5th RD50 Workshop on
Radiation hard semiconductor devices for very high luminosity colliders
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Oxygen dimer enriched silicon

- RD50 dimer task force -

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Motivation: Defect engineering

- **Aim: Produce silicon that contains only O_2 and no mono-atomic O**
  - **Standard silicon: O (neutral)** -- contains oxygen in mono-atomic form (O)
  - **Dimerized silicon: O_2 (neutral)** -- contains oxygen in form of dimers (O_2)

  ⇨ **no change of detector properties before irradiation**

Yesterday (5.5.04), Bengt Svensson: "I would say that the chances are 9 out of 10 that the X-center is the V_2O."

- **What would change during irradiation?**

Standard Si : $V+O \rightarrow VO$ **(neutral)**

$VO + V \rightarrow V_2O$ → **charged and producing current**
(I. Pintilie interpretation, I defect)

?

very bad

Dimerized Si : $V+O_2 \rightarrow VO_2$ **(neutral)**

$VO_2 + V \rightarrow V_2O_2$ → **should have levels in bandgap but most probably not as unfortunate positioned as the V_2O**

maybe good

Furthermore:

Defect kinetics will be very different from standard Si (e.g. IO_2 formation)

⇨ **Learn about defect kinetics**

⇨ **Test a new material**

How to create dimers ?

- **"Pre-irradiation" of detectors at high temperature**

  - **Produce point defects at a temperature at which**
    - **the VO is mobile but does not break up**
    - **the O_2 is produced but does not break up**
    - **the formation of thermal donors is kept at a minimum**

  ➔ Co^{60}-γ or electron irradiation at 350°C

$$V + O \rightarrow VO$$
$$VO + O \rightarrow VO_2$$
$$VO_2 + I \rightarrow O_2$$

- Problem:

  Formation of many other defects! (e.g. TD)

  (very strong temperature dependence)

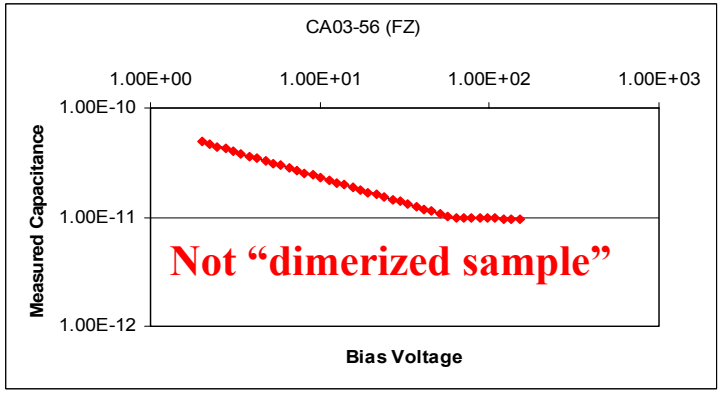
RD50 dimerization experiments

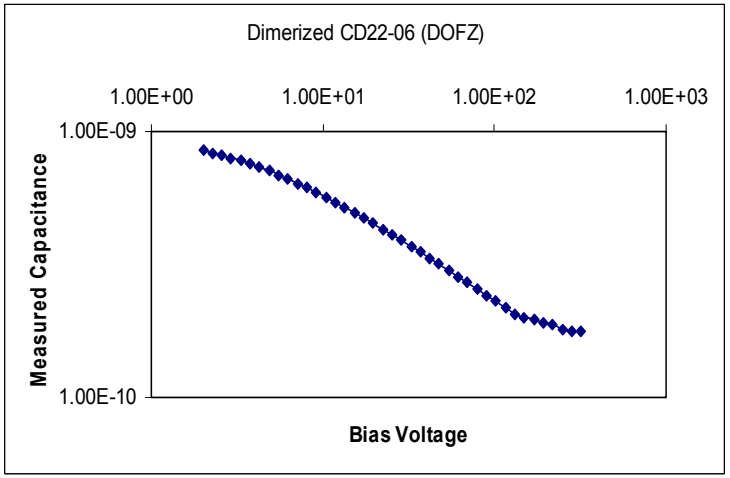
- **First experiment: June 2003**
  - **6 MeV electrons (KTH Stockholm)**
  - **Fluence of $1x10^{18}$ e/cm^2**
  - **Temperature: 330-340 °C**
  - **Samples with different oxygen concentration:**
    - **Bulk material for FTIR: FZ and CZ**
      (3mm thick from ITME, Poland)
    - **PAD-diodes: FZ, DOFZ, CZ**
      (0.25cm^2, p$^+$nn$^+$, 300µm from Hamburg University)
  - **Irradiation experiment: CERN PS 24 GeV/c protons up to 10^{16} p/cm^2**

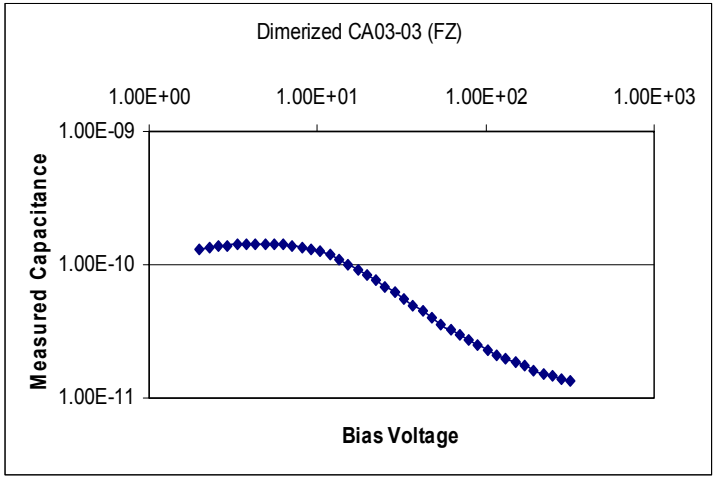
- **Second experiment: March/April 2004**
  - **6 MeV electrons (KTH Stockholm)**
  - **Fluence of 2, 5, $10x10^{17}$ e/cm^2**
  - **Temperature: 350°C**
  - **Samples:**
    - **Bulk material for FTIR: p, n-type MCZ, CZ**
      (Okmetic, ITME)
    - **PAD-diodes: CZ, MCZ**
      (Hamburg University, Helsinki Institute of Physics)
  - **Analysis in progress….**

