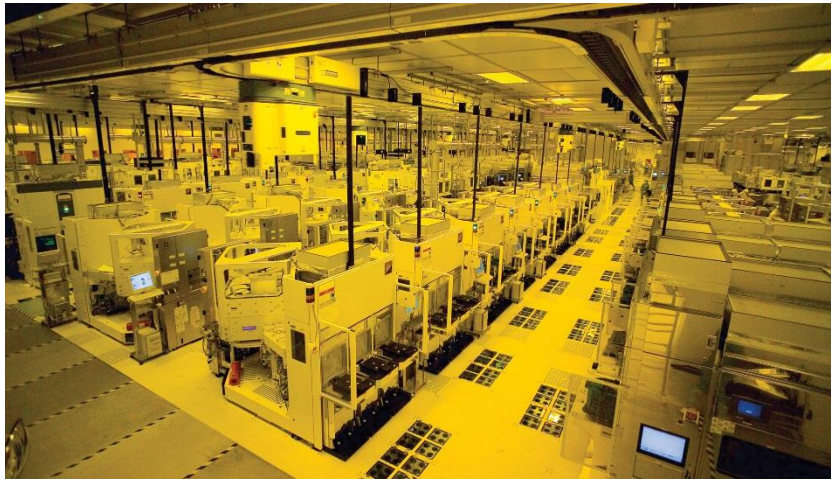
MICROELECTRONICS/SEMICONDUCTOR

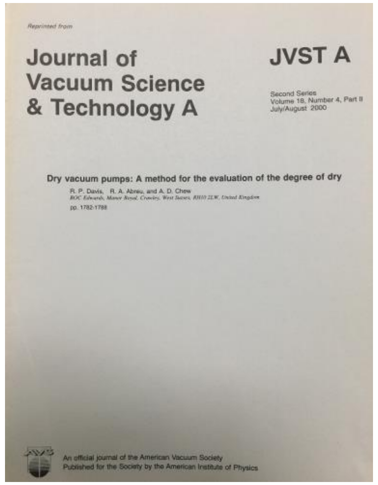


Wafer pulling

He, Ar

Large primary pumps





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JVST A

Second Series
Volume 18, Number 4, Part II
July/August 2000

Dry vacuum pumps: A method for the evaluation of the degree of dry

R. P. Davis, R. A. Abreu, and A. D. Chew
BOC Edwards, Manor Royal, Crawley, West Sussex, RH10 2LW, United Kingdom
pp. 1782-1788

An official journal of the American Vacuum Society
Published for the Society by the American Institute of Physics

https://www.edwardsvacuum.com/Semiconductor_Processing/

https://en.wikipedia.org/wiki/Semiconductor_device_fabrication#/media/File:Comparison_semiconductor_process_nodes.svg

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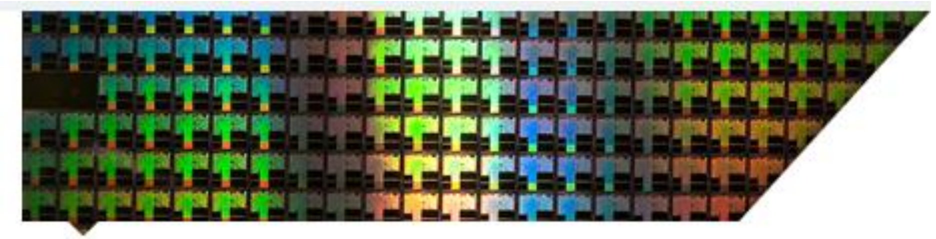
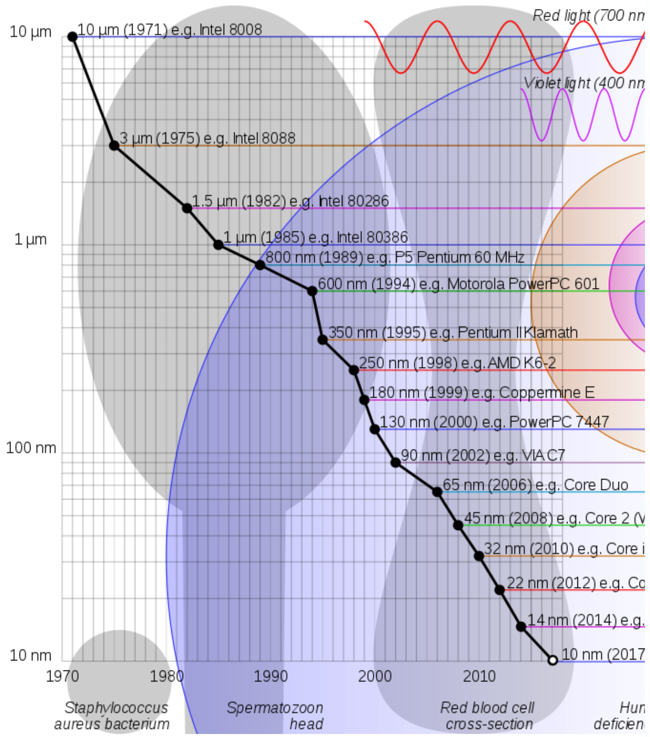
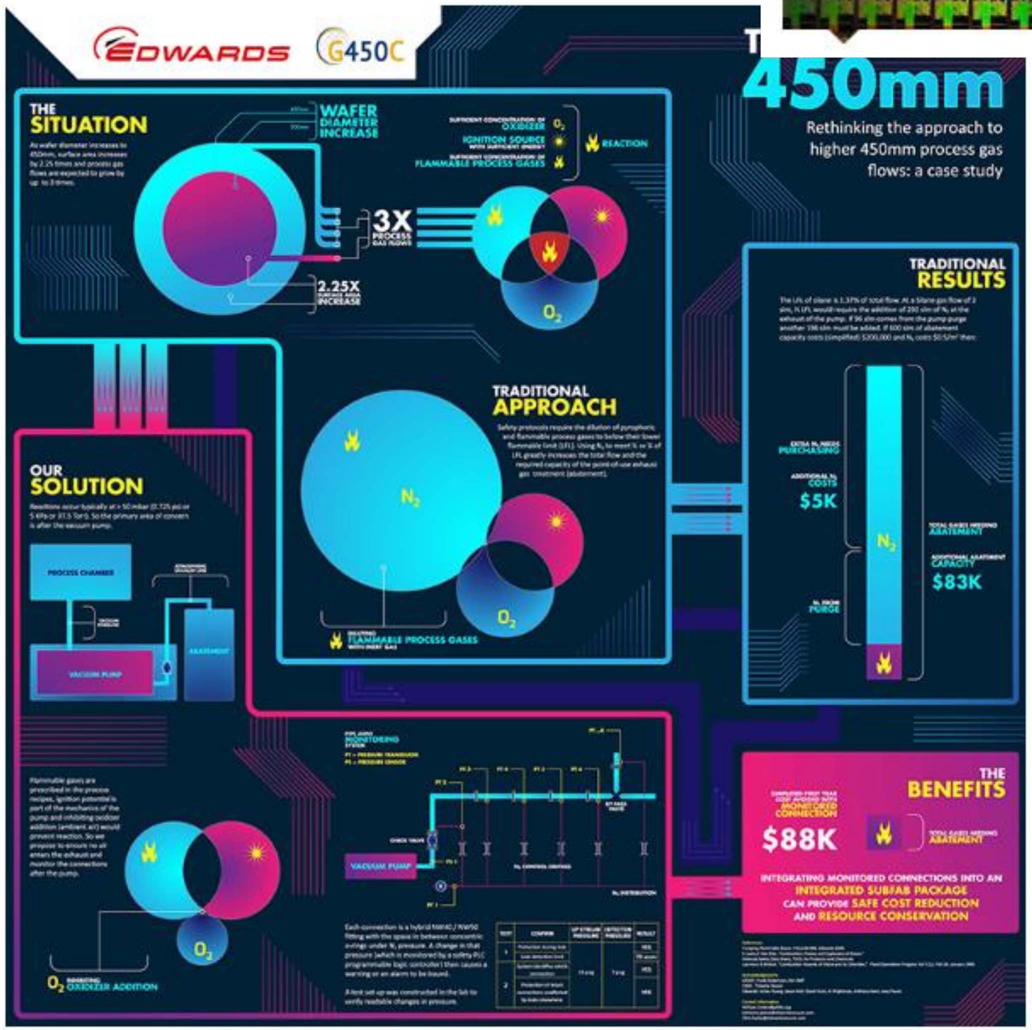
SEMICONDUCTOR

Semiconductor industry is driving
towards logic dimensions of 7nm = 70 Å







https://en.wikipedia.org/wiki/Semiconductor_device_fabrication#/media/File:Comparison_semiconductor_process_nodes.svg

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1980'S SEMICONDUCTOR – 'GAME CHANGING' DRY PUMP

http://www.edwardsvacuum.com/newsletters/vacuum_particles/0109/pArticles_files/fun_fact_henry_wycliff.pdf

2009

Feature

Corrosive handling

Twenty five years' dry vacuum pumping

Dr Andrew Chew, market and applications development manager at Edwards, looks at the important development of the dry, oil-free vacuum pump, which solved the back streaming problems that had previously plagued major industry sectors for years – metallurgy, vacuum drying and semiconductor manufacture among them.

In 1953, a young Polish man, unable to return home after the war, decided to embark on an engineering degree in London. Following his graduation he joined a small family business called Edwards. What no-one could possibly foresee was that this engineer would go on to invent a radical new technology – the dry pump – that would become the foundation for a legacy of products for one of the world's largest engineering firm.

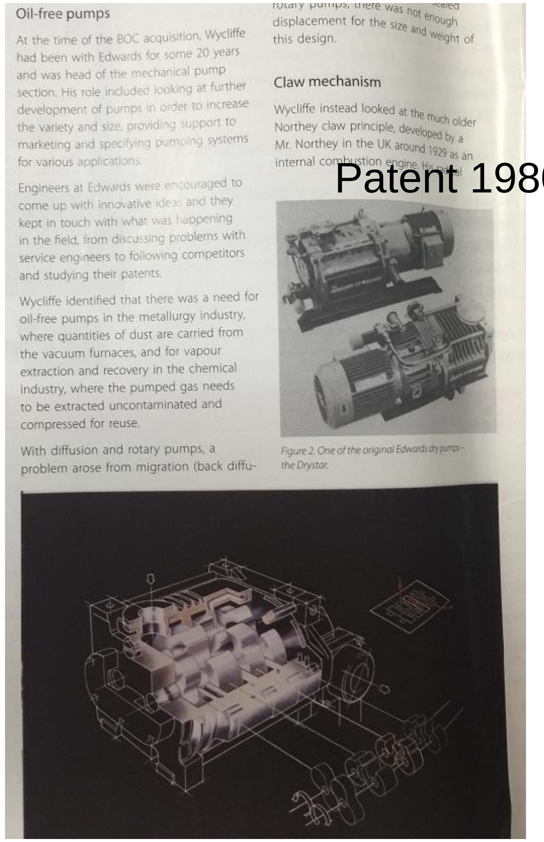
Henry Wycisk was born in 1925 in Katowice in Upper Silesia. He was 14 when the Germans invaded Poland in 1939. After the war, he settled in the UK where he became an engineering student in 1948 and gained a BSc (Eng.) with second-class honours.

