PICTS of impurities and defects in Germanium

N. Fourches - CEA-Saclay/IRFU/SEDI

EDELWEISS collaboration meeting

1 - Thermal spectroscopy of impurities and defects

2 - Incidence of electrically active defects on detector operation

- *Dopant species, deep levels, surface states*

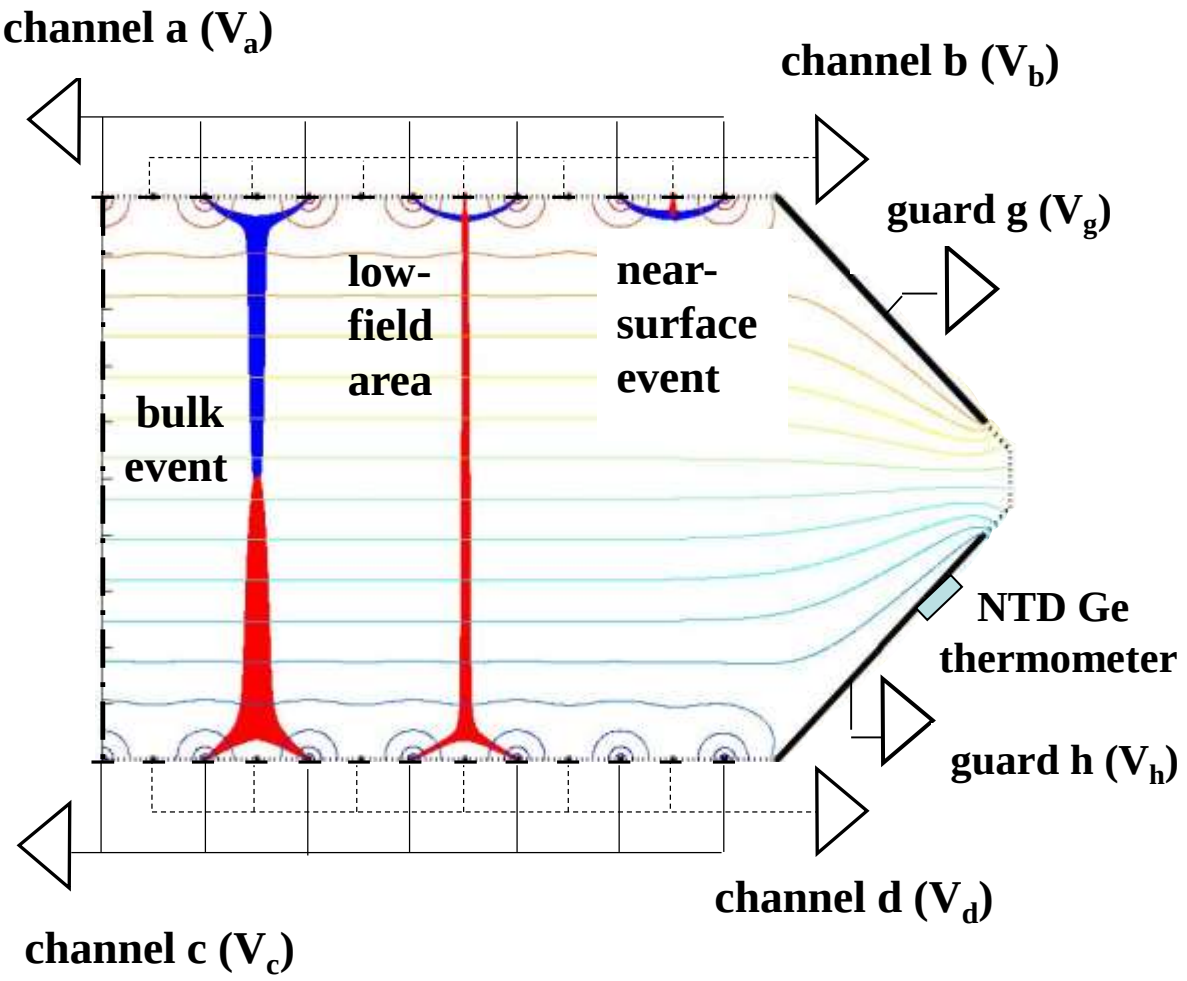
3 – Materials studies, detector validation and commissioning

-*"On-line" characterization of detector material*

➔ *PICTS, ODLTS, PTIS other ?*

InterDigitized detectors:

Complex electrode configuration and biasing scheme compared with simple p+in+ structures: need to investigate material issues on both detector and material



*** Voltage biases: V_a = 2V, V_b = 1V, V_c = -2V, V_d = -1V, V_g = 0.5V, V_h = -0.5V**

1- Impurities and defects in detector material : incidence on charge collection at cryogenic temperatures

Issues:

- Operating conditions to ensure optimal charge collection efficiency

- Trapping effects, space-charge build-up & detector reset

Methods:

-Direct studies of the detector :

-Charge collection efficiency measurements using radioactive sources & pulsed LEDs

-Time-resolved acquisition of the charge collection signals

-Material studies :

-Thermal and optical spectroscopy using electrical signals for high sensitivity

2 – Incidence on detector operation:

a) Trap densities, orders of magnitude in HP-Ge

Trapping length: $\Lambda_t = 1 / < \sigma N_t >$

(1) Λ_t is a function of the crystal quality (impurities, point defects, dislocations), of the charge state of the defects (ionized vs. neutral), and of the nature (electron or hole) and velocities of the carriers.

