An Extended Dose Metrology Tool For A Wide Range of Ion Implant Applications

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Abstract

A review of the performance of an extended performance optical metrology system for ion beam dosimetry system with an energy range from 0.25eV to over 6MeV and a dose range of high E10 to E17 is presented. The dose sensitivity of the instrument over a dose range (E13 – High E16) averages > 0.7 and as high as 1.0+. An optical reflectivity model is presented describing the measurement technique and its response due to ion implant.

The tool exhibits repeatable performance with ultra low energy implant at high dose with a dose sensitivity of 0.75 to 0.9 for silicon wafers as well as with intermediate doses (E12 to E15) and up to 1E17 H/cm^2 for Hydrogen implants. The non-destructive nature and speed of the measurements, < 4.5 minutes for a 300 mm wafer and provides a rapid, repeatable "snap-shot" of the process result. The very high resolution produces photographic-like images and will provide more than 800 possible map configurations of specific measurements – with a single measurement event. Data demonstrating the gauge capability of the instrument are shown.

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I. Introduction

In order to meet the pressing demands of ion implanter and alternative doping measurements for sub-100nm technology there are critical requirements for spatial resolution, speed of measurement and dose sensitivity that are not found together in the same metrology tool. The Cormap optical dosimetery system, until late 2002, was used essentially for low dose implants (<1E13 nominal) down to high E10 across a range of energies from < 20 keV to 5 MeV+. This system was shown (1) to have high dose sensitivity, $S_d = 0.7+$ due to the changes by ion implant, on a special coating.

Over the past 2 years, the capability of the same system was extended and now includes dosimetry measurement with bare or oxide coated wafers for ultra low energies/ULE (down to 0.25 keV) and through intermediate dose regimes up to very high doses of H^+ for “wafer splitting” applications. For the applications presented here, the system uses the same, single wavelength LED and essentially the same optics as described earlier (1) but with changes to the illumination calibration and the software to quantify the various levels of amorphization from the implant. The system exhibits high dose sensitivity for all implanted species. No pre or post implant processing is required although some users do premeasure the wafer prior to implant in order to have a more sensitive map display. A premeasurement, however, is not mandatory. The present configuration of the CorMap provides a spatial resolution of 86,700-datapoints/300mm wafer in < 300 seconds. The number of measured points is directly related to the area of the wafer – a measured point for every 0.8 mm^2 of substrate.

II. Principals of Operation

The refractive index, $\hat{n}$, in a conducting medium, e.g., a lossy dielectric or metal, is written as the complex number

$$\hat{n} = n + jk \tag{a}$$

where n is the real part, equal to the speed of light in vacuum, c_0, divided by the speed of light in the medium c, and k is the imaginary part, called the extinction coefficient. At a sharp interface between air (or vacuum) and a conducting halfspace, the reflectivity (intensity reflection coefficient) of light incident from the air normally, i.e., on perpendicular rays, is

$$\mathsf{R} = \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2} \tag{b}$$

where $\mathsf{R} \equiv R^2$ and R is the (amplitude) reflection coefficient.

At a wavelength of 595 nm, the wavelength normally used in the CorMap, intrinsic (in undoped silicon) crystalline silicon has a refractive index of

$$\hat{n} = 3.95 + j\,0.019 \tag{c}$$

so, from (b), the reflectivity is

$$\mathsf{R} = 0.355177 \tag{d}$$

Note that for zero loss ($k = 0$), $\mathsf{R} = 0.355168$. Hence, the intrinsic extinction coefficient increases reflectivity only very slightly.

For 1D (plane wave) light propagation along the z-axis, say, the electric field is written

$$\underline{E} = E_0 e^{j(\underline{k} z - \omega t)} \tag{e}$$

where $\underline{k} \equiv 2\pi / \lambda$ is the wavenumber, not to be confused with extinction coefficient *k*. Field intensity *I* is:

$$I = E_0^2 e^{j2\underline{k} z} e^{-j2\omega t} = E_0^2 e^{-\alpha z} e^{j(4\pi/\lambda_0)nz} e^{-j2\omega t} \quad , \quad \alpha \equiv \frac{4\pi}{\lambda_0} k \tag{f}$$

Substituting (c), propagation power loss coefficient α in intrinsic silicon at λ_0 = 595 nm is

$$\alpha = 4013/\text{cm} \tag{g}$$

This means that the intensity of a plane wave decreases by 1/e = 0.368 when $z = 1/\alpha$ = 2.49 μm (so-called penetration depth), or by $1/e^2$ = 0.135 at twice this depth, approximately 5 μm.