Need for vacuum

In August 1953 Henry Wycisk, now having changed his surname to Wycliffe,

www.worldpumps.com 0262 1762/09 ©2009 Elsevier Ltd. All rights reserved

Patent 1980



Oil-free pumps

At the time of the BOC acquisition, Wycliffe had been with Edwards for some 20 years and was head of the mechanical pump section. His role included looking at further development of pumps in order to increase the variety and size, providing support to marketing and specifying pumping systems for various applications.

Engineers at Edwards were encouraged to come up with innovative ideas and they kept in touch with what was happening in the field, from discussing problems with service engineers to following competitors and studying their patents.

Wycliffe identified that there was a need for oil-free pumps in the metallurgy industry, where quantities of dust are carried from the vacuum furnaces, and for vapour extraction and recovery in the chemical industry, where the pumped gas needs to be extracted uncontaminated and compressed for reuse.

With diffusion and rotary pumps, a problem arose from migration (back diffu-

...rotary pumps, there was not enough displacement for the size and weight of this design.

Claw mechanism

Wycliffe instead looked at the much older Northey claw principle, developed by a Mr. Northey in the UK around 1929 as an internal combustion engine. His radial

Figure 2. One of the original Edwards dry pumps – the Drystar.

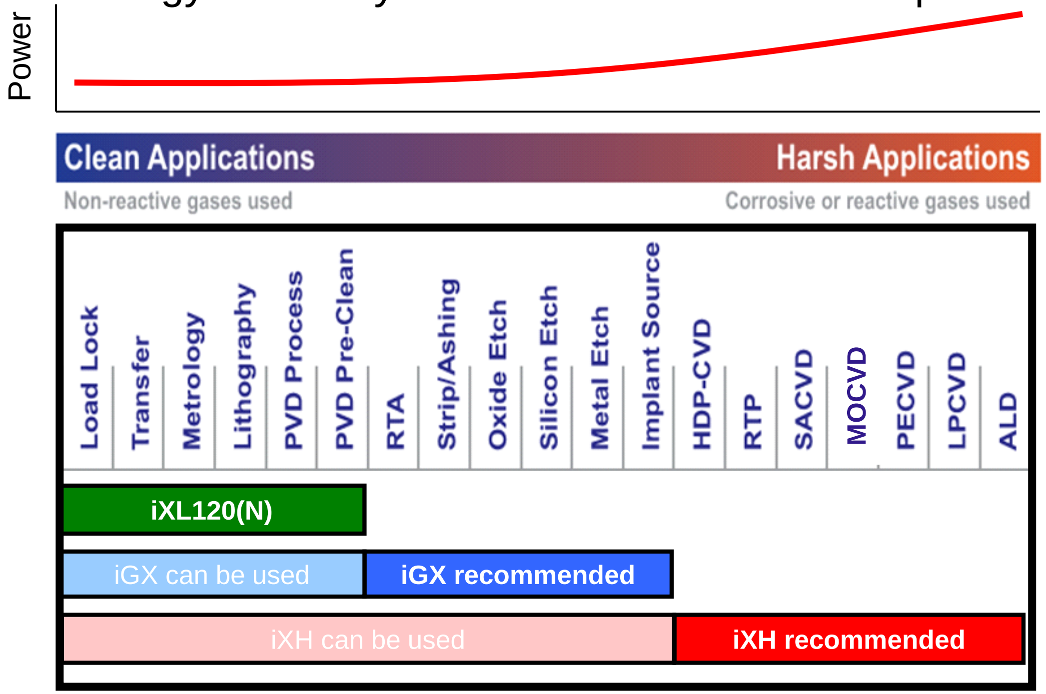
Henryk Wycliffe 2017

EDWARDS

PROCESS SEGMENTATION AND POWER REQUIREMENTS

Part of the energy balance offered across all semiconductor applications

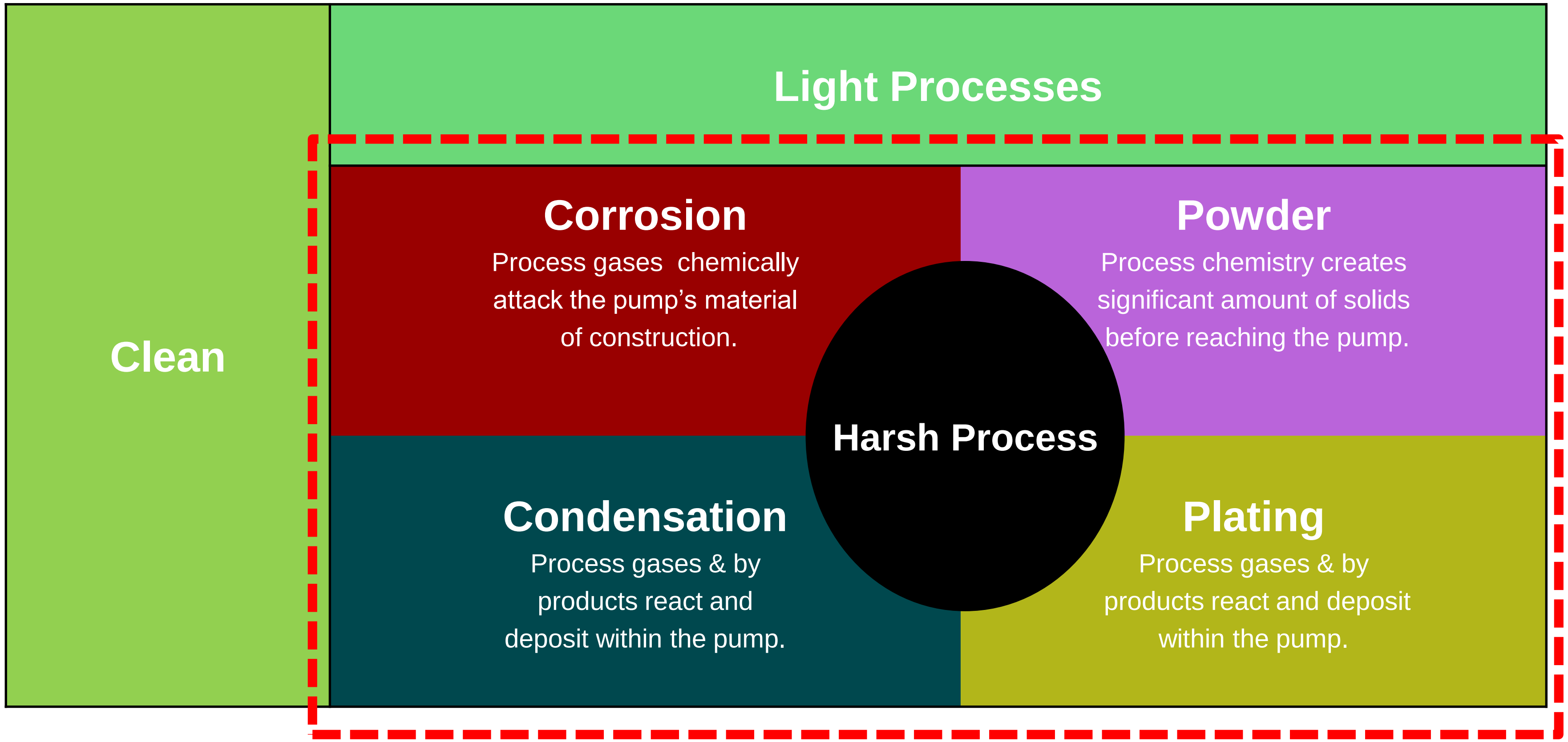
Maximises energy efficiency across the fab without compromising reliability on process



- "No Wafer Scrap" policy is king
- Some processes require high temperature = higher power
- The application requirements dictate the required pump

- 1 kW power reduction per pump equates to ~$1,000 annual savings at $0.12 / kW-h.
- However, a single pump failure can more than obliterate any savings in energy through lost wafers and tool downtime.

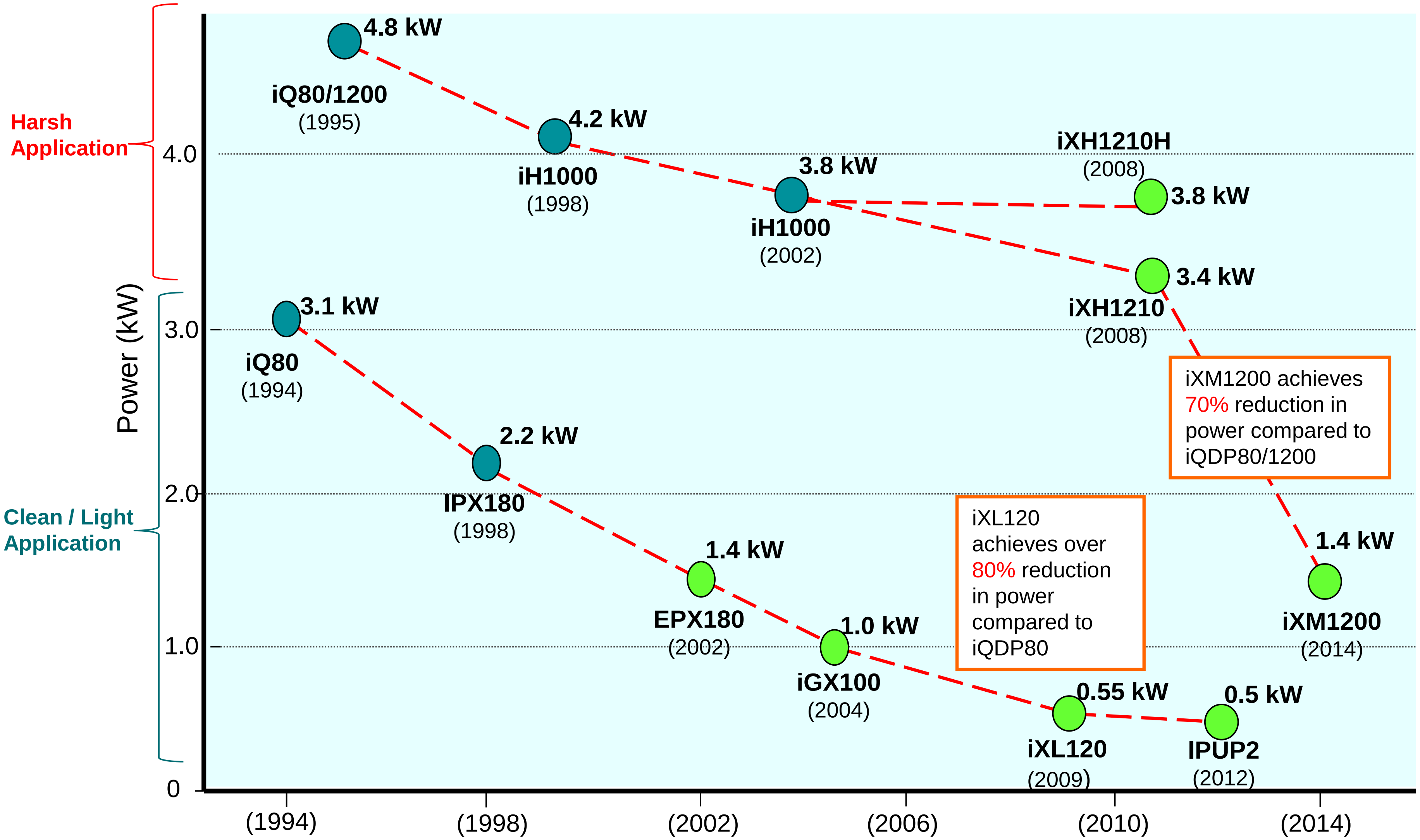
CLASSIFICATION OF SEMICON APPLICATIONS



- Low energy solutions can be optimized for light to medium duty applications with little to no risk of process induced failures.
- Harsh duty applications require more robust pumps with application specific solutions.

