as negative vacancies associated with the metastable state of the native mid-gap donor, the so-called EL2 centres which control compensating mechanisms in semi-insulating GaAs (see figure). The technique is able to show that the open volume of these vacancies is smaller than that of Ga or As vacancies, strongly supporting recent models which propose a [111]-oriented vacancy-interstitial complex for the structures of these centres. Furthermore, As vacancies seem to play an important role as recombination (RC) centres in GaAs since positron annihilation has demonstrated that their concentration is correlated with that of RC centres. The latter are detected by infra-red absorption and have been shown to control the minority carrier lifetime in bulk semi-insulating GaAs.

Proof that the characterisation of defects in semiconductors by positron annihilation is becoming more firmly rooted also stems from interesting studies by a group based in Geneva and Lausanne of the negatively charged As vacancy in doped GaAs. By combining Car/Parrinello-type *ab initio* electronic structure/molecular dynamics calculations with measurements of the momentum density of electron-positron pairs by observing the two-dimensional angular correlation between the 511 keV annihilation quanta (the so-called two-dimensional ACAR technique), it can be established that the atoms around the vacancy relax in an outward direction when a positron is trapped in the vacancy (see insert). This type of study is important for understanding the behaviour of positrons in defects.

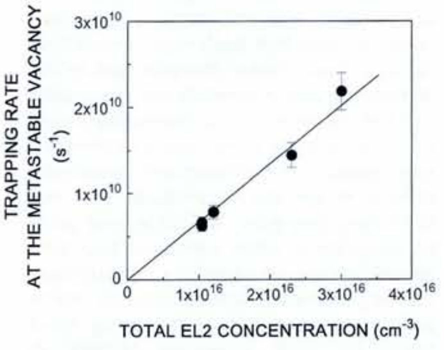
A simple but powerful extension of the Doppler broadening method has been shown to allow one to distinguish between various kinds of defects. It is actually a revival of an old idea [Mantl S. & W. Triftshäuser W., *Phys. Rev. B* **17** (1978) 1645] and consists of simultaneously examining the variations of the *S* and *W* parameters. It has been shown for CdTe and that the data points representing samples with different concentrations of a specific type of defect (*e.g.*, monovacancies) fall on a straight line in a *S* versus *W* plot, while samples containing a different type of defect (say divacancies) define a different straight line in the same plot. This represents a powerful method of defect identification. Furthermore, it has been demonstrated in $Cd_{(1-x)}Te_xHg$ that positrons can be used to discriminate ion-type acceptors from vacancy-type acceptors and to determine the concentration of each type.

The participants at the first Europhysics Industrial Workshop (EIW) on Industrial Applications of Positron Annihilation (10-12 March 1994) which was held in a secluded hotel near the picturesque village of Oisterwijk in the south of The Netherlands. EIWs aim to bring together scientists from universities and from industry in order to promote the application of new physical methods to industrial problems. The workshop, the 12th in the series of EIWs and chaired by A. van Veen (IRI, Delft) and C. Corbel (Saclay), attracted some 40 scientists from both sectors. The proceedings of the workshop will be published as a supplement to the Journal de Physique.

Other Materials, Large Scales

Reports at the workshop about depth profiling in diamond-like coatings, magnetic multilayers and layers of paint show that the application of positron annihilation is not limited to metals and semiconductors. Nor are positron methods restricted to the microscopic realm, as is witnessed by work on positron emission tomography at Shell that was reported by G. Jonkers. With the aid of gamma-ray cameras and positron emitting tracers it is possible to study processes as diverse as the flooding of oil-filled reservoir rock with water, the movement of particles in a rotating drum and the oil flow in engines while they are running. The value of the use of positron annihilation is the feasibility of safe *in situ* imaging of complicated processes without disturbing them.

P.J. Mijnarends, *IRI, Delft*



Positron annihilation is particularly successful in identifying negative vacancies associated with the metastable state of the EL2 centre in GaAs. The figure gives the positron trapping rate at the metastable vacancies generated when EL2 centres are excited to their metastable state. The data are plotted as a function of the EL2 concentration determined from Fourier transform infra-red absorption in bulk GaAs crystals from various suppliers [C. Le Berre, Université d'Orsay, Paris XI (1994), unpublished]. The data strongly support the model of a (111)-oriented vacancy-interstitial complex for the structure of these centres [Krause R. et al., Phys. Rev. Lett. ***65*** *(1990) 3329].*

POSITRON FACILITIES

Facilities-based Capabilities Increase

W. Triftshäuser from the Institut für Nukleare Festkörperphysik, Universität der Bundeswehr, Munich, described at the Europhysics Industrial Workshop *Industrial Applications of Positron Annihilation* Europe's move towards larger and more sophisticated facilties for positron annihilation.