Ion implantation changes the refractive index of crystalline silicon in a variety of ways. The two principal mechanisms appear to be implant damage (as-implanted) and the introduction of free-carriers (after anneal). Implant damage plays a dominant role in this case. It can be characterized as three distinct phases: (i) the onset of amorphization, (ii) partial and (iii) full amorphization. The thickness of this layer is proportional to the specie and energy, the amount of damage within the layer is proportional to dose.

III. Dose Sensitivity

The calculation for Dose Sensitivity (S_d) has been consistently reported (2, 3, 4) as:

S_d = % Δ Measurement / % Δ Dose

Traditionally a target recipe is used and a few measurements taken at the target dose and at + and – 10% of that dose. Sheet resistance sensitivity for example in the E13 to high E15 dose ranges, typically falls in the 0.7 to 0.8 range - in some cases higher and in some, lower. For the CorMap, the dose sensitivity for low energy Boron (0.25 to 5keV) exceeds 0.8. See Fig. 1 for the sensitivity study on one particular implanter type at 1.0 keV, B. The focus area, circled on the graph, of 1E15 +/- 10% shows a sensitivity to dose of 0.84. For intermediate energies and doses, a recent test was completed with a requested Nitrogen implant. A series of N_2^+ implants were done at 25 kV (12.5 keV particle) at a nominal 2E14 N/cm^2 dose. The dose sensitivity was 0.91 with a sensitivity test reproduceability of 0.87 – 0.93 over 4 separate tests – see Fig 2. The repeatability of one selected wafer from the N_2 set over 20 measurements (over a 4 day period) was 0.18%, 1δ.

IV. General Resolution and Gauge Performance

The resolution is such that it provides slightly more than one data point every 1.0-mm thereby providing 300 points across many selectable diameters of a 300mm wafer including the critical diameter. Most modern implanters have a scheme where the beam scan profile, in the “plane of dose correction” is automatically adjusted for a specific scan uniformity (5). In the case of most measurement types that might take long periods of time to measure > 150 points across the entire wafer, many fabs/end users are asking for at least 200, possibly 300 measured points across the diameter of interest (6). The CorMap does 300 points on the diamter on 300mm wafers in addition to mapping the entire wafer – with the single measurement scan. The high resolution can provide immediate notification of implanter issues such as scan lock ups, neutral streams (causing vertical stripes which may be otherwise unobserved in other tools), non-uniformities characteristic of energy impurity (5, 7) and most micro striping.

The resolution allows for multiple dose measurements on large devices (intra-device) whereby dosing gradients within the device may be observed and for smaller devices where there are many hundreds on a wafer, all or a majority of the devices are measured. Note the maps in Fig 3 that shows a batch implanter with low energy Boron with a subtle, intentional scan fault.

(“notch” is to implant wheel hub) and a serial implanter also with an intentional setup fault. Measurement repeatability with one wafer over a period of 3 to 4 – one with N_2 and one with low energy Boron implanted wafers are surprisingly similar - seeFig 4 a and b.

H^+ and H_2^+ implants in the ranges of 40 to 140 keV and >5E16 H/cm^2 have shown excellent sensitivity (~ 0.9) and, like other maps (see Fig 5) show an expected implanter signature, i.e., the mean value is in the plane of the “uncorrected scan”.

V. Summary

We have presented an extension of an existing metrology tool that offers high spatial resolution, high speed and high dose sensitivity across a wide range of energies and doses on bare and oxide-coated wafers. The repeatability and reproducibility of sensitivity are shown to be well within the requirements for advanced fabs and development facilities and may be unmatched. It is useful for ion beam equipment diagnosis as well as process development and diagnosis. The high number of data-points will provide for every conceivable map configuration without the need for re-measurement or for archiving expensive substrates.