EDWARDS

EDWARDS' DRY PUMP POWER REDUCTION TREND



EDWARDS

STEEL DEGASSING – HYDROGEN PUMPING

1,000,000 m^3h^{-1} at 0.5 mbar for Chong Qing Steel Group Co. (Chongqing, China)

Mechanical vacuum pump system for steel degassing

Vacuum Degassing (VD) and Vacuum Oxygen Decarburisation (VOD) are often used in the production of speciality steel alloys. They are used to reduce the levels of hydrogen, carbon and other impurities during the secondary steel making process.

Historically large multi-stage steam ejector systems, backed with liquid ring pumps, have been used. However, these are energy inefficient, rely on high steam quality for consistent performance, and cause foreline dust deposits that develop into “cakes” making cleaning difficult.

Steel degassing in tanks or in the ladle involves two basic processes: Vacuum Degassing (VD) and Vacuum Oxygen Decarburising (VOD). For these processes two types of vacuum pump system have been operated over the past 25 years.

1. The steam ejector system uses multi-stage high pressure steam ejectors usually supported by water sealed Liquid Ring pumps.

2. The alternative mechanical system uses multi-stage mechanical boosters supported by completely dry primary vacuum pumps.

The completely dry pump system has proven to be the most effective. The cost saving is significant, as shown over the page. There are also metallurgical benefits from the elimination of back-streaming of water vapour. Combined with the better ultimate vacuum, this leads to reduced residual hydrogen in the metal. Faster evacuation and more flexible operational characteristics allow for closer chemistry control. This leads to more consistent formulation and opportunities for new steel qualities.

All maintenance costs are reduced, including cost for cleaning the pumps and pipework. The waste disposal costs for the dry dust are also reduced, or the dust can be recycled reducing costs further and limiting the impact on the environment.

Why mechanical pumps?

- Cost saving
  - Energy costs reduced by over 90%
- Reduced maintenance
  - Elimination of fore line deposits
- Reduced effluent costs
  - Easier disposal or recycling of dry waste
- Reduced cycle times
  - Vacuum on demand
- Consistent processing
  - Reliable and dependable vacuum level
- Better steel quality
  - Lower hydrogen levels achieved in VD
- Improved stainless quality
  - Better VOD control
- New steel qualities
  - Easier control of chemistry

application note

EDWARDS
Vacuum science... product solution.

Operating cost comparison:

Dry mechanical vacuum pumps vs. steam ejectors

Melt mass (tonnes) = 60

Production tonnage = 300.000

Cycle time in vacuum (mins) = 25

Boiler size (kg/h) = 10000

Process = VD

Cost criterion		Condition	Specific cost		Steam ejectors				Dry running pumps including filter operating costs			
Consumption												
- steam		12 bar, 194°C	20,00	€/t	69,4	kg/t	1,3888889	€/t				
- contact water		3 bar, 32°C	0,04	€/m³	4,5	m³/t	0,1805556	€/t				
- non-contact water		4 bar, 32°C	0,03	€/m³					0,0875000	m³/t	0,0026250	€/t
- compressed air		5 bar	0,02	€/m³					0,0002500	m³/t	0,0000050	€/t
- nitrogen		5 bar	0,10	€/m³					0,0550000	m³/t	0,0055000	€/t
- gear box oil			3,00	€/liter					0,0004400	liter/t	0,0013200	€/t
- power (pumps+auxiliaries)			0,05	€/kWh	0,69	kWh/t	0,0347222	€/t	0,3750000	kWh/t	0,0187500	€/t
Subtotal consumption							1,6041667	€/t			0,0282000	€/t
Maintenance	€ per hour	man hours										
- pump service	35,00	4	140,00	€/pump	5000	tappings	0,0014000	€/t	5000			
- pump cleaning	35,00	40	1400,00	€/job	200	tappings	0,1166667	€/t				
- heat exchanger cleaning	35,00	12	420,00	€/job					5000			
- filter bag changing	35,00	8	280,00	€/job					2083			
- dust disposal			0,00	€/t	0,00	kg/t	0,0000000	€/t	0,20			
- contact water disposal			1,00	€/m³	0,45	m³/t	0,4513889	€/t				
Subtotal maintenance							0,5694556	€/t				
Spares	€ each	number										
- filter bags	15,00	216	3240,00	€/change					0,000003			
- seals and bearings	2000,00	per installed pump			3	pumps	0,0100000	€/t	9			
Subtotal spares							0,0100000	€/t				
TOTAL							2,1836222	€/t				
Difference							0,0000000	€/t				
Annual saving												

Operating costs	Steam ejectors	Dry running pumps including filter
	€/ton	€/ton
Energy and fluids	1,6041667	0,0282000
Maintenance	0,5694556	0,0042014
Spares	0,0100000	0,0300000
TOTAL	2,1836222	0,0624014
Saving	0%	97%

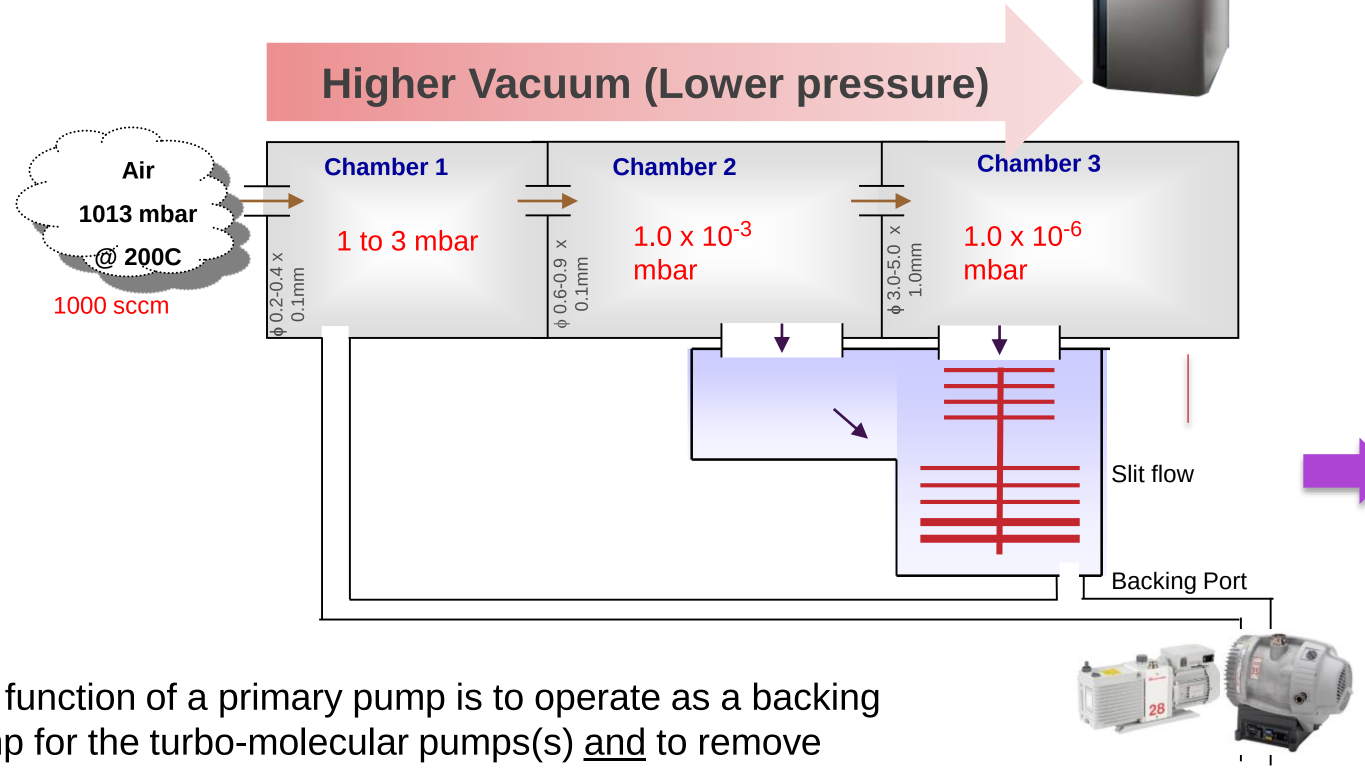
EDWARDS

LCMS - QUADRUPOLE

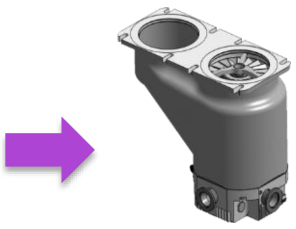
Waters Synapt G2

What types of LCMS are there?

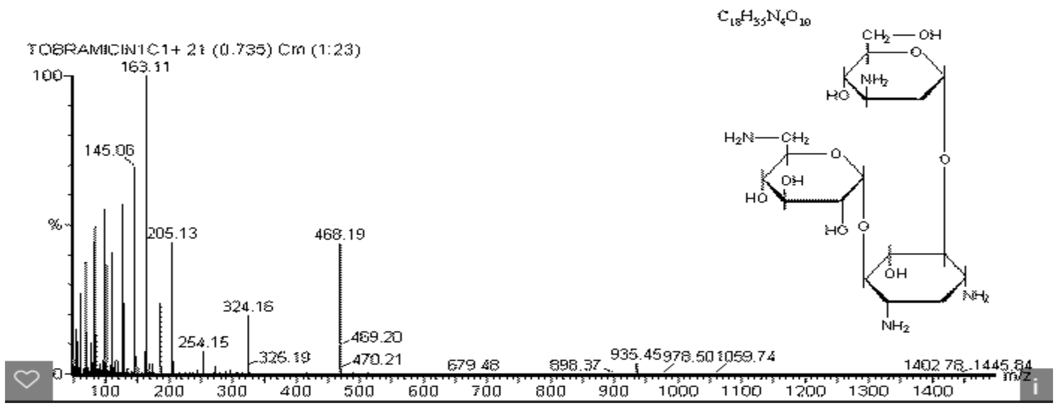
Single quadrupole	1,500 - 3,000 amu	**Simple**
Ion trap	1,500 - 3,000 amu	
Triple quadrupole	1,500 - 3,000 amu	
Time of Flight	15,000 -20,000 amu	
Quadrupole Time of Flight	16,000 – 30,000 amu	
FT Ion Cyclotron Resonance	40,000 - 50,0000 amu	**Sophisticated**