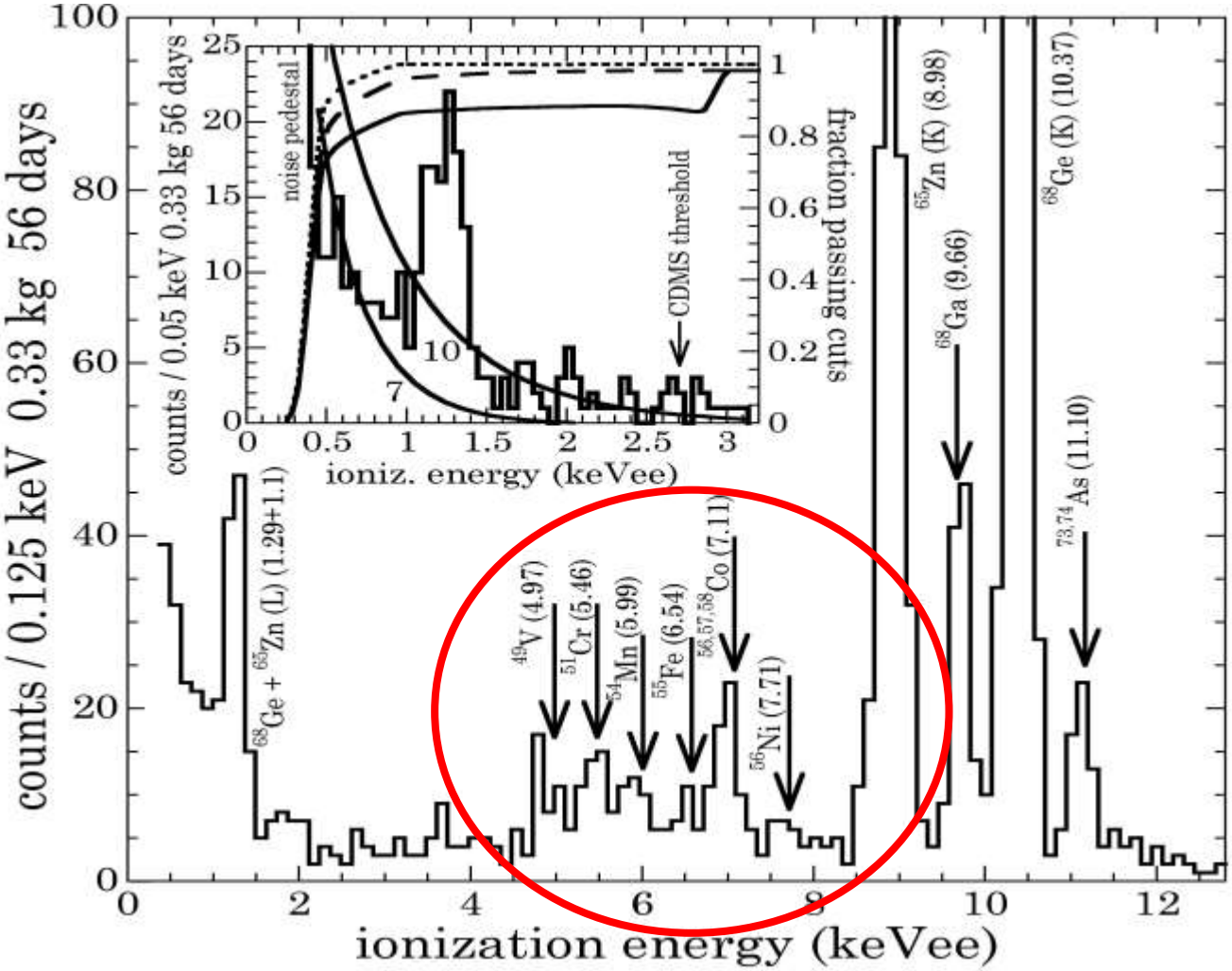
(2) Orders of magnitude for hot electrons in HP-Ge at cryogenic temperatures (20 mK) (velocities of a few 10^6 cm/s): Depending on field strength, Λ_t @ a few cm up to several tens of cm in a 'well regenerated' crystal.

(3) A simple estimate:
Take $N_t = 10^{10}$ cm^{-3} (HP-Ge) ➔ σ has to be of the order of 10^{-11} cm^2, which would be expected for carrier trapping by ionized, rather than by neutral defects.

But this is clearly inconsistent with the assumption of a full neutralization of the charged defects as expected from the reset procedure by gamma or IR irradiation.

➔ **Either defect neutralization is less effective than we think, or there are more electrically active defects than we think !**

b) More specific issues: transition metal impurities in HP-Ge



Low-energy spectrum after all cuts, prior to efficiency corrections. Arrows indicate expected energies for all viable cosmogenic peaks.

(C.E Aalseth ,Collar et al., arXiv:1002.4703v2 [astro-ph.CO] 2010).