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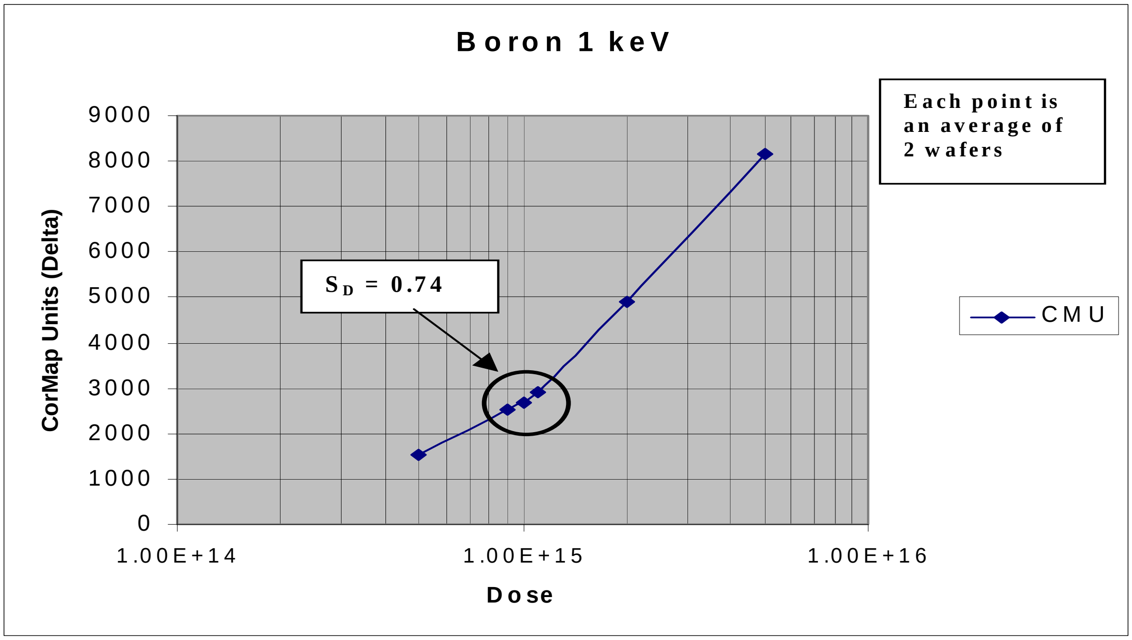