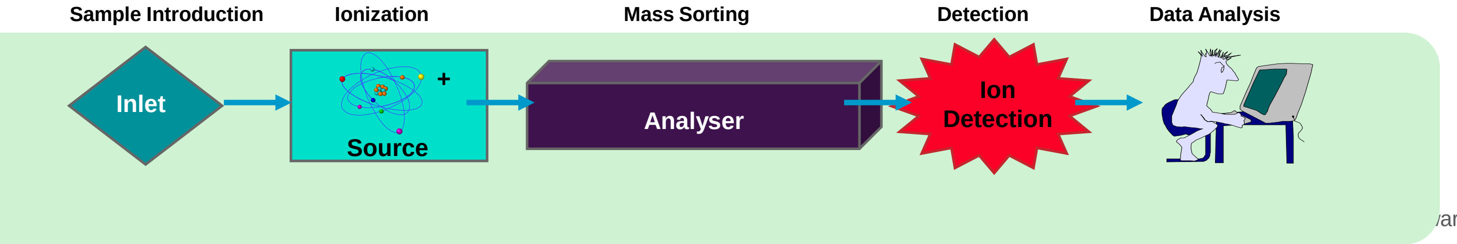


High vacuum conditions prevent collisions of ions with residual molecules in the analyser during the flight from the ion source to the detector: they increase the efficiency of ion transfer and detection



The function of a primary pump is to operate as a backing pump for the turbo-molecular pumps(s) and to remove carrier gas and/or solvent carry over





LCMS VACUUM HISTORY: 1990S – 2000S – 2016/FUTURE

Secondary pumps: TMPs

Replaced Oil diffusion pumps: no ‘accidents’ and lower CoO (power)

Move to fewer discrete TMPs: lower system and service costs = higher ‘up-time’

- Communications protocols
- Modelling – fewer iterations on NPI

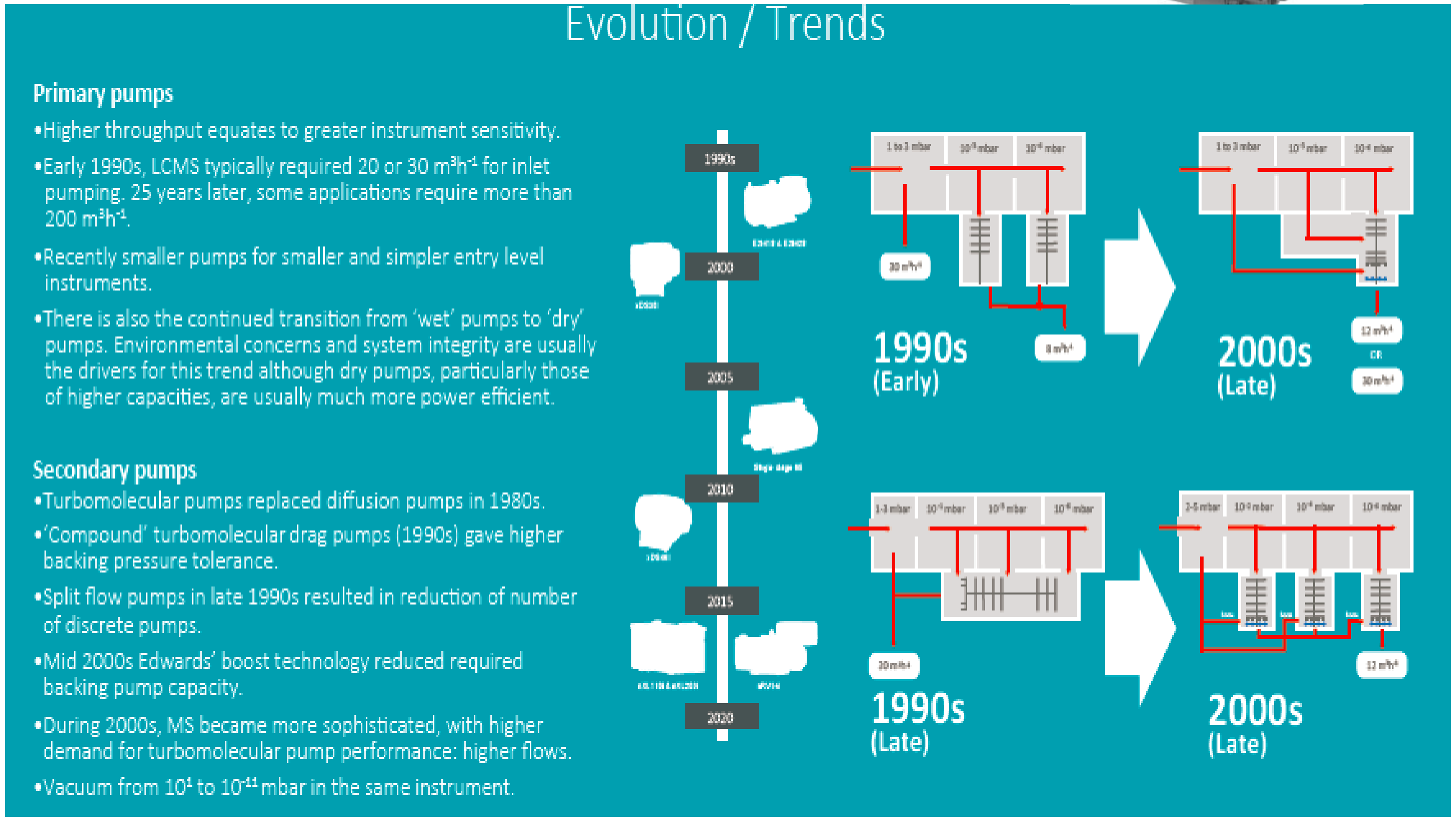
Primary pumps

‘Wet’ to ‘dry’ pumps – smaller (then larger)

Lower power = low heat generation and lower CoO

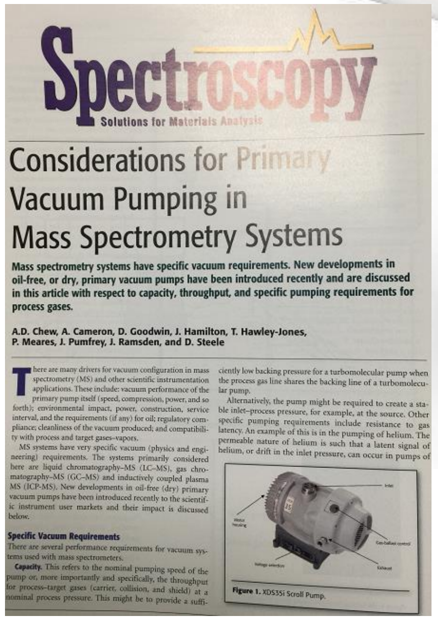
<u>No oil to dispose of</u>

<u>Local service possible</u>



EDWARDS

LCMS TMP CONFIGURATIONS



Spectroscopy

Solutions for Materials Analysis

Considerations for Primary Vacuum Pumping in Mass Spectrometry Systems

Mass spectrometry systems have specific vacuum requirements. New developments in oil-free, or dry, primary vacuum pumps have been introduced recently and are discussed in this article with respect to capacity, throughput, and specific pumping requirements for process gases.

A.D. Chew, A. Cameron, D. Goodwin, J. Hamilton, T. Hawley-Jones, P. Meares, J. Pumfrey, J. Ramsden, and D. Steele

There are many drivers for vacuum configuration in mass spectrometry (MS) and other scientific instrumentation applications. These include: vacuum performance of the primary pump itself (speed, compression, power, and so forth); environmental impact, power, construction, service interval, and the requirements (if any) for oil; regulatory compliance; cleanliness of the vacuum produced; and compatibility with process and target gases–vapors.

MS systems have very specific vacuum (physics and engineering) requirements. The systems primarily considered here are liquid chromatography–MS (LC–MS), gas chromatography–MS (GC–MS) and inductively coupled plasma MS (ICP-MS). New developments in oil-free (dry) primary vacuum pumps have been introduced recently to the scientific instrument user markets and their impact is discussed below.

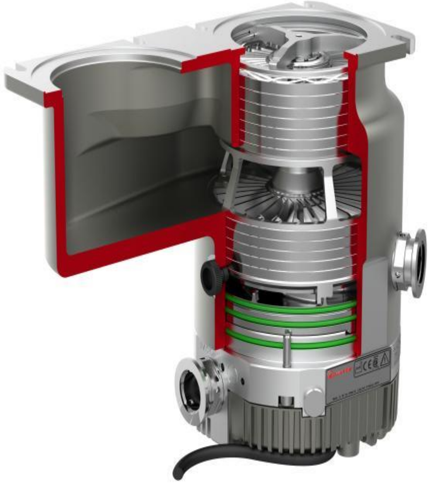
Specific Vacuum Requirements

There are several performance requirements for vacuum systems used with mass spectrometers.

Capacity. This refers to the nominal pumping speed of the pump or, more importantly and specifically, the throughput for process–target gases (carrier, collision, and shield) at a nominal process pressure. This might be to provide a sufficiently low backing pressure for a turbomolecular pump when the process gas line shares the backing line of a turbomolecular pump.

Alternatively, the pump might be required to create a stable inlet–process pressure, for example, at the source. Other specific pumping requirements include resistance to gas latency. An example of this is in the pumping of helium. The permeable nature of helium is such that a latent signal of helium, or drift in the inlet pressure, can occur in pumps of

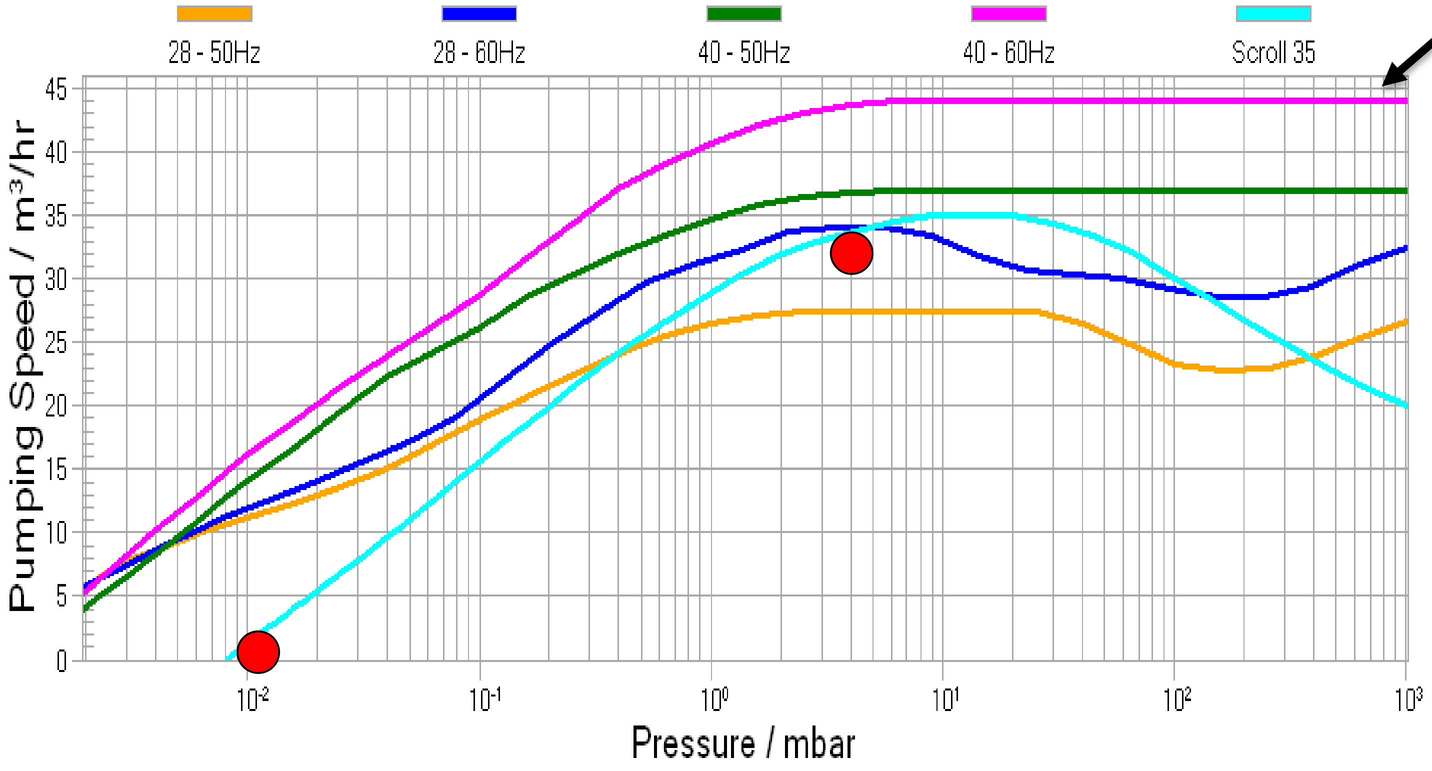
Figure 1. XDS35i Scroll Pump.