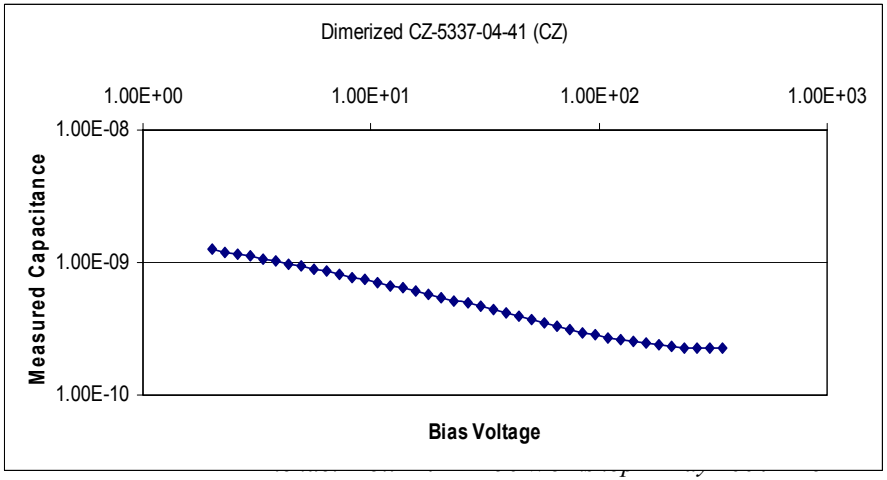
Diodes after dimerization process

- **CV/IV characterization of dimerized diodes**
  - **All dimerized samples could not be fully depleted**