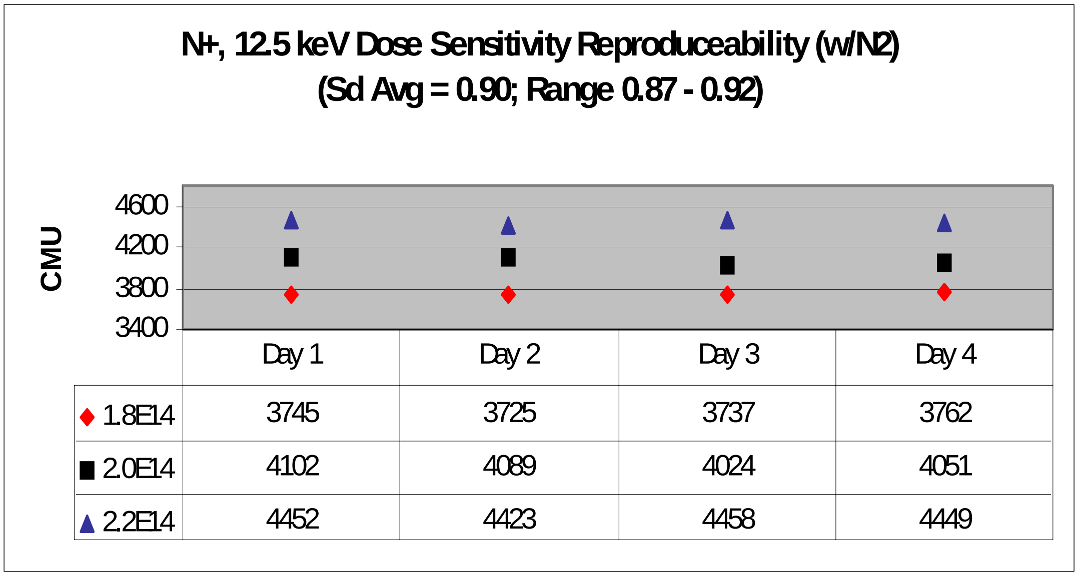
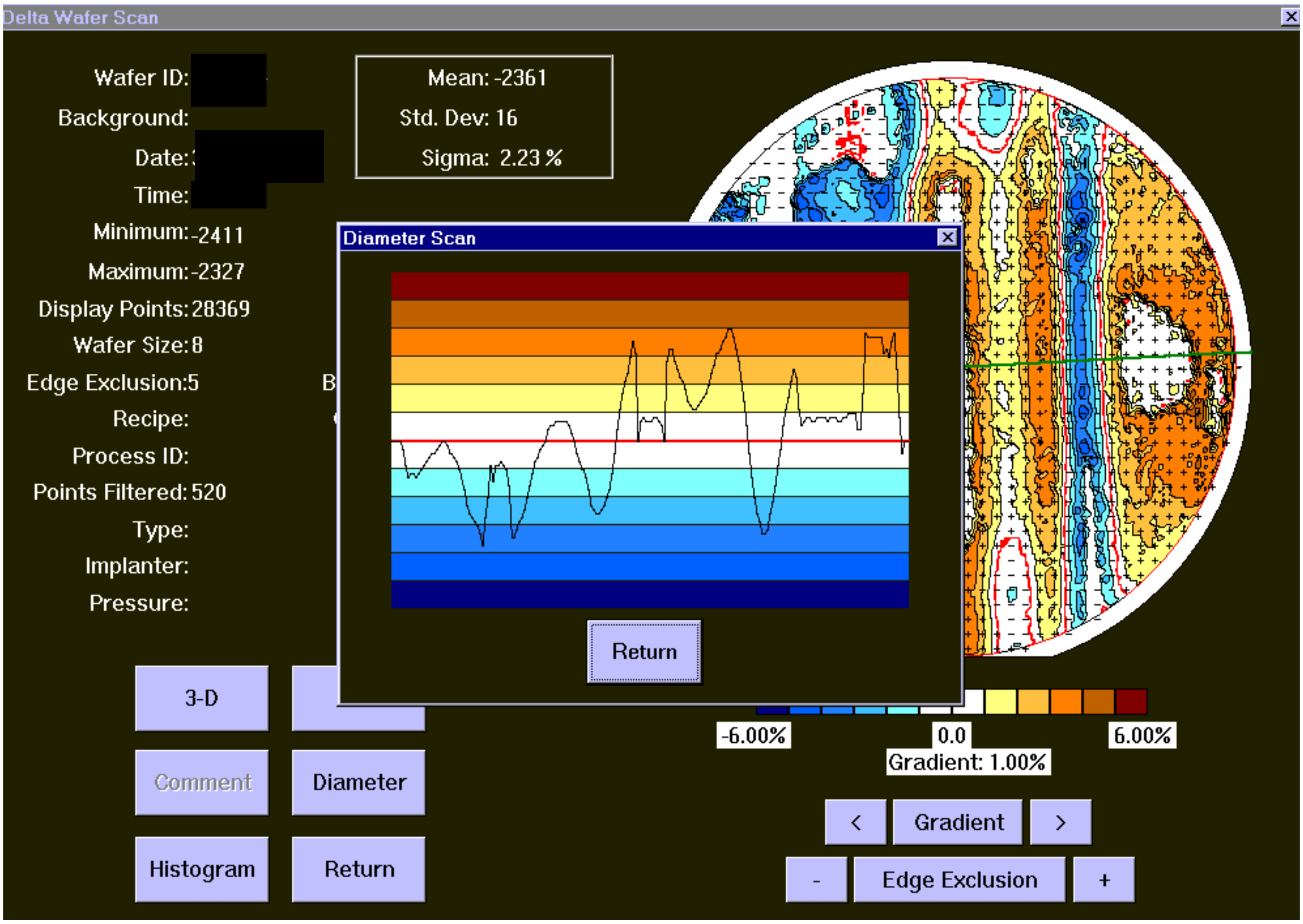