Many groups are using positrons from radioactive sources in lab-scale devices to tackle a variety of applications (see *Directory of Positron Groups in Europe*, p. 181). A few, together with at least one commercial company, have developed equipment to measure the angular correlation of positron annhilation radiation which gives detailed information on the electron-positron momentum density, especially if positron-sensitive detectors are used. However, opportunities are limited since the single crystal sample must be fairly large (about the same size as the 100-200 μm depth to which positrons from radioactive sources penetrate into the sample). It is clearly advantageous to have available high intensity, narrow beams capable of probing small samples. So there is a trend towards dedicated positron sources operating as user facilities that offer monoenergetic continuous beams of variable energy and of high intensity. At the same time, pulsed systems originally designed for surface studies are being developed as scanning microscopes by reducing considerably the beam size.

Continuous Beams

The application of "conventional" low-energy continuous positron beams has increased significantly these last few years owing to the development of more efficient moderators to give beams with a narrower distribution of energy. Positrons from primary radioactive sources are passed into a moderator acting as a secondary source of low-energy positrons and the low- and high-energy positrons are then separated and guided electrically and/or magnetically to the target.

However, the intensity of radioisotope source-based beams are limited by self-absorption. One approach to increase the intensity is based on pair production from Bremsstrahlung in a linac, but heating and cooling of the target foil used to produce the positrons impose serious limitations. Another disadvantage is that most linacs are pulsed so the positron beam is also pulsed. A group at the University of Gent uses a specially designed Penning trap to generate a semi-continuous beam of some 4 x 10^7 positrons/s by smearing out pairs of pulses.

Reactor-based beams are attractive because they are inherently continuous. Two different approaches are being exploited, with a group at the IRI in Delft using activation of short-lived positron-emitting isotopes by thermal neutrons near the reactor core. ^{64}Cu with a half life of 12.8 hours is produced by neutron capture in ^{63}Cu, and after a certain irradiation time depending on the neutron flux, an equilibrium positron intensity is obtained. The positrons are guided magnetically from the Cu-source and separated from the neutron flux. The objective is beam with an intensity of 2 x 10^8 positrons/s and a diameter of 10 mm after remoderation.

The alternative approach of using pair production from high-energy gamma rays after capture of thermal neutrons in ^{113}Cd is being developed at the Universität der Bundeswehr, Munich. Tungsten foils placed after the gamma-ray emitting Cd target are used simultaneously as converters for pair production and as moderators to obtain a low-energy positron beam with an expected intensity of 10^9 positrons/s and a 5 mm beam diameter after remoderation. A prototype is planned which may then be installed at the Institut Laue-Langevin in Grenoble to give a flux of about 10^{11} positron/s.

From the left, C. Corbel (CE-Saclay) and A. van Veen (IRI, Delft), who co-chaired the industrial workshop, with M. Eldrup (Risø National Laboratory, Roskilde).