Deep level characterization in ultra-pure germanium

N. Fourches et al. , 1991
DLTS on ultra-pure Ge

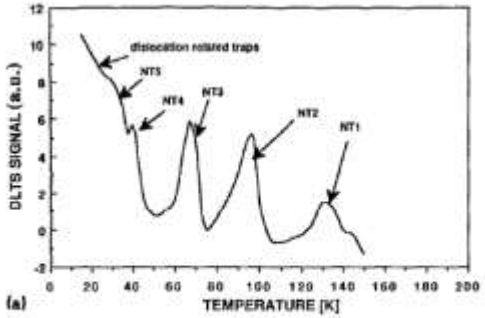
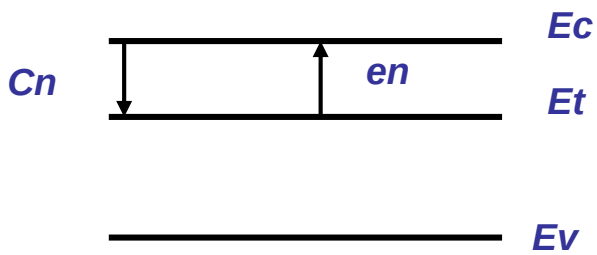


FIG. 2. (a) Typical DLTS spectrum obtained in *p*-type high-purity germanium: NT1–NT5 are the native deep levels (experimental conditions are emission rate: 56 s^{-1}; filling pulse width: 1 ms; reverse bias: − 8 V; filling pulse bias: 0 V). (b) Typical DTLS spectrum obtained in As-grown *n*-type high-purity germanium showing the presence of a broad peak (experimental conditions are emission rate: 56 s^{-1}; filling pulse width: 1 ms; reverse bias: − 8 V; filling pulse bias: − 1 V).

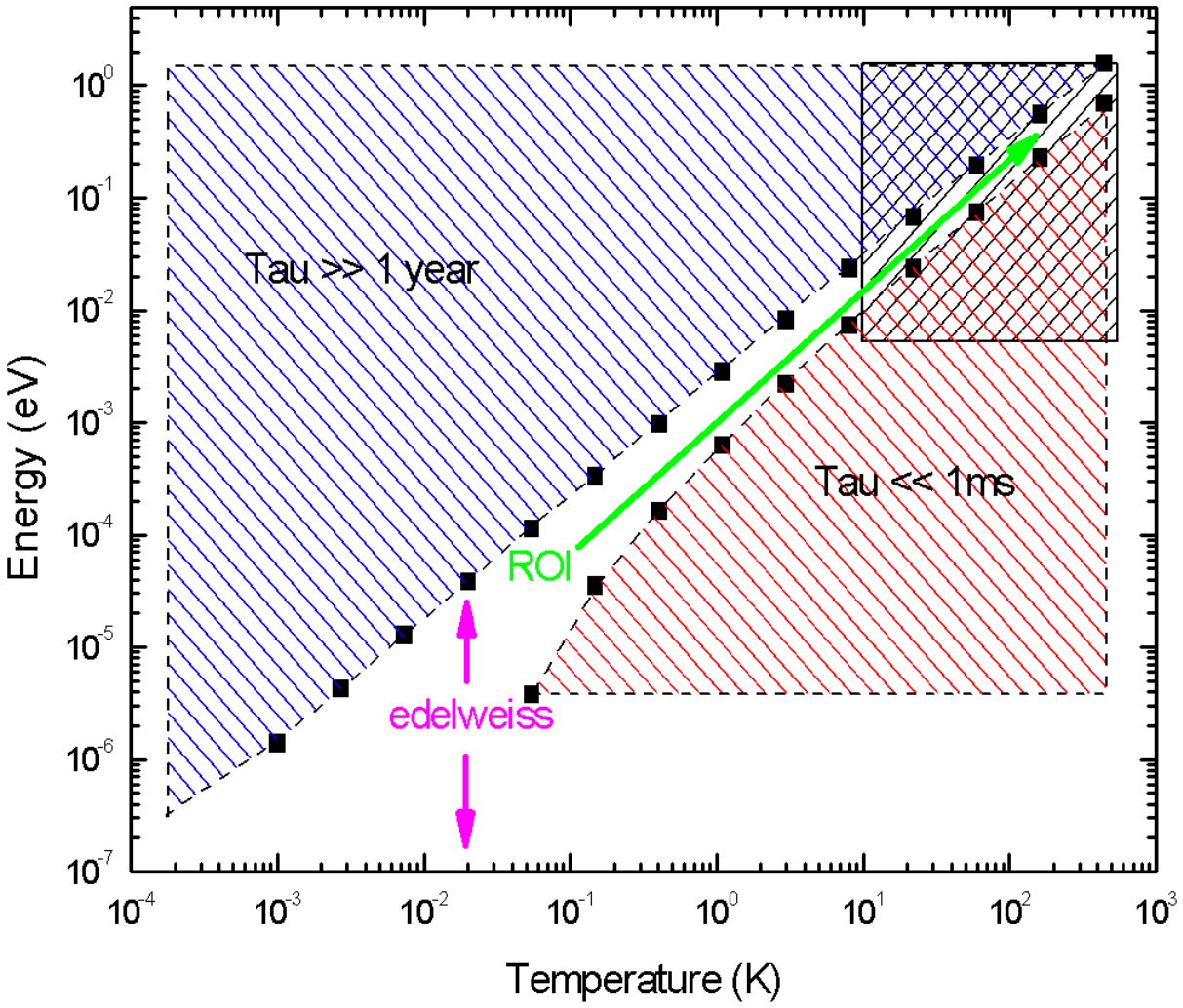
- *How to perform deep level thermal spectroscopy directly on detectors ?*
- *Use photo-induced current transients.*
- *Some advantages:*

- would apply to detector fully mounted, fitted with regeneration LED facing Ge crystal.