Fig 1. Boron 1keV Dose Sensitivity



	Day 1	Day 2	Day 3	Day 4
◆ 1.8E14	3745	3725	3737	3762
■ 2.0E14	4102	4089	4024	4051
▲ 2.2E14	4452	4423	4458	4449

Fig 2. N^+ dose sensitivity and repeatability of S_d



Wafer ID: [redacted]

Background:

Date: [redacted]

Time: [redacted]

Minimum: -2411

Maximum: -2327

Display Points: 28369

Wafer Size: 8

Edge Exclusion: 5

Recipe:

Process ID:

Points Filtered: 520

Type:

Implanter:

Pressure:

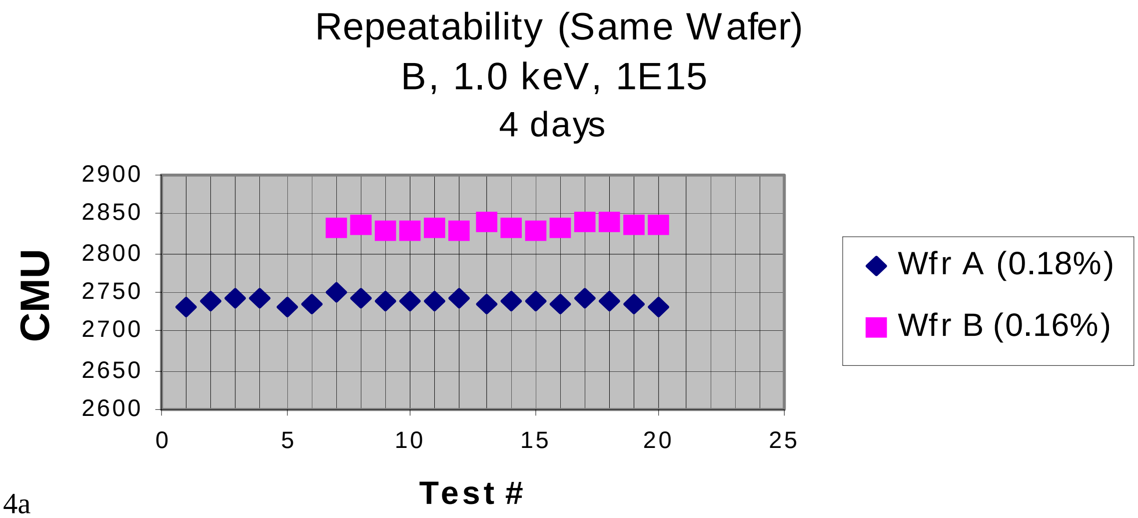
Mean: -2361

Std. Dev: 16

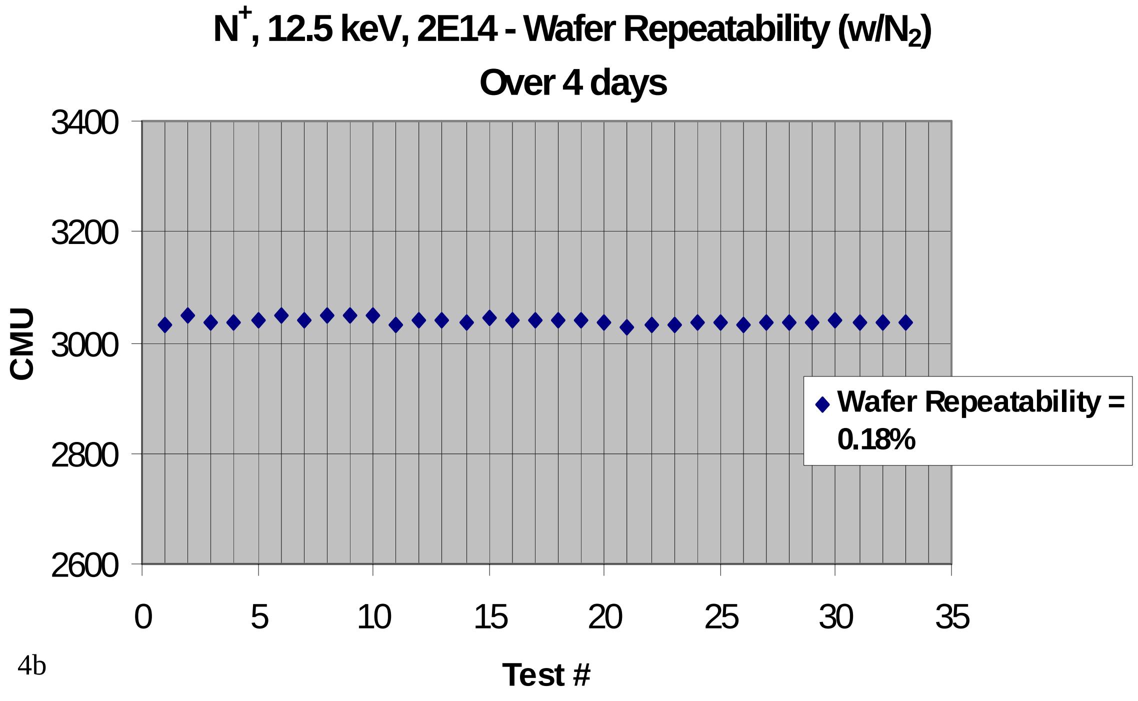
Sigma: 2.23 %

Gradient: 1.00%

Figure 3. Serial high current implant with intentional poor setup