Directory of Positron Groups in Europe

	Affiliation	Group Head	Techniques	Applications
A	Vienna Univ.	V. Gröger	B L	m n
	TU Graz	H. Sormann	T	f e
B	Rijksuniversiteit Ghent	D. Segers	B L D	m s
	SCK/CEN, Mol	L. Van Hoorebeke	L	m
BU	Acad. of Sci., Sofia	T. Troev	B L A_1	m e f
CH	Geneva Univ.	A.A. Manuel	L A_2	m s e h i b
	ETH Zurich	J. Brunner	L	l p
CZ	Inst. Phys. Materials, Brno	M. Sŏb	B T	m e l
	Charles Univ., Prague	I. Prochazka	B L	m s i
D	Stuttgart Univ.	H.-E. Schaefer	L B	m n k
	Stuttgart Univ.	J. Major	B	b f
	MPI Metallforschung, Stuttgart	H. Stoll	L B H G	m f
	MPI Metallforschung, Stuttgart	A. Seeger	T	f
	Bundeswehr Univ., Munich	W. Triftshäuser	B L D A_2 M P	m s l e
	Bonn Univ.	K. Maier	B L Z	i s l
	Fraunhofer Inst., Saarbrücken	J. Schreiber	L	m
	Halle Univ.	R. Krause-Rehberg	L D	m n s k
	Res. Centre Rossendof	G. Brauer	B L D	m s p
DK	Risö Nat. Lab.	M. Eldrup	B L A_1	m n k p
E	Complutense, Madrid	N. de Diego	B L	m s
FR	UMR-CNRS-CEA, Saclay	R.I. Grynszpan	B L	m n l p
	INSTN CE-Saclay	C. Corbel	B L	m s
	CENG/SPMM/MP, Grenoble	P. Moser	B L	m p
	Aix-Marseilles Univ.	G. Moya	B L	m
GB	Univ. of East Anglia	P.G. Coleman	S D R M	m s f u
	Bristol Univ.	M.A. Alam	B L A_2	m s e t k
	Royal Holloway Coll., London	P. Rice-Evans	D B Ps	s l g
	Univ. College , London	M. Charlton	L Ps	g f
	AEA Technology, Harwell	M.T. Hutchings	B	m
H	Eötvös Loránd Univ., Budapest	A. Vértes	B L	p e t
IT	Politecnico di Milano	A. Dupasquier	B L A_1	m s
	Trento Univ.	A. Zecca	B L D R	m s n p h
	ENEA, Bologna	M. Biasini	B L A_2	m s e
NL	IRI, Delft Univ. of Technology	A. van Veen	B L D M A_2	m s l i p e
P	Coimbra Univ.	A.P. de Lima	B L D	m
PL	Wroclaw Univ.	M. Dębowska	B L A_1	p e
	Acad. of Sci., Wroclaw	H. Stachowiak	T	e u
	Pedagogical Univ, Czestochowa	J. Filipecki	L A_1	n p
	Inst. of Nucl. Physics, Cracow	J. Dryzek	B A_1	m s
	Inst. Fiz., UMCS, Lublin	T. Goworek	L A_1	i p
RU	Acad. of Sci., Moscow	V.P. Shantarovich	L A_1	m s p k
	Inst. Surface Chem., Kiev	V.T. Adonkin	L A_1	e
SF	Helsinki Univ. of Tech.	P. Hautojärvi	B L D	m s l c
SL	Acad. of Sci., Bratislava	K. Kristiakova	B L G	m n p h

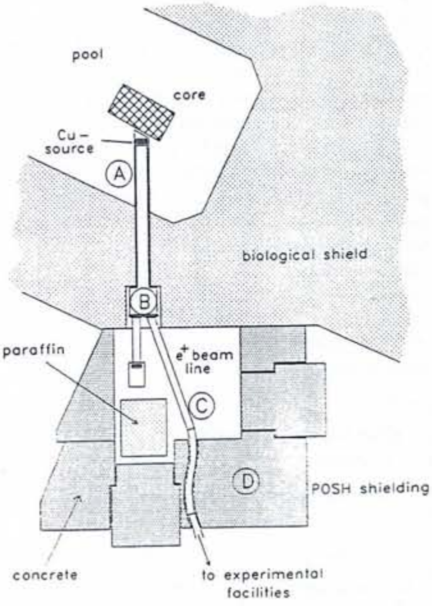
	Techniques
B	Doppler **B**roadening
L	**L**fetime
D	**D**epth profiling
A_1	1D-**ACAR**
A_2	2D-**ACAR**
R	**Re**-emission or positron Auger electron spectroscopy (PAES)
M	Positron **M**icroscope
P	**P**ulsed lifetime
Z	polari**z**ed slow positrons
G	A**g**e-momentum
H	**H**igh-energy (MeV) positron beam
Ps	**Positronium** beam
T	**T**heory
S	**S**urface measurements

	Applications
m	defects in **m**etals
s	defects in **s**emiconductors
i	**i**nsulators
f	**f**undamental
l	(multi-) **l**ayers, thin films, coatings
b	magnetism
c	**c**atalytic materials
p	**p**olymers and glasses
e	**e**lectronic structure
t	phase transitions
g	**g**ases
n	powders, **n**ano-/quasi-crystals
k	ceramics
h	**h**igh-T_c superconductors
u	s**u**rface studies

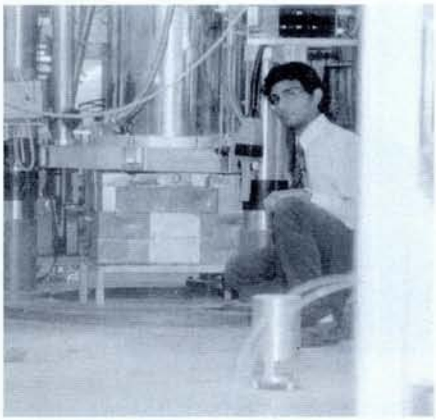
The feasibility of a radioactive isotope based approach for high-intensity low-energy beams has been demonstrated by the Paul-Scherrer Institute. An intense primary positron source (*e.g.*, ^{18}F) is deposited as a thin layer on a very thin foil. Confining electric and magnetic fields force the high-energy positrons to return towards the foil and to pass through several times during which time they are slowed down. Just before reaching the capture energy, the positrons are led to to a solid Ne moderator where low-energy positrons are extracted. An user facility based on this very interesting approach is currently being planned.