EDWARDS

PUMPING SPEED COMPARISONS: SCROLL - OSRV

now > 100 m³/h



Design points for LCMS

nXL110i/nXL200i

- 25 slm
- higher throughput = higher sensitivity
- Air-cooled!

CAT 1 LRP: STYRENE DEVOLATIZER SYSTEM

LEGISLATIVE REQUIREMENTS - ATEX ETC.

- ATEX is a European directive **2014/34/EU** ‘Equipment and protective systems intended for use in potentially explosive atmospheres

• IECEx is a **global certification** scheme, countries can chose to join
•Based on European EN standards, but with deviation

- Japan : Technology Institution of Industrial Safety
- Korea: Korea Gas Safety Corporation
- Brazil – INMETRO

All based on EN standards but with national deviations.

29.3.2014 EN Official Journal of the European Union L 96/309

DIRECTIVE 2014/34/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 26 February 2014

on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres (recast)

(Text with EEA relevance)

THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION,

Having regard to the Treaty on the Functioning of the European Union, and in particular Article 114 thereof,

Having regard to the proposal from the European Commission,

After transmission of the draft legislative act to the national parliaments,

Having regard to the opinion of the European Economic and

framework for the marketing of products (6) lays down common principles and reference provisions intended to apply across sectoral legislation in order to provide a coherent basis for revision or recasts of that legislation. Directive 94/9/EC should be adapted to that Decision.

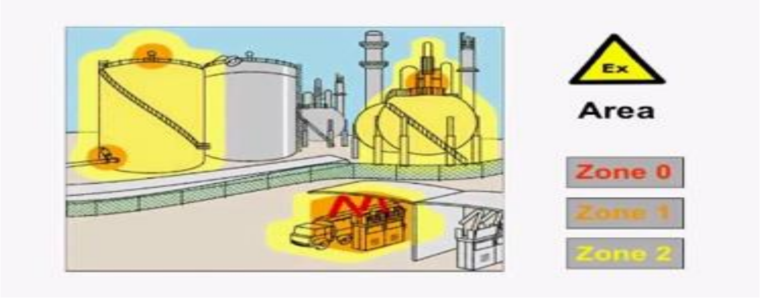
(4) This Directive covers products which are new to the Union market when they are placed on the market; that is to say they are either new products made by a manufacturer established in the Union or products, whether new or second-hand, imported from a third country.

(5) This Directive should apply to all forms of supply,

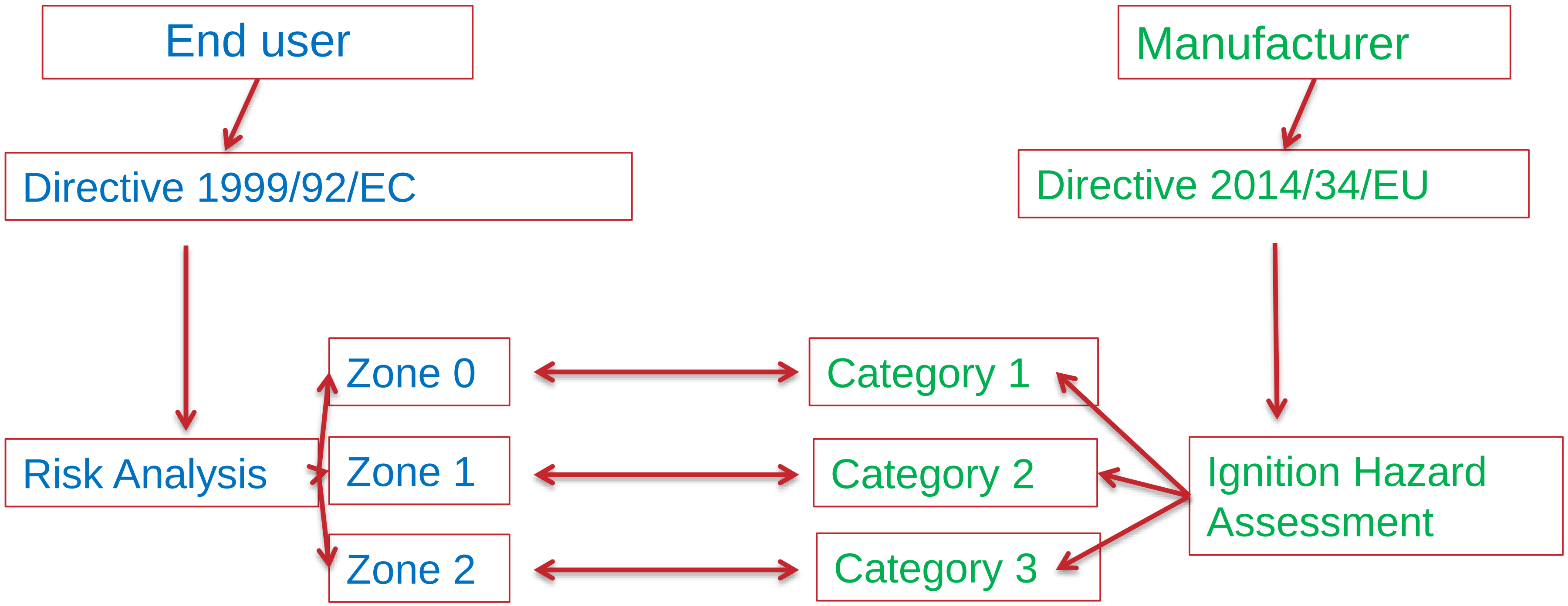
EDWARDS

ATEX ETC.

- Explosion: material **reacts violently with Oxygen** as the temperature rises
- **Deflagration**: Flame travels below or up to the speed of sound, the resulting explosion pressure is about 10 times the starting pressure
- **Detonation**: Flame travels faster than the speed of sound, resulting explosion pressure is far more than 10 times the initial pressure
    - **Zone 2**: an explosive atmosphere is not likely to occur during normal operation and if it does it is only there for a short period of time
    - **Zone 1**: an explosive atmosphere is likely to occur in normal operation occasionally
    - **Zone 0**: an explosive atmosphere is present continuously or for a long period



ATEX ETC.


End user
Directive 1999/92/EC
Risk Analysis
Zone 0
Zone 1
Zone 2
Category 1
Category 2
Category 3
Manufacturer
Directive 2014/34/EU
Ignition Hazard Assessment

ATEX ETC.

II 2 G Exd [ia] IIB T4

Equipment Group;
Group I: mining
Group II: non mining

Important for Vacuum pumps: Internal and external marking required!

Equipment Category

G = Gas, D= Dust

Ex d [ia] = protection concept, c = constructional safety, b = control of ignition sources