- optical excitation allows to separate the electron and hole trap centers contributions by simple reversal of the electrode bias polarities.



"standard" thermal spectroscopy : range of investigation



For a capture cross section: 10^{-15} cm^2

Emission rate >>detrapping time constant: Tau)

- **Improvements required**
- **capture and emission behaviour in the temperature range of Edelweiss still under study**

Emission rate =Nc<vth>$\sigma_n$exp(-Ea/kT) derived from the detailled balance equation

Photo Induced Current Transient Spectroscopy

Background : Capacitance Transient Spectroscopy of Deep Levels in Semiconductors (D.V. Lang 1974)

PICTS : introduced by Hurtes et al. (1978), Merlet et al.(1978) predominantly for high resistivity Semiconductors

(GaAs, InP …)

Materials studied : PbI_2 (Zielinger et al. 1985)

GaAs (Hurtes et al. 1978) PbI_2 , Cu_2O (J.C. Balland ,1984),

CdTe (P. Wurm ,1995)

CdTe (Zielinger et al. 1993, Castaldini et al., 1997)

Photo Induced Current Transient Spectroscopy

- ***General principle (1978)***

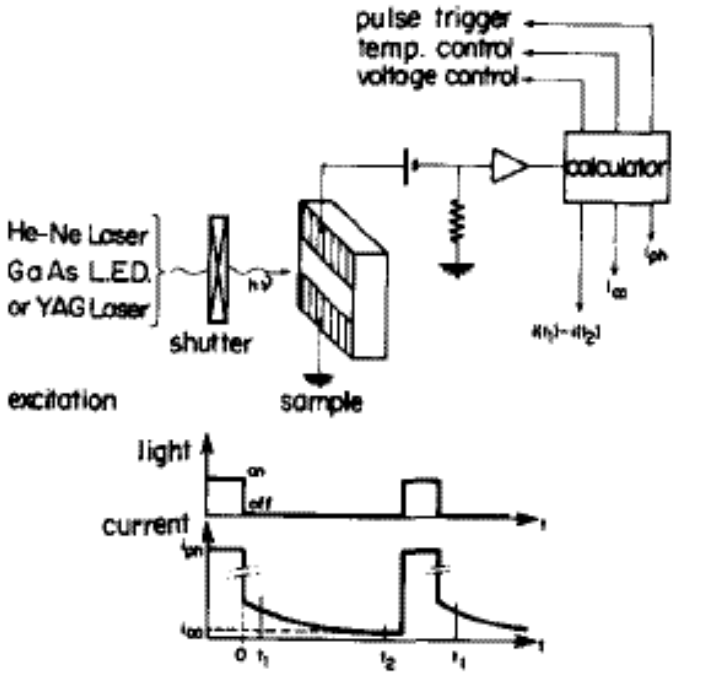


FIG. 1. Principle of the experiment.

- ***Simple experimental set-up***
- ***No need for extensive signal processing***
- ***High sensitivity***
- ***Bulk or near surface defects and impurities interface states contribute but are not the primary interest of the technique***
- ***Usable on a variety of samples and geometries***

Environment

- ***New context : EURECA with many more detectors***
- ***Cost : use of less pure material***
- ***A post-process control would then be welcome. What is an appropriate technique ?***
- ***Probe the contamination of the material***
- ***Non destructive***
- ***High sensitivity : <<10^9 /cm^3 , DLTS and PICTS , OK***
- ***Contactless: PICTS no, optical techniques & EPR yes***
- ***Use of real detectors with their LEDs for optical injection . Current measurements : PICTS***
- ***Usable in a final step when the germanium detectors are ready to be installed. No more handling then needed***

Background

- ***DLTS (1974, Lang), DLOS (1979, Chantre),TSC (1960),TSCAP (1972)***
- ***Class of experimental techniques based on the relaxation of carriers trapped on defect (impurity) levels***

Detection mode	*Excitation mode*	*Stimulation mode*
Capacitance(Current)	*Electrical*	*Thermal (DLTS)*
Capacitance	*Thermal*	*Thermal (TSCAP)*
Capacitance	*Optical*	*Thermal (ODLTS)*
(Trans)conductance	*Electrical*	*Thermal (C-DLTS)*
Current	*Thermal*	*Thermal (TSC)*
Capacitance	*Electrical-Optical-Thermal*	*Optical (DLOS)*
Current	*Electrical-Optical-Thermal*	*Optical (DLOS)*
Current	*Optical*	*Thermal (PICTS)*