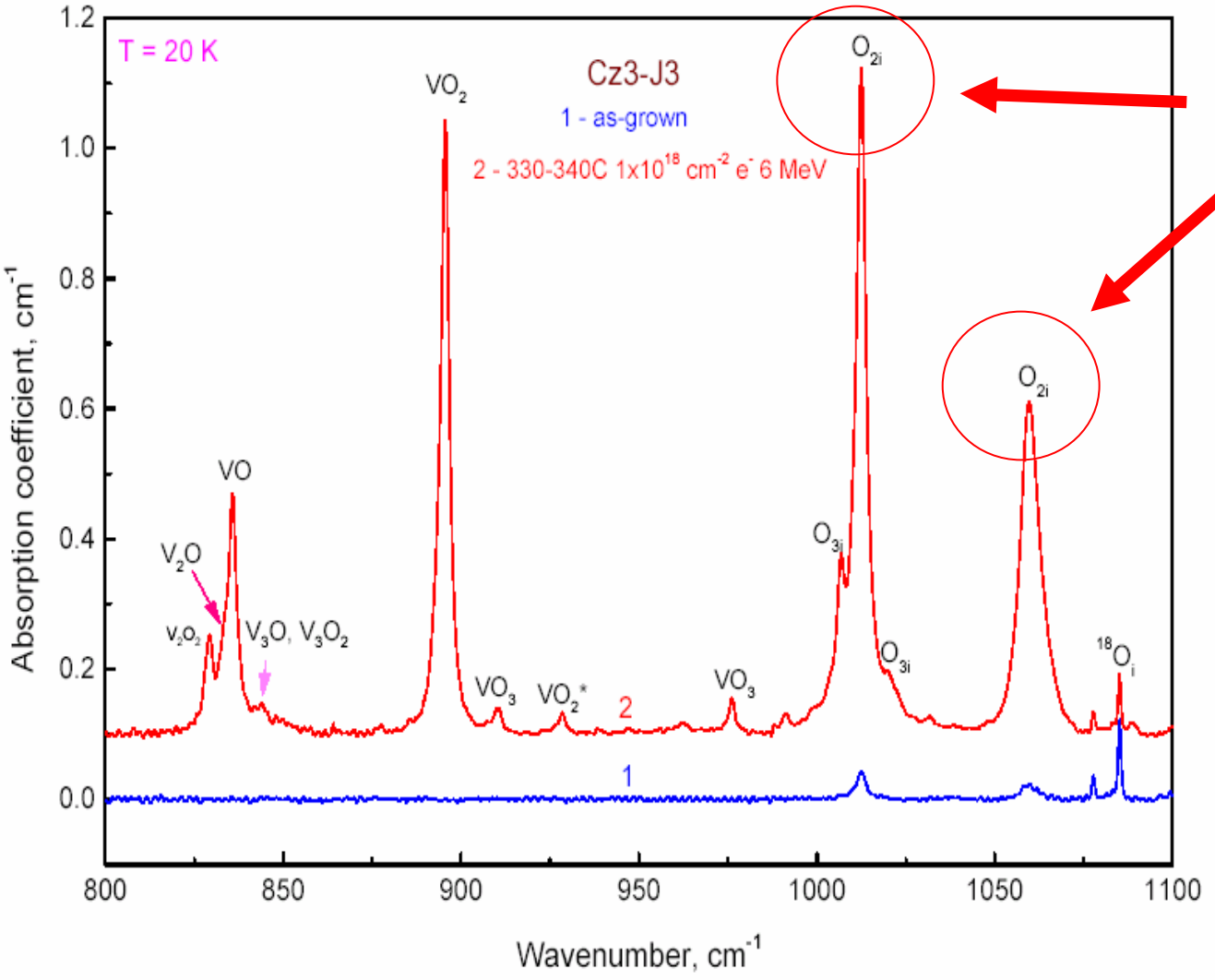








FTIR results: Cz silicon



Oxygen dimer detected

[O] = 9.3x10^{17} cm^{-3}
[O_2]= 4 x 10^{16} cm^{-3}

[VO_2]~2x10^{16} /cm^3
[VO]~ 1.3x10^{16} /cm^3

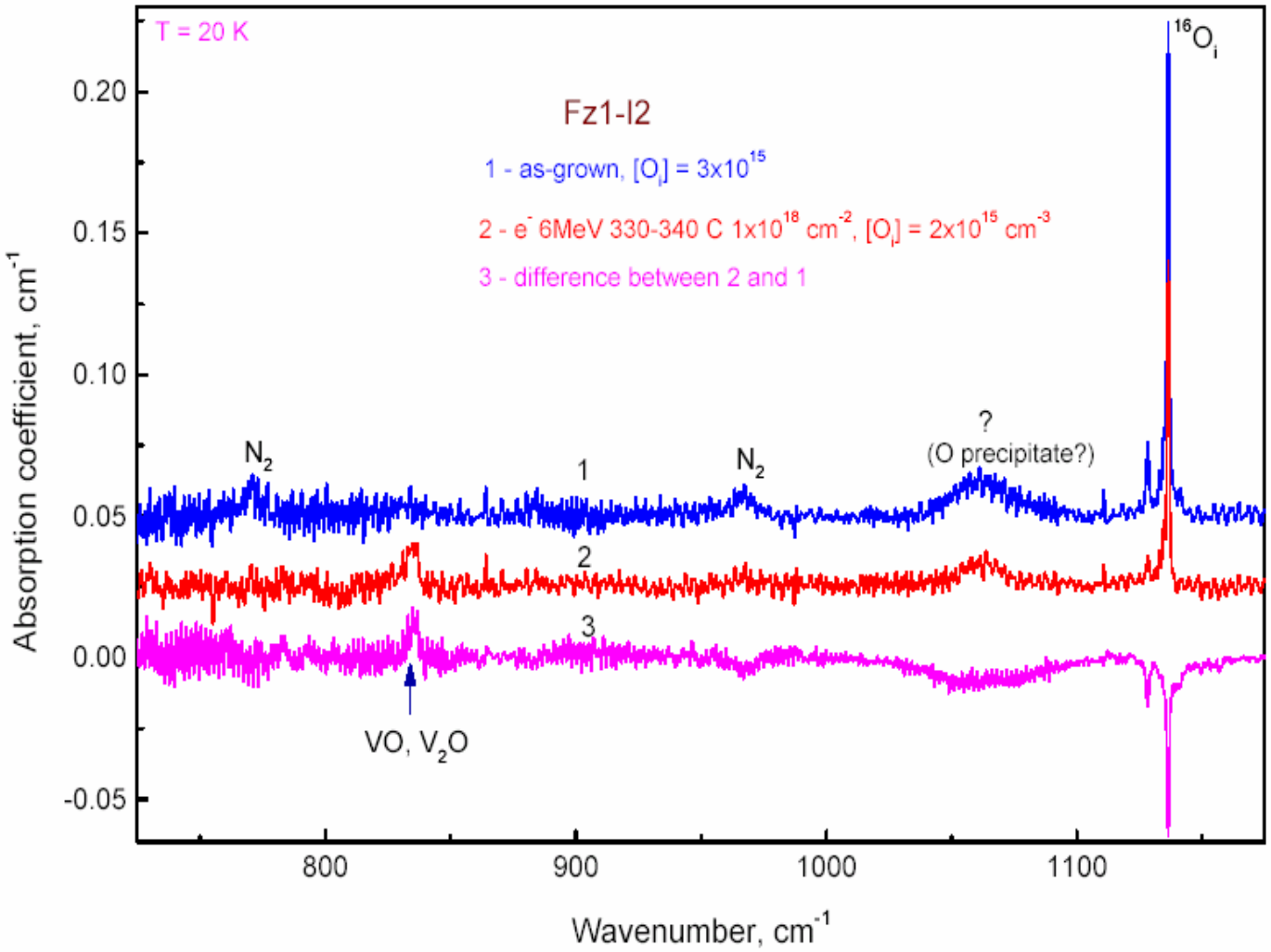
[V_2O_2]~5x10^{15} /cm^3
[V_2O]~2x10^{15} /cm^3