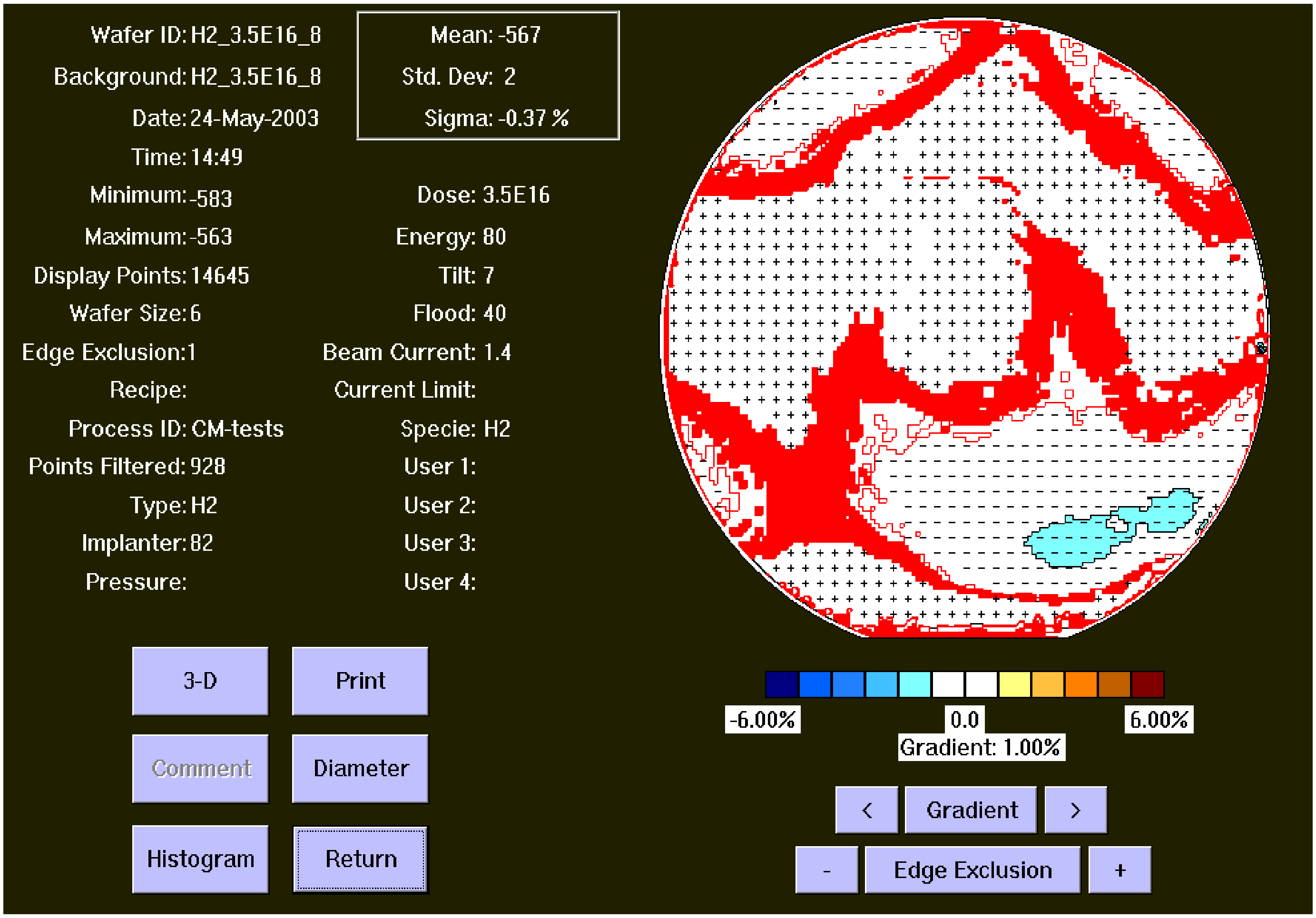


4a



4b

Fig 4a. ULE B repeatability (1.0 keV)   Fig 4b. N^+, 12.5 keV repeatability



Wafer ID: H2_3.5E16_8
Background: H2_3.5E16_8
Date: 24-May-2003
Time: 14:49
Minimum: -583
Maximum: -563
Display Points: 14645
Wafer Size: 6
Edge Exclusion: 1
Recipe:
Process ID: CM-tests
Points Filtered: 928
Type: H2
Implanter: 82
Pressure:

Mean: -567
Std. Dev: 2
Sigma: -0.37 %

Dose: 3.5E16
Energy: 80
Tilt: 7
Flood: 40
Beam Current: 1.4
Current Limit:
Specie: H2
User 1:
User 2:
User 3:
User 4:

Fig 5 H_2^+, 80 kV, 7.0E16 H/cm^2 (dose sensitivity ~0.9)