IIB = Gas Group

Temperature Class T4

FOOD – FATTY ACID DEODERISATON

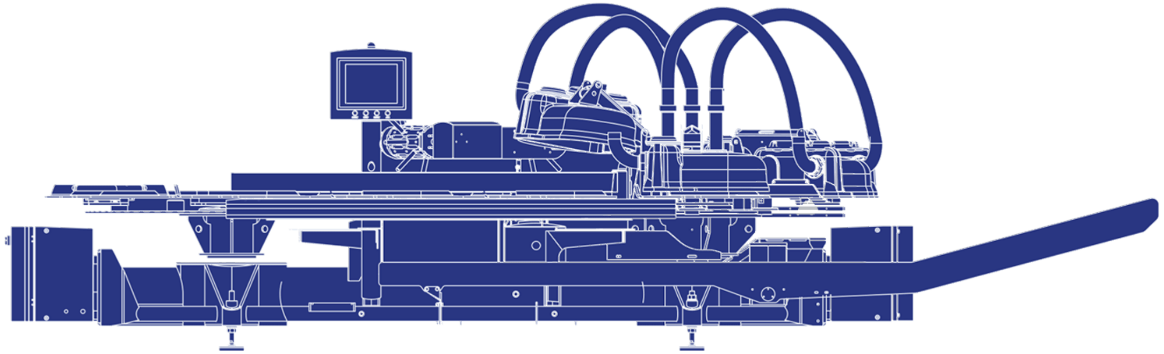
EDWARDS

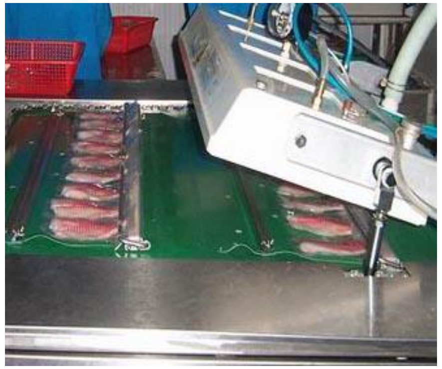
TOTAL RECIRCULATION LRP PACKAGES

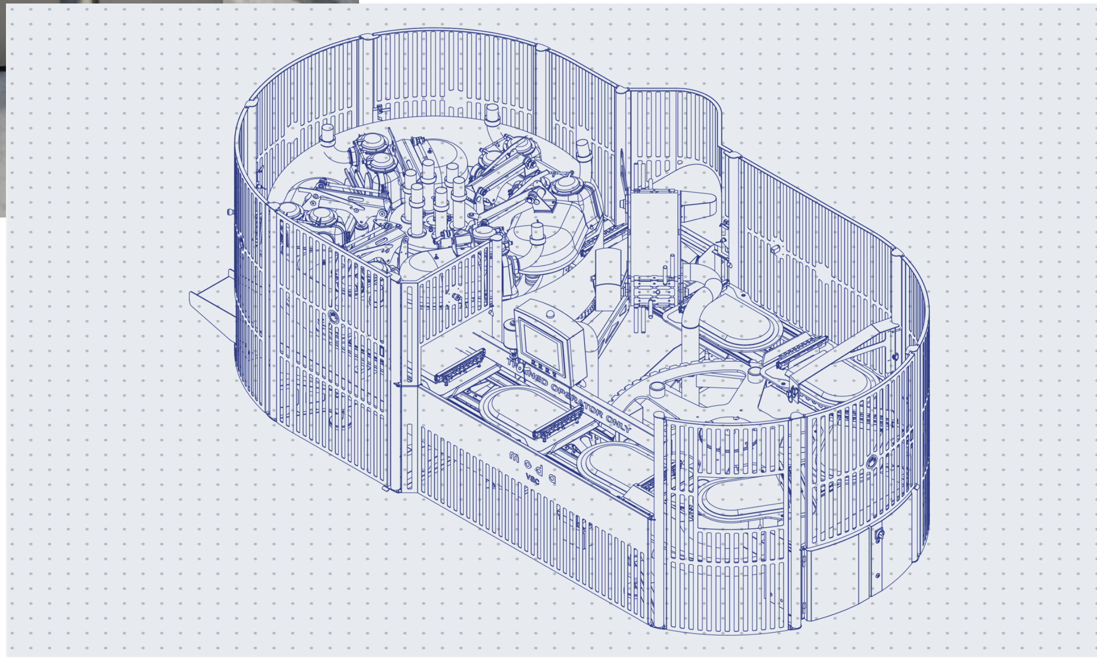
OTHER (COATING) SYSTEMS ETC…

FOOD PACKAGING

ModaVac New Zealand

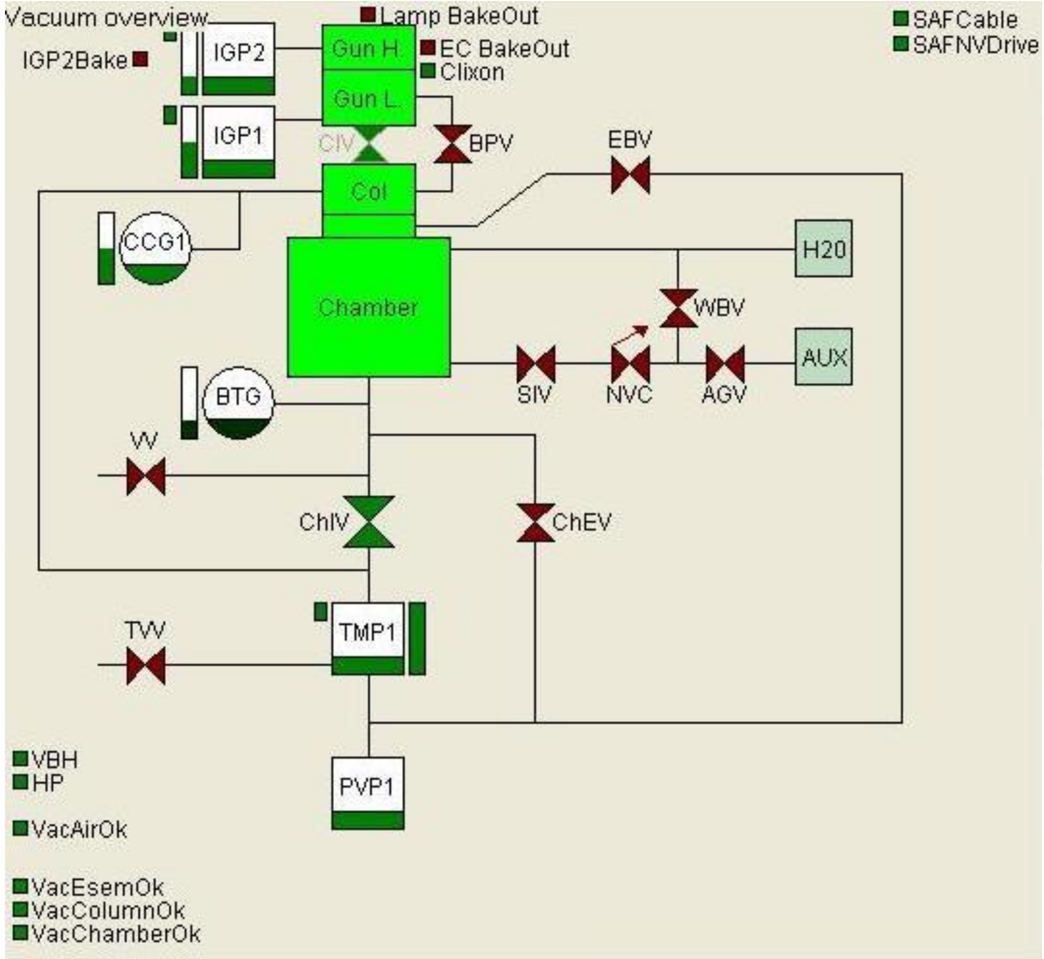






40–45 packs per minute @1.0mbar (0.75 torr)
Stainless steel construction – T304
6 chamber rotary indexing

ELECTRON MICROSCOPY - SYSTEMS



http://www.cvgs.k12.va.us/curric/SRSEM/emlab/svt.htm

http://www.tescan.com/gallery-gallery.php?menu=2

Some use ‘vacuum reservoir chamber’ with TMP off during experiments

ELECTRON MICROSCOPY VACUUM CONSIDERATIONS

- Typical EM electron m.f.p. ~1m @ 1e-4 mbar

Need lower pressures to prevent collisions with residual gas molecules

- At pressures <10^{-4} mbar – molecular flow regime: here conductance C of the pipe ~ r^3/l

- Conductance is pressure independent

$$1/S_{eff} = 1/C + 1/S_{pump}$$

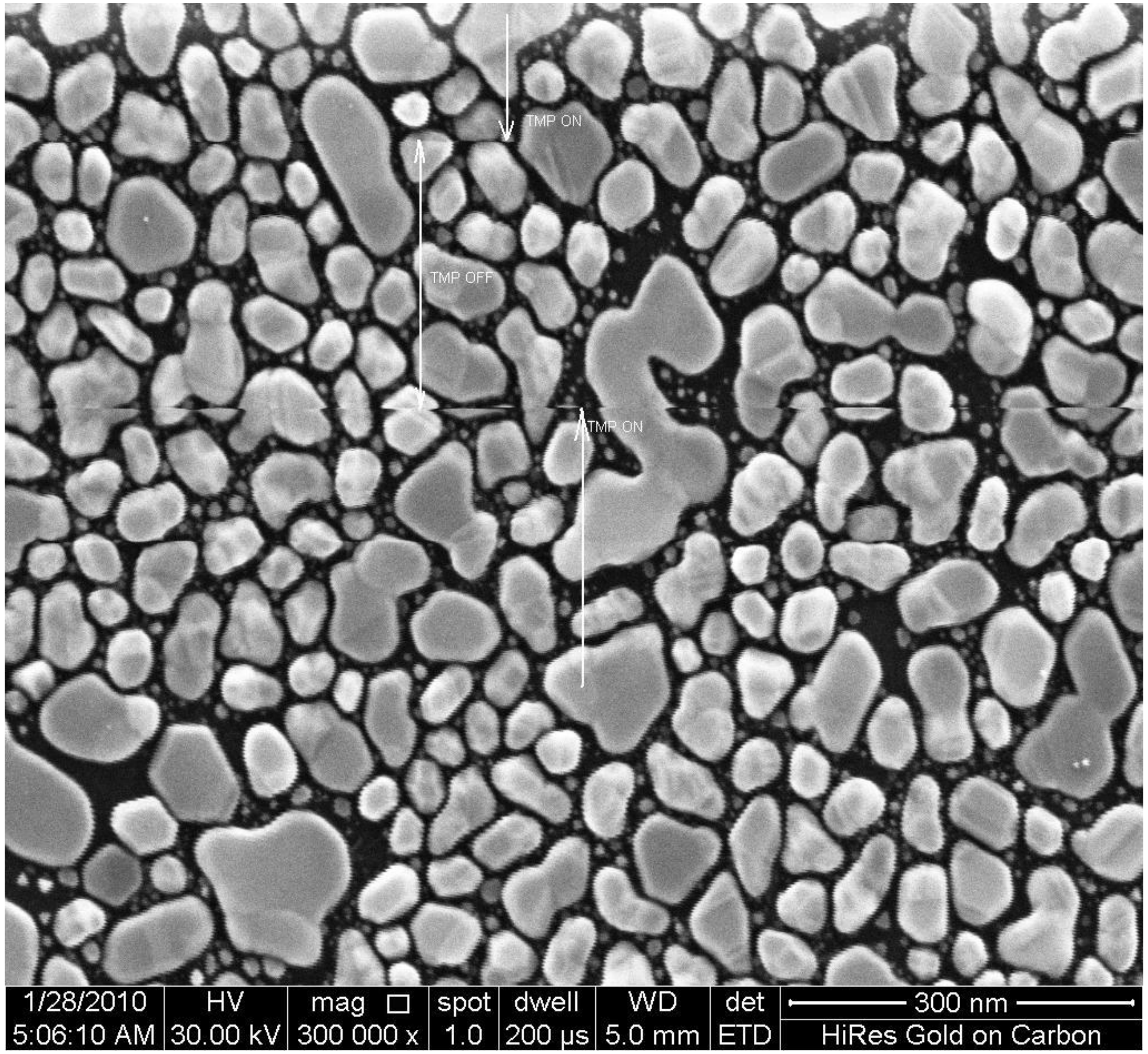
To maximise effective speed – minimise pump connections (use transmission probabilities for lower pressures)

Vacuum pumping system

- Vacuum requirements vary: ~10 mbar to <1e-10 mbar
- Move from Diffusion pumps to TMPs (and Ion pumps)
- Move from OSRV to dry primary pumps (scroll)

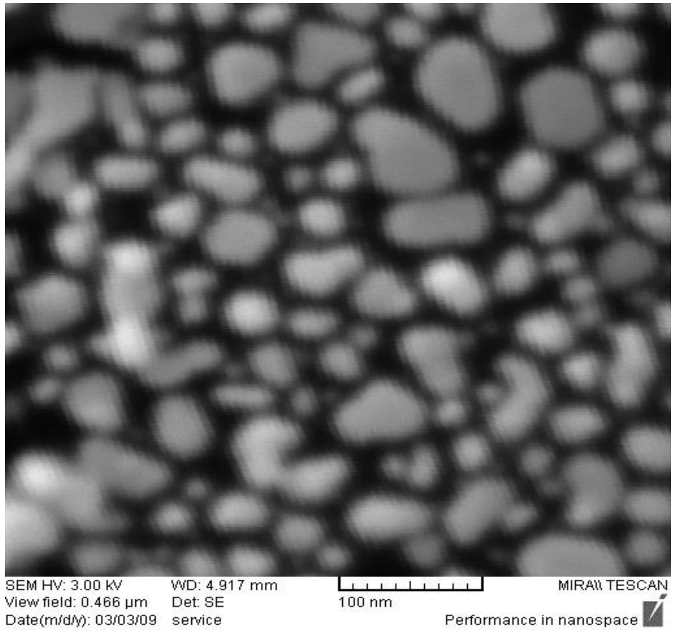
- Vacuum pumps should not disturb images!