[V_3O_2]~1x10^{15} /cm^3
[V_3O]~5x10^{14} /cm^3

Data: Leonid Murin, Lund & National Academy of Sciences of Belarus

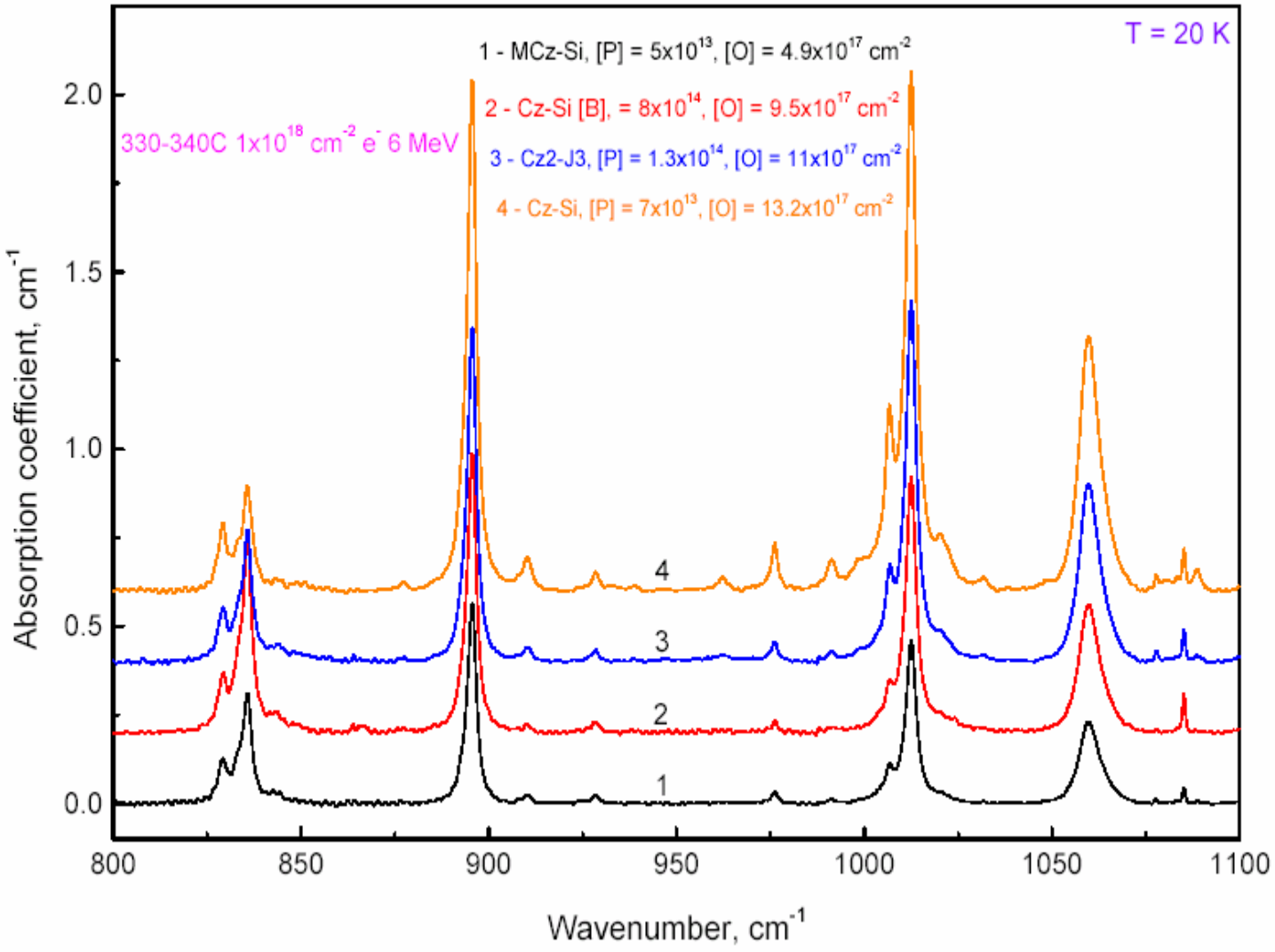
FTIR results: FZ silicon

Data: Leonid Murin, National Academy of Sciences of Belarus

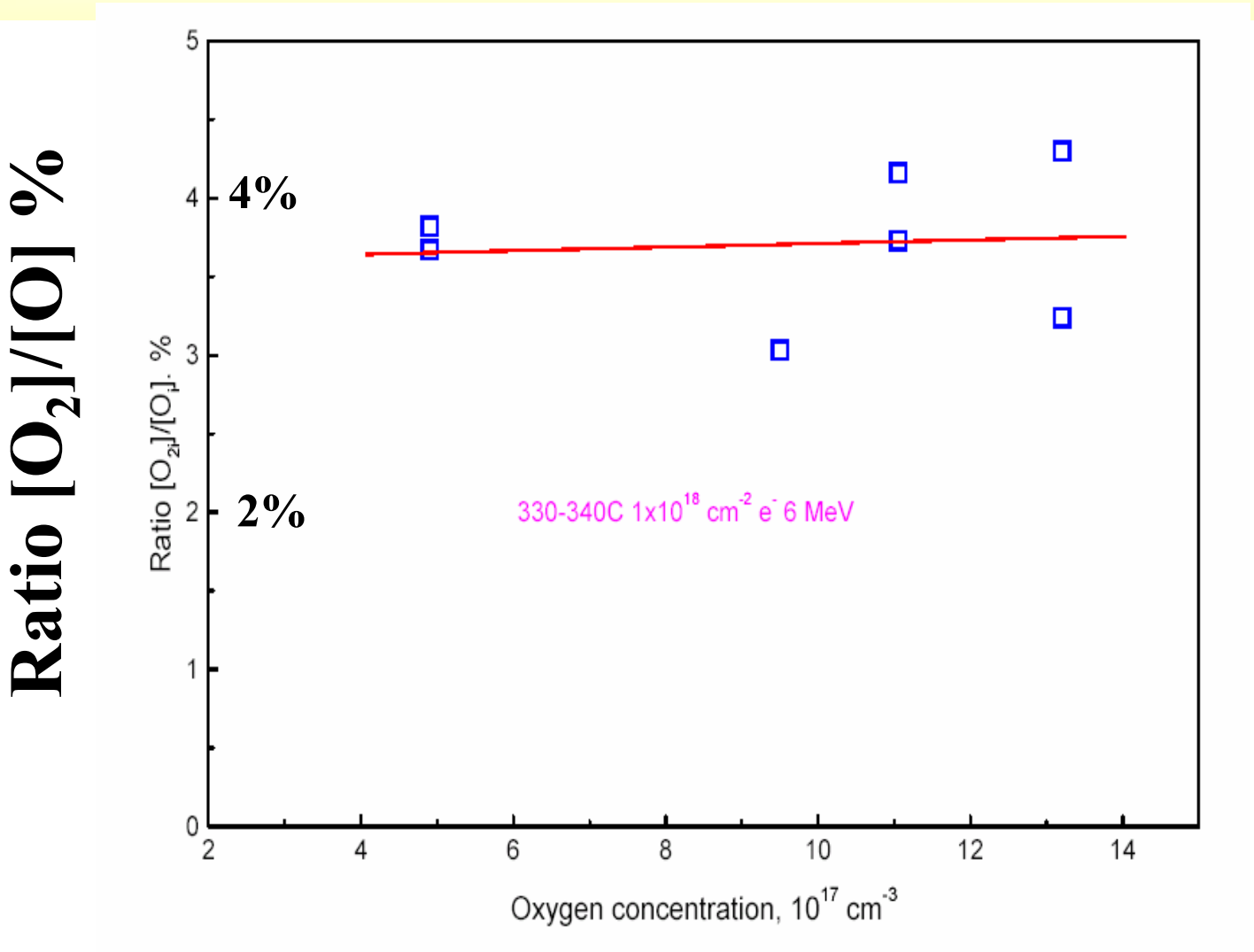


FTIR results – various CZ

Data: Leonid Murin, Lund & Minsk University