Background

- **Physical quantities used to build the signal (DLTS, PICTS…) are simply analyzed through a time constant filtering**
- **The experiment consists in fact in an energy scan using the temperature (DLTS) or the wavelength (DLOS)**
- **Numeric DLTS is now commonly implemented using a sampling and digitizing board which allows the digitization of the transient**

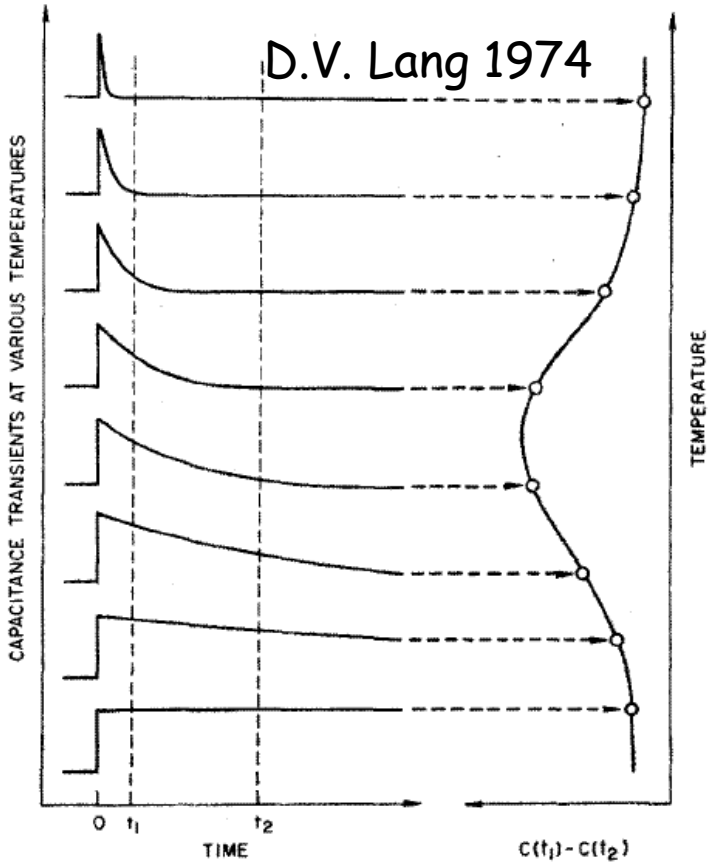


FIG. 6. Illustration of how a double boxcar is used to define the rate window. The left-hand side shows capacitance transients at varius temperatures, while the right-hand side shows the corresponding DLTS signal resulting from using the double boxcar to display the difference between the capacitance at time t_1 and the capacitance at time t_2 as a function of temperature.

PICTS of ultra-pure germanium

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Photoinduced current transient spectroscopy of deep defects in *n*-type ultrapure germanium

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(Received 22 February 1999; accepted for publication 8 April 1999)

Photoinduced current transient spectroscopy (PICTS) is used to study deep minority carrier traps in *n*-type ultrapure germanium (shallow concentration of the order 10^9 cm^{-3}). In this technique, which is a variant of deep level transient spectroscopy (DLTS), a neutral structure with two ohmic contacts applied on two opposite faces of the sample is illuminated through one of the contacts with intrinsic, strongly absorbed light. The current transients which follow after interrupting the photoexcitation are analyzed using classical double lock-in DLTS resulting in the detection of centers in the minority half of the band gap (provided the back ohmic contact is negative). After correcting the PICTS spectra for the temperature dependence of the mobility, six peaks superimposed on a broad background are clearly resolved. The peaks are the same as the ones found earlier in high-purity *n*-type germanium (shallow concentration of the order 10^{10} cm^{-3}) using optical DLTS. These peaks are mainly Cu related. A formula to calculate concentrations from the PICTS spectra is deduced and verified experimentally. © *1999 American Institute of Physics.* [S0021-8979(99)02814-5]

Shallow concentration < 10^9 /cm^3

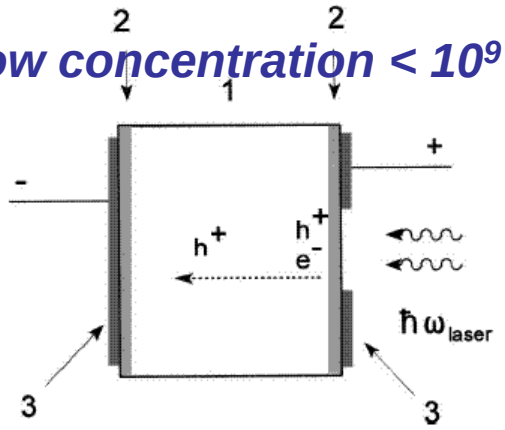


FIG. 2. Schematic configuration of the sample in PICTS of *n*-type ultrapure germanium. (1) Neutral semiconductor; (2) n^+ ohmic contact (Li diffused); (3) In foil.