Pulsed Beams

Radio-frequency pulsed, slow positron beams have proved in recent years to be very valuable for positron lifetime spectroscopy in the near-surface region. A facility at the Universität der Bundeswehr, Munich, began operating in the late 1980s, and a similar system was installed soon after in Japan (the Munich system has since been upgraded). It is based on compressing a beam of monoenergetic positrons produced by a conventional radioactive source (*e.g.*, ^{22}Na) into sub-150 ps pulses. The beam is 4-5 mm in diameter at 15-28 keV and generates about 130 counts/s in the detector. The device has



Schematic illustration of the positron beam facility at the Interfaculty Reactor Institute (IRI), Delft. Indicated are the Cu source with a vacuum tube (A), deflection system (B), positron beam guide (C), and shielding (D).



R. Ambigapathy with Geneva University's 2D-ACAR system. The main structure is the liquid helium cryostat (the window through which the γ-rays resulting from positron annihilation emerge is towards the bottom). One of the detectors is to the right in the foreground (the diametrically opposed detector is hidden behind the cryostat. The sample is irradiated with positrons from a radioactive ^{22}Na source.

the great advantage that there is no restriction on the positron intensity owing to accidental coincidences. One of the timing signals is taken from the RF system so the final coincidence rate is equivalent to the counting rate of the detector for annhilation photons.

Microscopes

A natural extension is to reduce the diameter of the pulsed beam from several mm into the micrometre region, thereby realising a positron microscope. Two separate development are under way in Europe. Prototype positron emission microscopes have been built at the University of East Anglia (UK) which measure, at a faithful magnification, the spatially averaged emission from the surface. A spatial resolution of 1 µm is hoped for. As the fate of a positron diffusing to the surface is decided right at the surface, the microscope essentially examines the surfaces of materials with a negative work function (*i.e.*, those that re-emit positrons) — studies that are probably best carried out using pulsed and scanned microbeams.

A joint Munich/Trento project to build a scanning positron microscope started two years ago, and the first images are expected early next year. It builds on the experience gained with the RF-pulsed system. A conventional scanning electron microscope is being integrated into the device, using the same beam optics as for the positrons, to facilitate the comparison of surface topography and near-surface information.

1996 General Conference of the EPS Condensed Matter Division (CMD)

Stressa-Bavena, Lago Maggiore, Italy
22-25 April 1996

1st announcement: January 1995.

Conference Chair: A. Stella, Dip. di Fisica "A.Volta", Università di Pavia, via Bassi, 6, I-27100 Pavia. Tel.: +39-382-50 74 77; fax: +39-382-50 75 63.

There will not be a CMD conference in 1995.

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In der Forschung soll die Professor der Nichtlinearen Dynamik komplexer Systeme gewidmet sein.

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Die Abwendungen können etwas auf den Gebieten des Lasers und der nichtlinearen Optik, der Flüssigkeitsdynamik, der biophysikalischen Prozesse, der Strukturbildung und Strukturerkennung, der solitären Anregungen und der Chaostheorie liegen. Sie können generell sowohl klassische wie quantentheoretische Betrachtungsweisen umfassen.

Habiliterte Damen und Herren mit der beschriebenen Qualifikation werden gebeten, ihre Bewerbungen mit Lebenslauf, Angaben zur Lehrerfahrung, Publikationsliste und Kopien der wichtigsten Veröffentlichungen bis zum **16. Januar 1995** an den Dekan der Fakultät Physik, Herrn Prof. Dr. Dr. h.c. W. Weidlich, Pfaffenwaldring 57, D-70550 Stuttgart, zu richten.

The Faculty of Science of the University of Lausanne has an opening for a

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Applications (*curriculum vitae,* list of publications - reprints of three publications, research project and three references) should be sent before **December 15, 1994** to the Dean of the Faculty of Science, P.O. Box, CH-1015 Lausanne, Switzerland. For further information contact: Prof. J.-J. Loeffel, Tel. +41 (21) 692 37 51, Fax +41 (21) 692 36 05, E-mail: jvuille@ula.unil.ch.