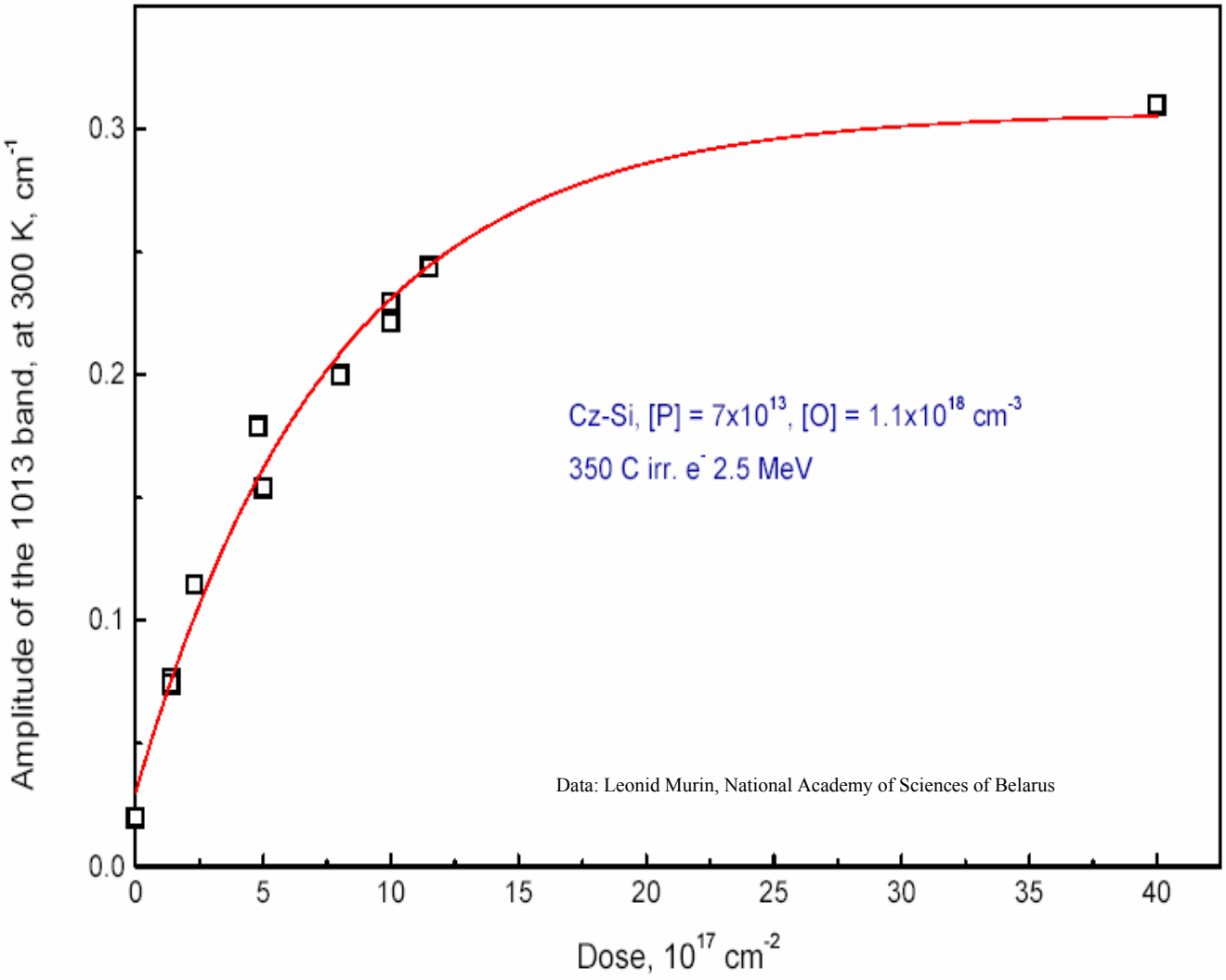


FTIR results- [O] dependence



- **Only ~4% of the oxygen (O_i) is transformed into oxygen dimers (O_{2i})**

Dimer formation - Saturation



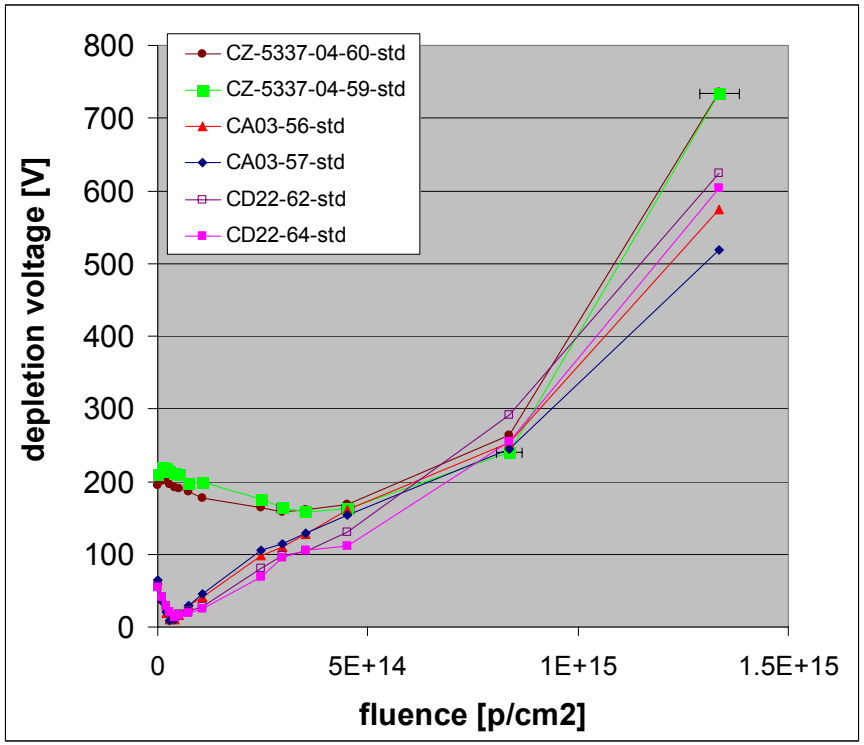
- **Increasing the electron fluence leads to saturation of oxygen dimer concentration**

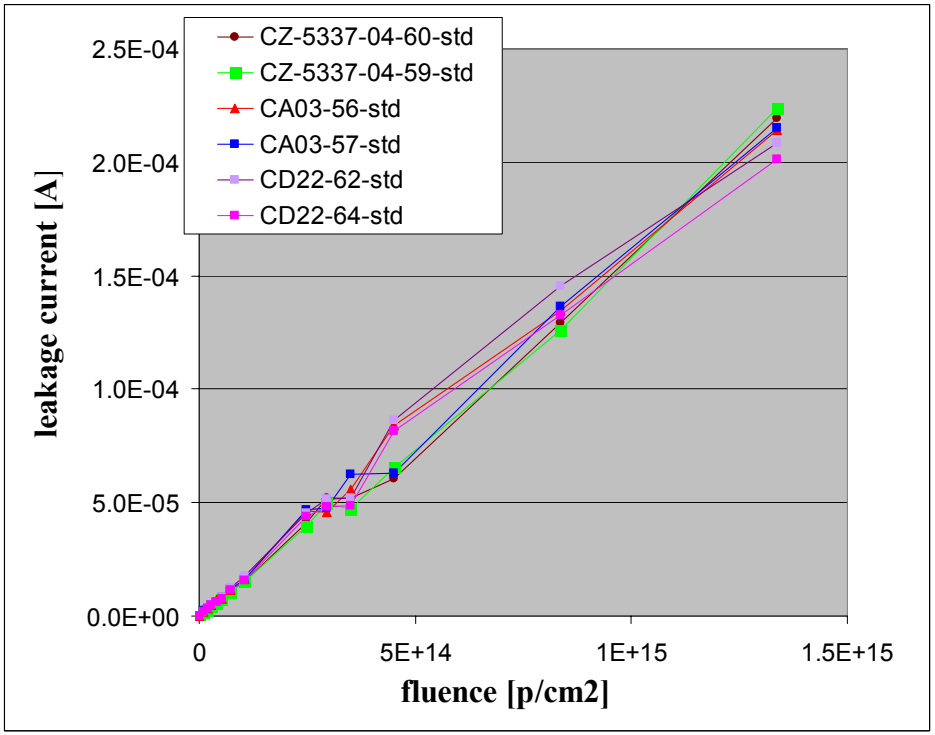
Irradiation test of "dimerized" Si

- **Performed "CERN scenario" using 24 GeV/c**
  - **Irradiation up to 1.5×10^{15} p/cm^2**
  - **Irradiated 9 diodes (Hamburg group, CIS):**
    - 3 dimerized diodes: (FZ, DOFZ, CZ)
    - 6 control diodes: (2 FZ, 2 DOFZ, 2 CZ)
- **Various bulk samples for IR measurements**
  - **Irradiated up to 10^{16} p/cm^2**