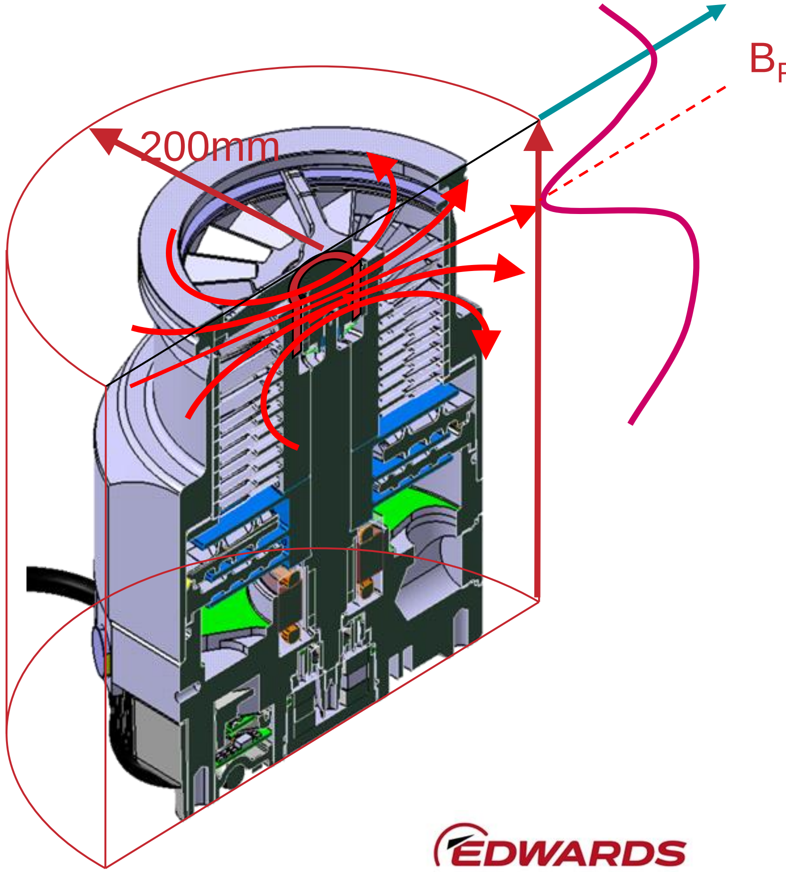
ELECTRON MICROSCOPY - DISTURBANCE IN THE IMAGE



- Turbomolecular pump (and fan) are only mechanical part on a microscope
- Potential of
  - Mechanical vibrations
  - Electromagnetic field
  - Audible noise!

ELECTRON MICROSCOPY – ELECTROMAGNETIC DISTURBANCE





- More pronounced at low accelerating energies

(Lorentz force)

- Use low field TMP versions ~ 0.1 to 1 mG

c.f. Earth’s field = 250 to 650 mG

DRIVERS IN EM AND SURFACE SPECTROSCOPY –

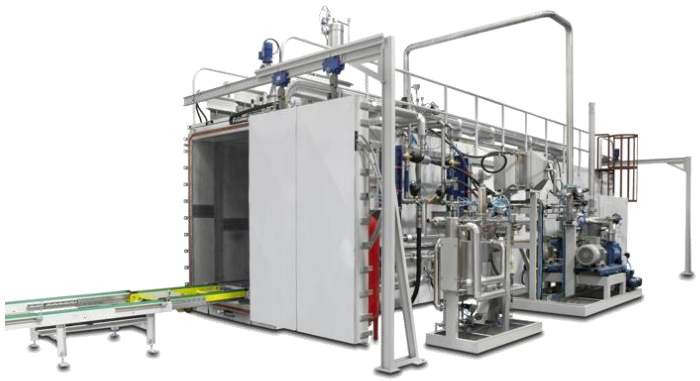
The future of electron microscopy
Yimei Zhu and Hermann Dürr
Physics Today **68**(4), 32 (2015)

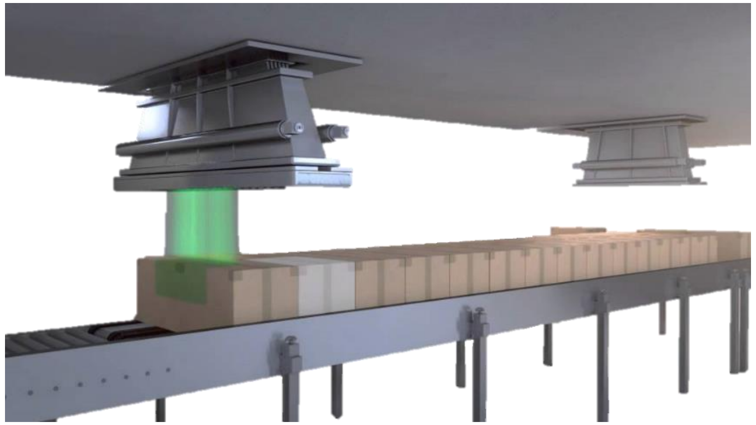
STEM allows analysis via other techniques
Secondary electrons, EDX, WDX, EELS

STERILIZATION

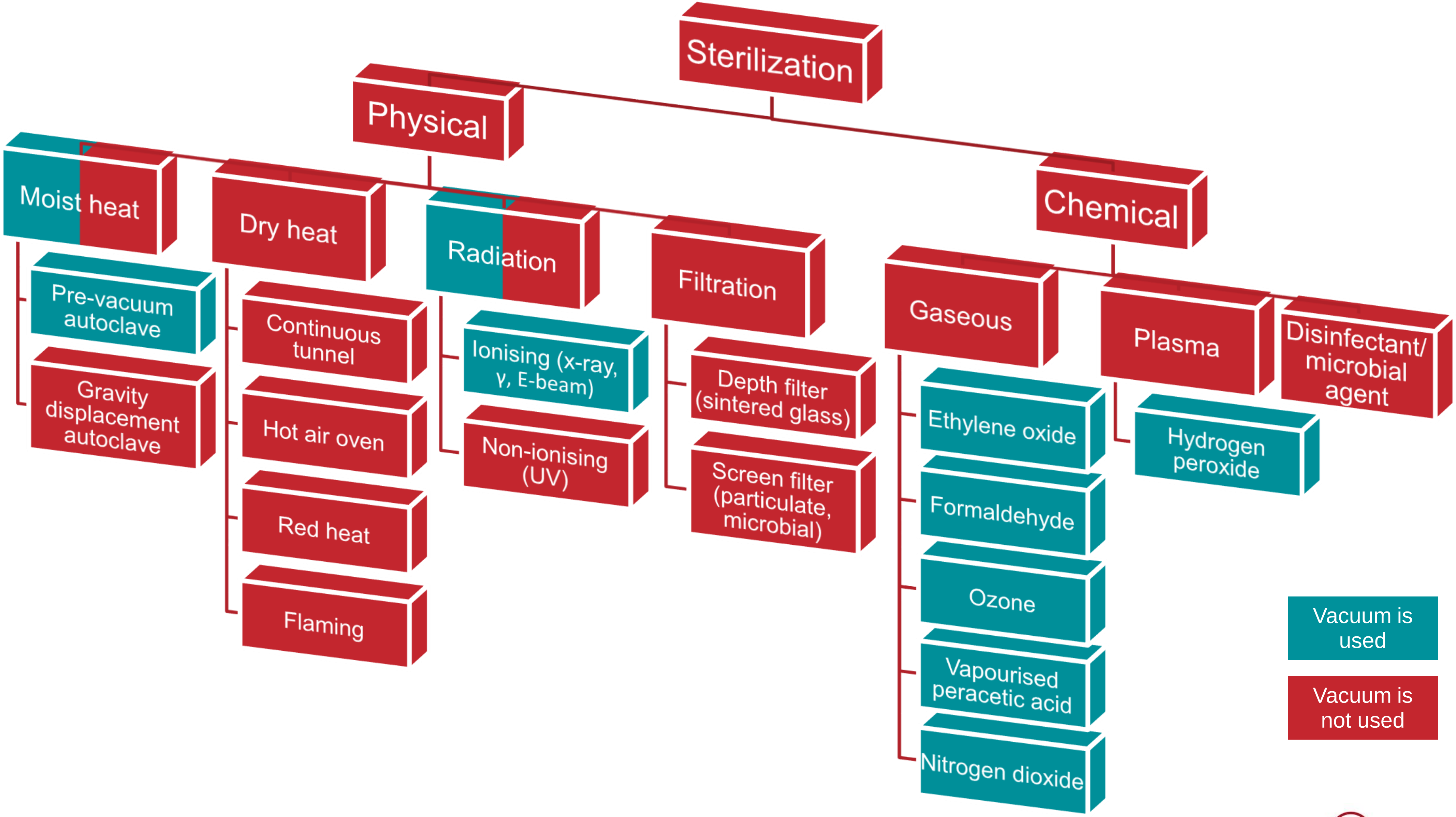
“The use of a physical or chemical procedure to destroy all microbial life, including highly resistant bacterial endospores”

- It is a process commonly used in medical and food industries to ‘clean’ items of biological contamination and reduce the chances of infection and illness.
- Successful sterilization means no more than a one in a million chance that a microorganism will survive the process.