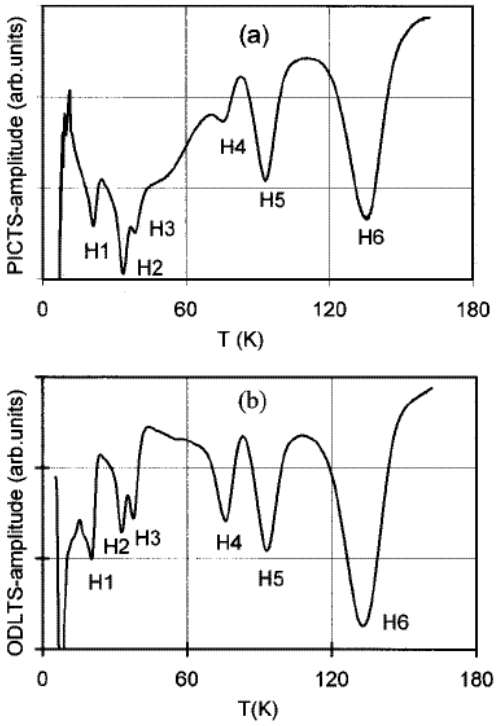


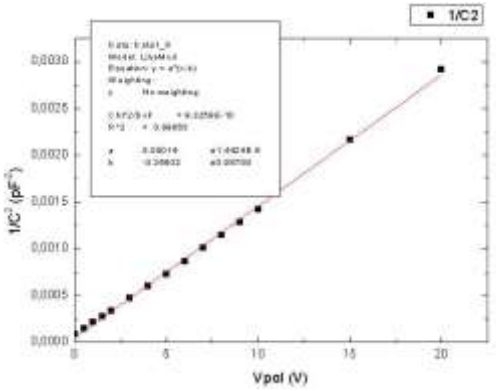
FIG. 5. (a) PICTS spectrum of *n*-type UP Ge [corresponding to Fig. 4(a)] corrected for the temperature dependence of the mobility, $N_D - N_A \approx 10^9$ cm^{-3} [same measurement conditions as those in Fig. 4(a)]. (b) ODLTS spectrum of *n*-type HP Ge, $N_D - N_A \approx 10^{10}$ cm^{-3} [same measurement conditions as those in Fig. 4(a)].

. . . *ultra pure germanium*

- ***Blondeel (1999) ,Forment (2006)***
- ***What we are able to do now (DLTS limited to specific samples)***

TABLE II. Comparison of deep level concentrations calculated from ODLTS and PICTS measurements on four different kinds of HP and UP n-Ge samples. (–: No peak; ?: background difficult to subtract.)

	$N_D-N_A=2\times10^9$ cm^{-3}		$N_D-N_A=2\times10^9$ cm^{-3}	
	ODLTS (cm^{-3})	PICTS (cm^{-3})	ODLTS (cm^{-3})	PICTS (cm^{-3})
$Cu_i^{0/-}$	1.4×10^8	1.4×10^8	4.8×10^7	9.6×10^7
$(Cu, H)^{0/-}$	3.8×10^8	2.6×10^8	1.1×10^8	1.3×10^8
V_2, H	1.8×10^8	1.3×10^8	7.5×10^7	5.1×10^7
Cu, H, Li	1.1×10^8	7.8×10^7	5.6×10^7	2.8×10^7
$(Cu, H)^{-/2-}$	2.5×10^8	3.2×10^8	9.8×10^7	8.1×10^7
$Cu_i^{-/2-}$	1.2×10^8	5.0×10^8	9.3×10^7	8.2×10^7
	$N_D-N_A=7\times10^9$ cm^{-3}		$N_D-N_A=1\times10^{10}$ cm^{-3}	
	ODLTS (cm^{-3})	PICTS (cm^{-3})	ODLTS (cm^{-3})	PICTS (cm^{-3})
$Cu_i^{0/-}$	–	–	?	1.0×10^8
$(Cu, H)^{0/-}$	–	–	2.1×10^8	2.5×10^8
V_2, H	1.7×10^8	2.6×10^8	2.1×10^8	2.8×10^8
Cu, H, Li	3.4×10^8	2.1×10^8	?	1.1×10^7
$(Cu, H)^{-/2-}$	1.0×10^8	5.9×10^7	1.3×10^8	3.2×10^8
$Cu_i^{-/2-}$	5.8×10^8	4.9×10^8	1.1×10^8	3.7×10^8



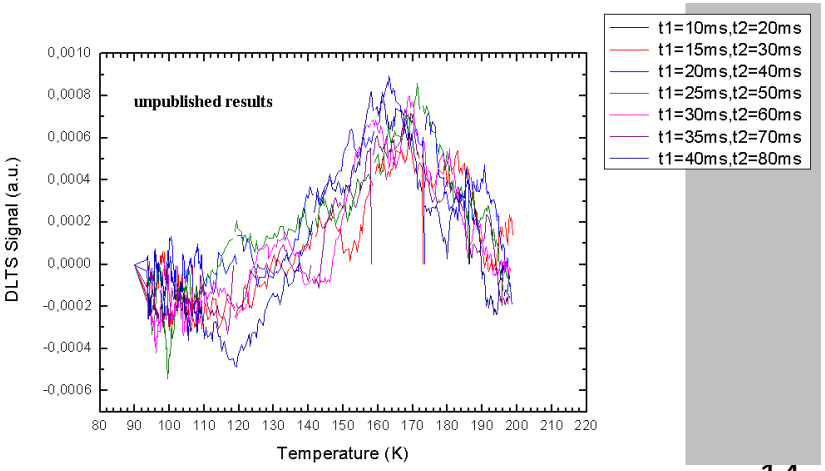
@77 K
HPGe
diode
CP4 etched

DLTS spectrum with our setup on p-type (10^{11} /cm^3) germanium. Capacitance transients are digitized with a sampling scope (limited resolution < 11 bits) Noise and resolution are still unoptimized.