24 GeV/c proton irradiation

- **Irradiation in "CERN scenario" using 24 GeV/c protons**

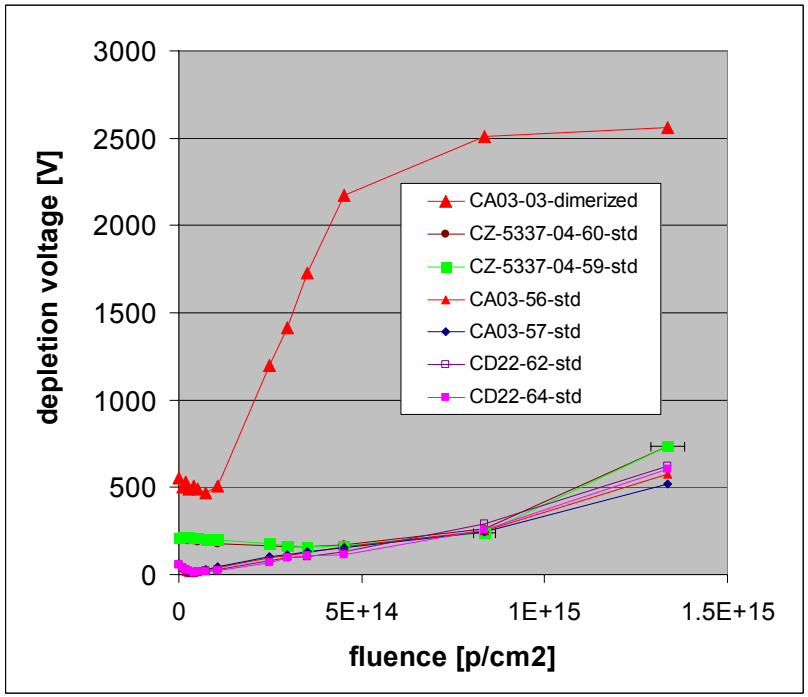




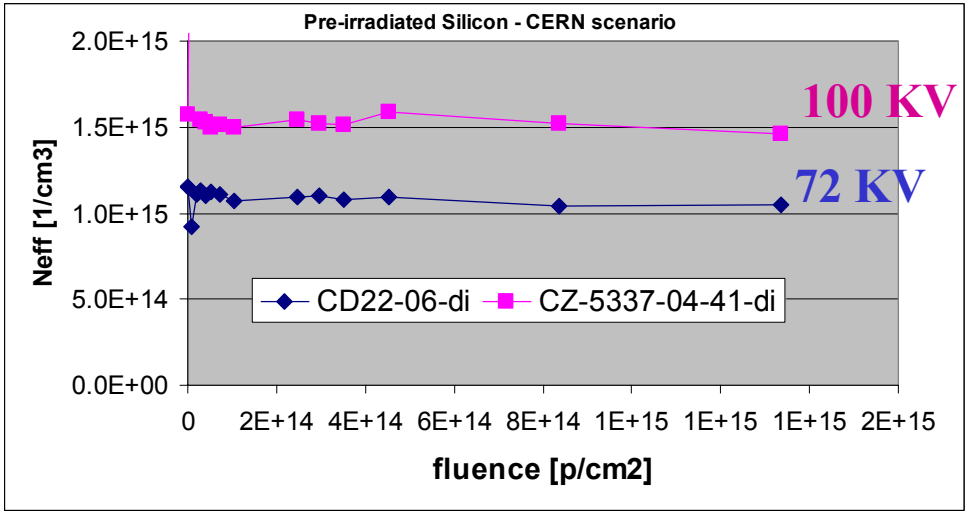
- **Expected behavior of control samples**

24 GeV/c proton irradiation

- **Diodes could not be depleted**
  - ⇒ **Infer N_{eff} and V_{dep} using the slope of $1/C^2$ vs V**
  - ⇒ **<u>Very unreliable method</u> for irradiated detectors, but best we could do**