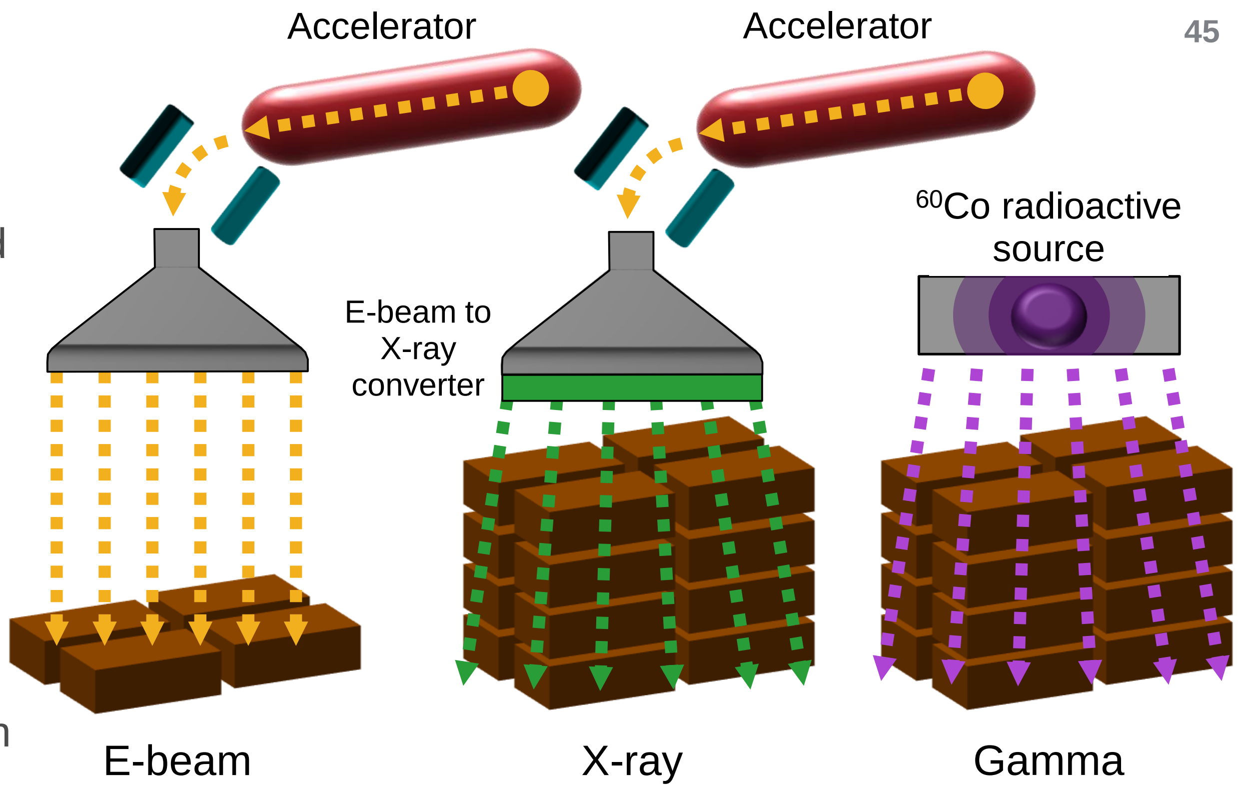


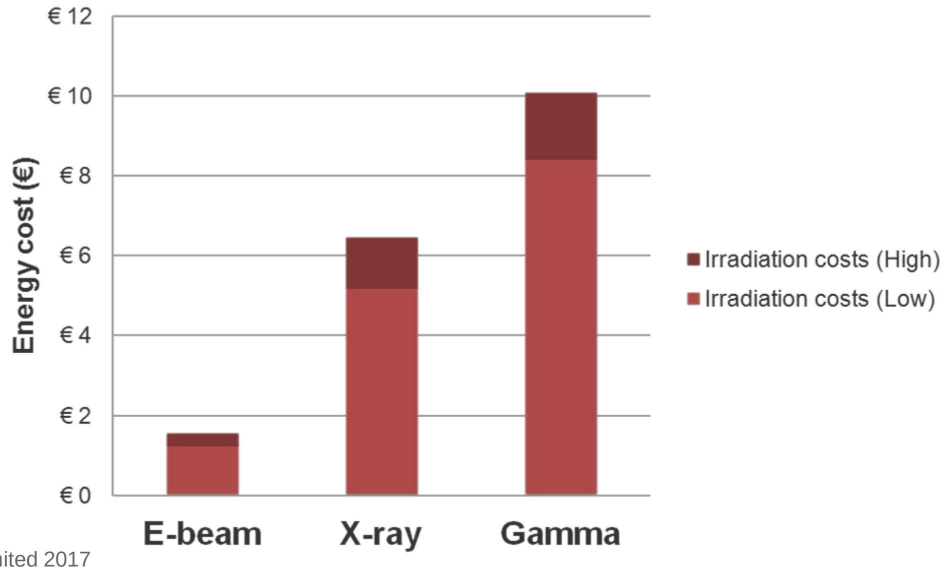

METHODS


Sterilization
Physical
Chemical
Moist heat
Dry heat
Radiation
Filtration
Gaseous
Plasma
Disinfectant/ microbial agent
Pre-vacuum autoclave
Gravity displacement autoclave
Continuous tunnel
Hot air oven
Red heat
Flaming
Ionising (x-ray, γ, E-beam)
Non-ionising (UV)
Depth filter (sintered glass)
Screen filter (particulate, microbial)
Ethylene oxide
Formaldehyde
Ozone
Vapourised peracetic acid
Nitrogen dioxide
Hydrogen peroxide
Vacuum is used
Vacuum is not used

RADIATION

- Ionising radiation is short wavelength and high-intensity and causes damage to genetic material of microorganisms
- Sterilization by ionising radiation can use one of three techniques:
  - Electron beam
  - X-ray
  - Gamma ray
- Sterilization can also be done with non-ionising UV radiation but due to the longer wavelength this cannot penetrate and is only used on surfaces
- Ionising radiation sterilisation is a low temperature process which is used for heat sensitive items
- Compared with other low temperature processes it is relatively high cost so is generally used for large scale sterilization
- The use of ionising radiation is increasing due to the increasing power of electron accelerators

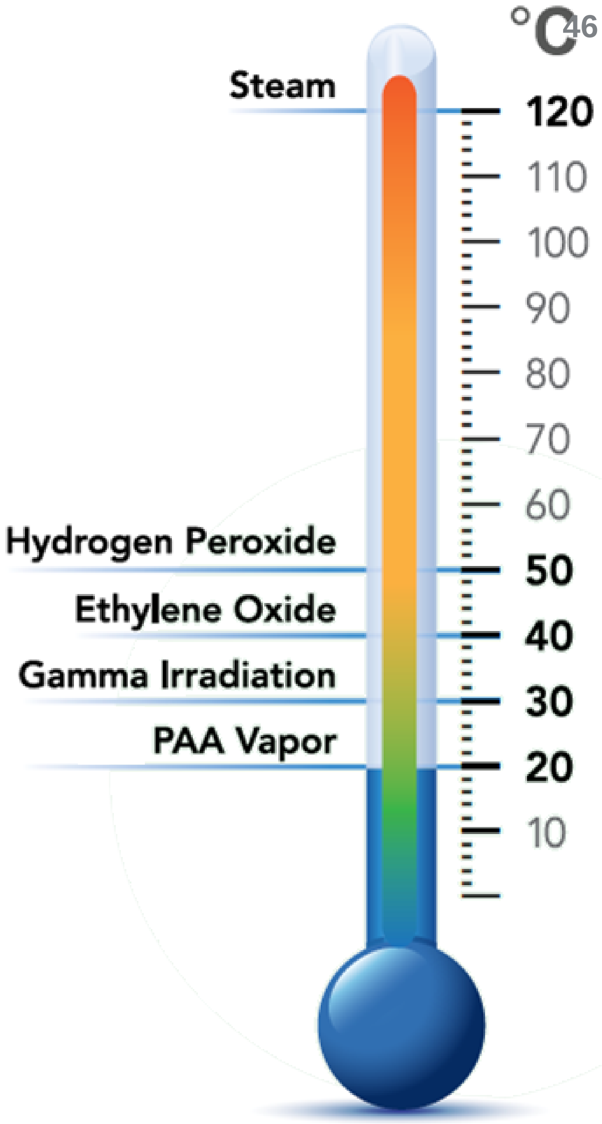




Cost of sterilizing 1m^3 with ionising radiation

GASEOUS

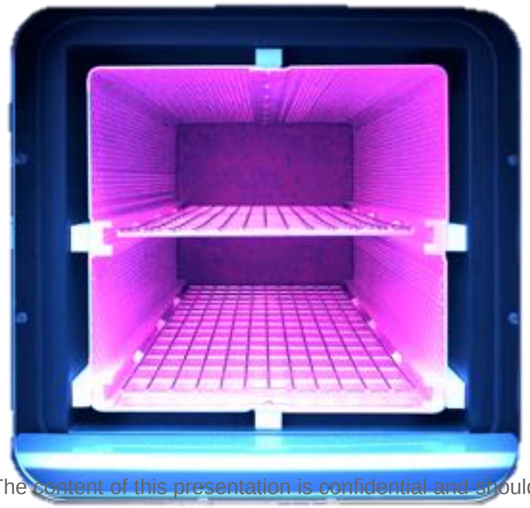
- Gaseous sterilization methods all use the same basic techniques with different gases injected:
  - Ethylene oxide
  - Ozone
  - Formaldehyde
  - Peracetic acid
  - Nitrogen dioxide
- The basic process for gas sterilization is pre-conditioning (air removal), sterilization (injection of gas) and degassing (removing gas and by-products)
- Generally gas treatments are 'low temperature' and are often used for items sensitive to temperature
- Gas injection can be combined with steam sterilization to increase efficiency
- During treatment, temperature and pressure are controlled
- The active gases used for sterilization are often toxic, flammable or volatile and are therefore generally mixed with inert gases

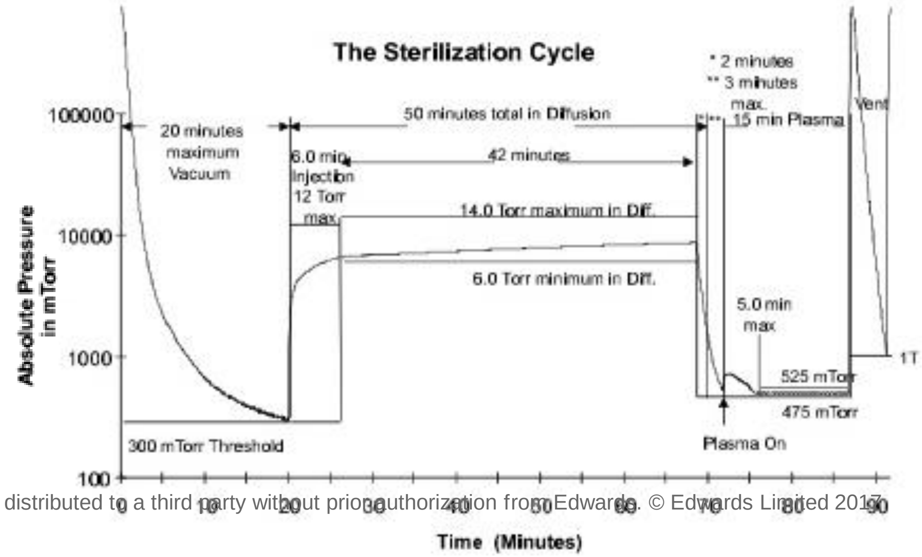


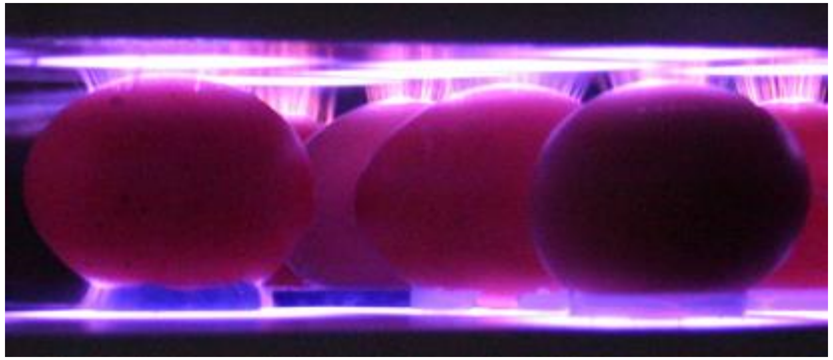
EDWARDS

HYDROGEN PEROXIDE (AND OZONE) PLASMAS

- Plasma sterilization usually uses hydrogen peroxide (H_2O_2) as the gas
- The H_2O_2 is activated and produces a plasma of charged particles which glow visibly
- The plasma phase of H_2O_2 is very effective, even at low concentration and low temperature
- The gas is vapourised and injected to the chamber under vacuum then an electric field is used to create the plasma
- Free radicals, IR/UV radiation and photon induced desorption lead to damage to the cells
- Many facilities are looking to replace EtO sterilizers with gas plasma however there are very few products available commercially, only small chamber volumes and worries over safety







SOME THEMES AND DRIVERS

Dry mechanisms – no oil to be disposed of (risk of accidents, leaks (seal deterioration), spills and suck-back

Lower Power

Smaller Footprint – *backwardly compatible*

Serviceability (by end-user)

Lower Cost-of ownership

Universal operation - *inverter driven hence constant performance independent of supply voltage*

Environmental

Life-time

Reliability

Safety/Legislation/ Compliance

Communications protocols

Modelling

DPDS400/EH2600

@ CNRS, Grenoble since 2003 with 0.76 g/s of helium at 10 mbar

Lots of 'cross-selling' = cross-use

CONCLUSION

Vacuum enables many, many applications and technologies

There is no such thing as ‘*Just*’ a Vacuum Pump

Systems are complicated and varied

Think where your vacuum skills could take you….

THANK YOU

INDUSTRIAL VACUUM APPLICATIONS

- A VERY PERSONAL PERSEPECTIVE

The CERN Accelerator School

MAX IV LABORATORY

CERN Accelerator School

in collaboration with

MAX IV Laboratory

are organising a course on

Vacuum for Particle Accelerators

DR ANDREW CHEW

SATURDAY 10TH JUNE

EDWARDS