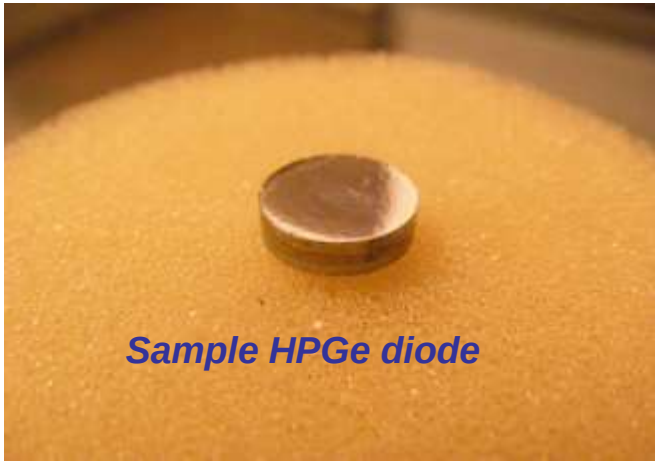
Table 1
Implantation conditions of the studied metals

Metal	Implantation energy (keV)	Dose (at/cm^2)	T_{peak} (K)	E_T (eV)	N_T (cm^{-3})
Hf	190	1×10^{14}	135	0.29	9.0×10^{11}
Ti	90	5×10^{14}	125	0.22	1.3×10^{14}
Cr	90	5×10^{14}	190	0.37	1.3×10^{14}
Fe	90	5×10^{14}	175	0.36	2.4×10^{14}
Co	90	5×10^{14}	155	0.33	9.9×10^{13}
Ni	90	5×10^{14}	95	0.16	2.6×10^{12}
			160	0.30	2.1×10^{12}

Annealing was performed at 500 °C for 5 min, except for the Ni-implanted sample that was annealed at 350 °C for 1 min. Also indicated is the peak position T_{peak}, the activation energy E_T and the trap concentration N_T derived from the DLTS analyses.



Optical Deep Level Transient Spectroscopy (ODLTS) & Photoinduced Current Transient Spectroscopy (PICTS) of electronic defects in low-purity grade Ge



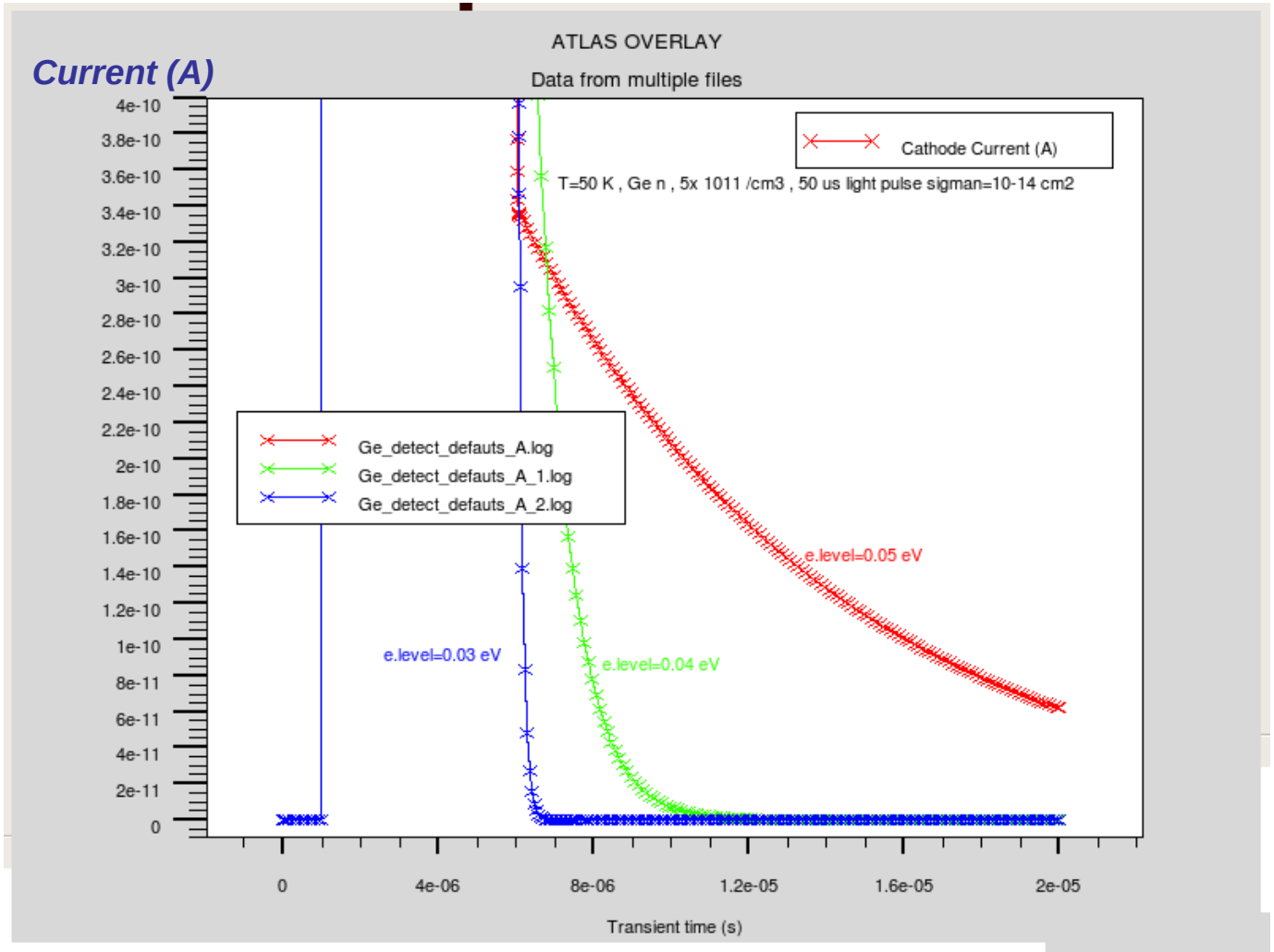
Sample HPGe diode

Experimental setup for PICTS/ DLTS under construction at CSNSM

DLTS operational but needs improvements

Oxford 23-09-2010

PICTS (germanium , simulations)



- Simulation based on a commercial software
- Current transients are slower when the level is deeper
- Dimensions :
- 300 µm thickness
- 1µm width
- 2 mm length
- Not a real detector

Limitations (with respect to PTIS)

- ***PICTS & DLTS , up to now : Investigations normally limited to deep traps***
- ***Shallower levels can be detected using Far Infrared Photoconductivity (PTIS)***

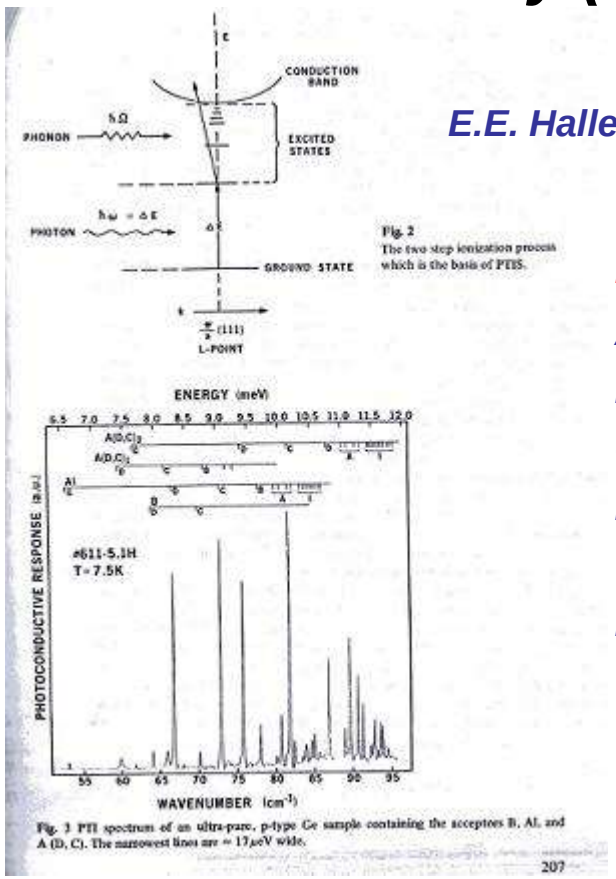


Fig. 2
The two step ionization process which is the basis of PTIS.

Fig. 3 PTI spectrum of an ultra-pure, p-type Ge sample containing the acceptors B, Al, and A (D, C). The narrowest lines are ≈ 17 μeV wide.

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E.E. Haller (Festkörperprobleme ,1986)

Photo Thermal Ionization Spectroscopy :

A lot of work has been done in the past !

Less pure germanium can be characterized

Complementary to both PICTS and DLTS

Not usable on a detector

No conclusion can be made now

What's proposed and under way

- ***PICTS on a real EDELWEISS detector***
- ***Spectrum : "fingerprint" of the device***
- ***Necessary to characterize detectors based on less pure Ge***
- ***PICTS and DLTS setup under development at Orsay (first step LN2 next step LHe)***

- ***Fast capacitance meter (CSNSM)***
- ***Fast current amplifier (CSNSM)***
- ***Temperature measurements (Pt resistor) (Saclay)***
- ***LN2 (Saclay) and LHe (CSNSM) cryostats***
- ***Pulse generator (CSNSM) : need for a new pulse generator***
- ***Pulsed LEDs (CSNSM)***
- ***DAQ + Software (Saclay) need to buy an appropriate acquisition board + laptop computer***