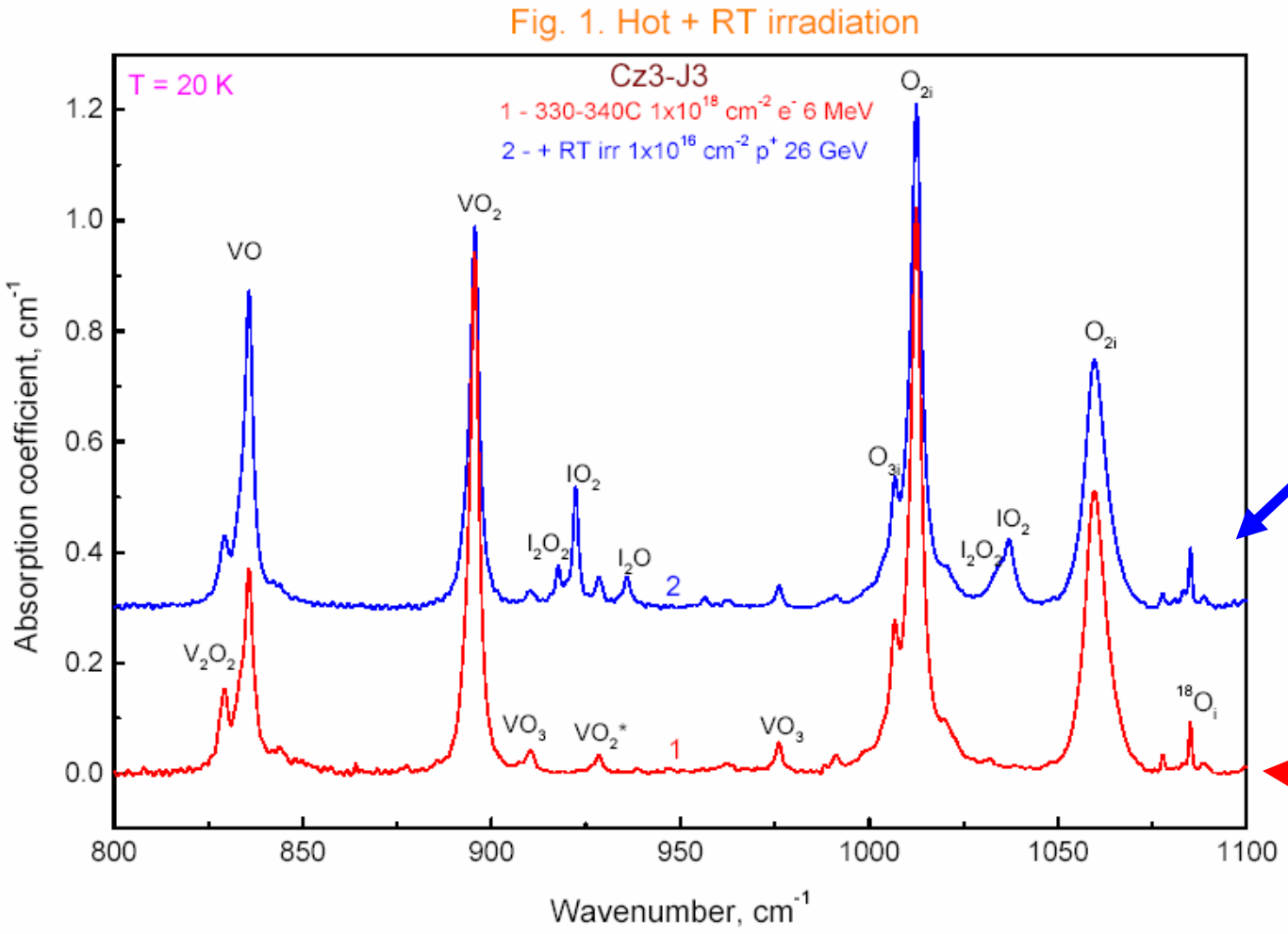
- **"dimerized" FZ**



- **"dimerized" CZ**
- **"dimerized" DOFZ**

RD50 Irradiation of dimerized Si (FTIR)

Data: Leonid Murin, National Academy of Sciences of Belarus



"dimerized"

and

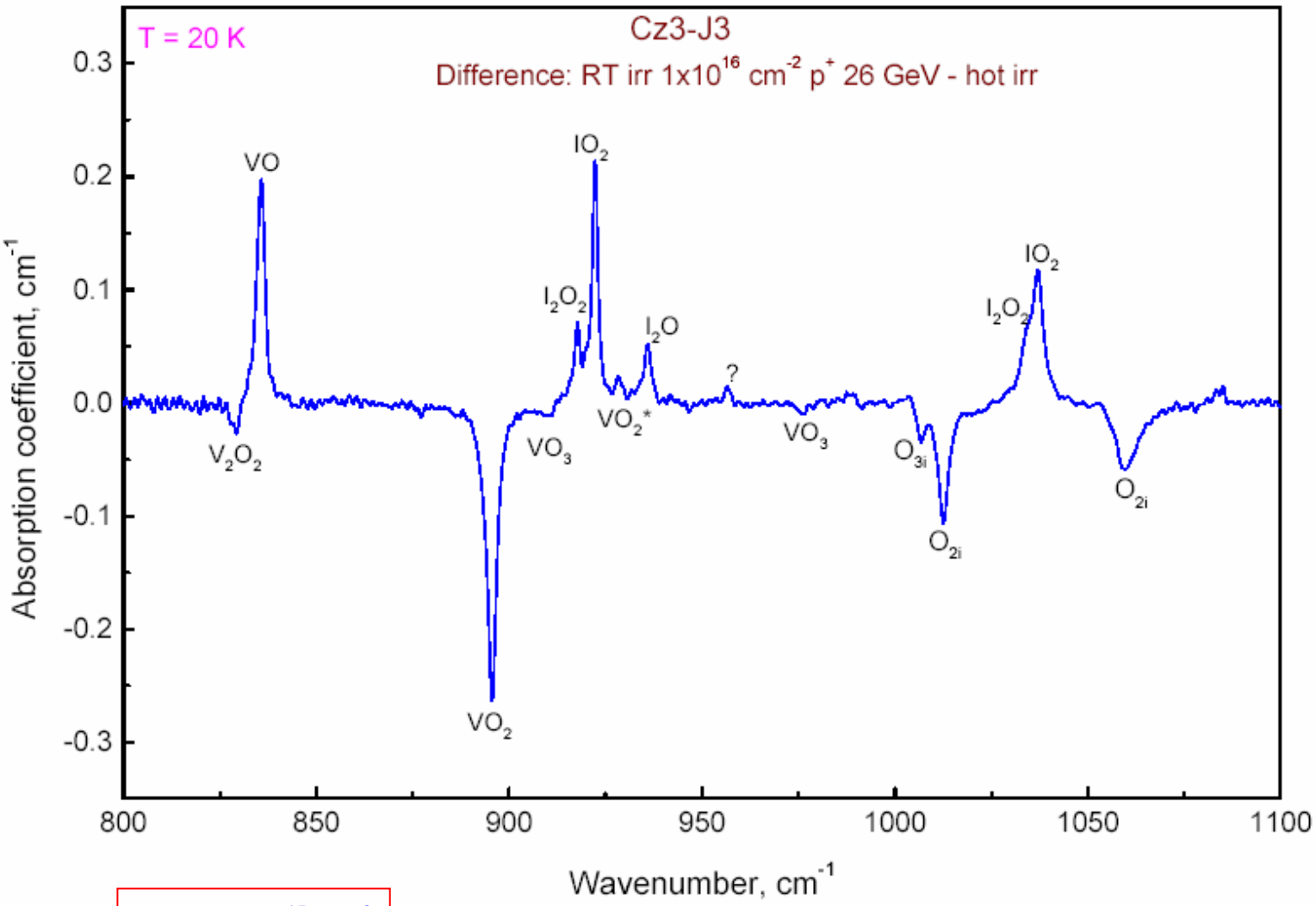
24 GeV/c proton irradiated (10^{16}cm^{-2})

"dimerized"

(hot electron irradiation)

Irradiation of dimerized Si (FTIR)

Fig. 2



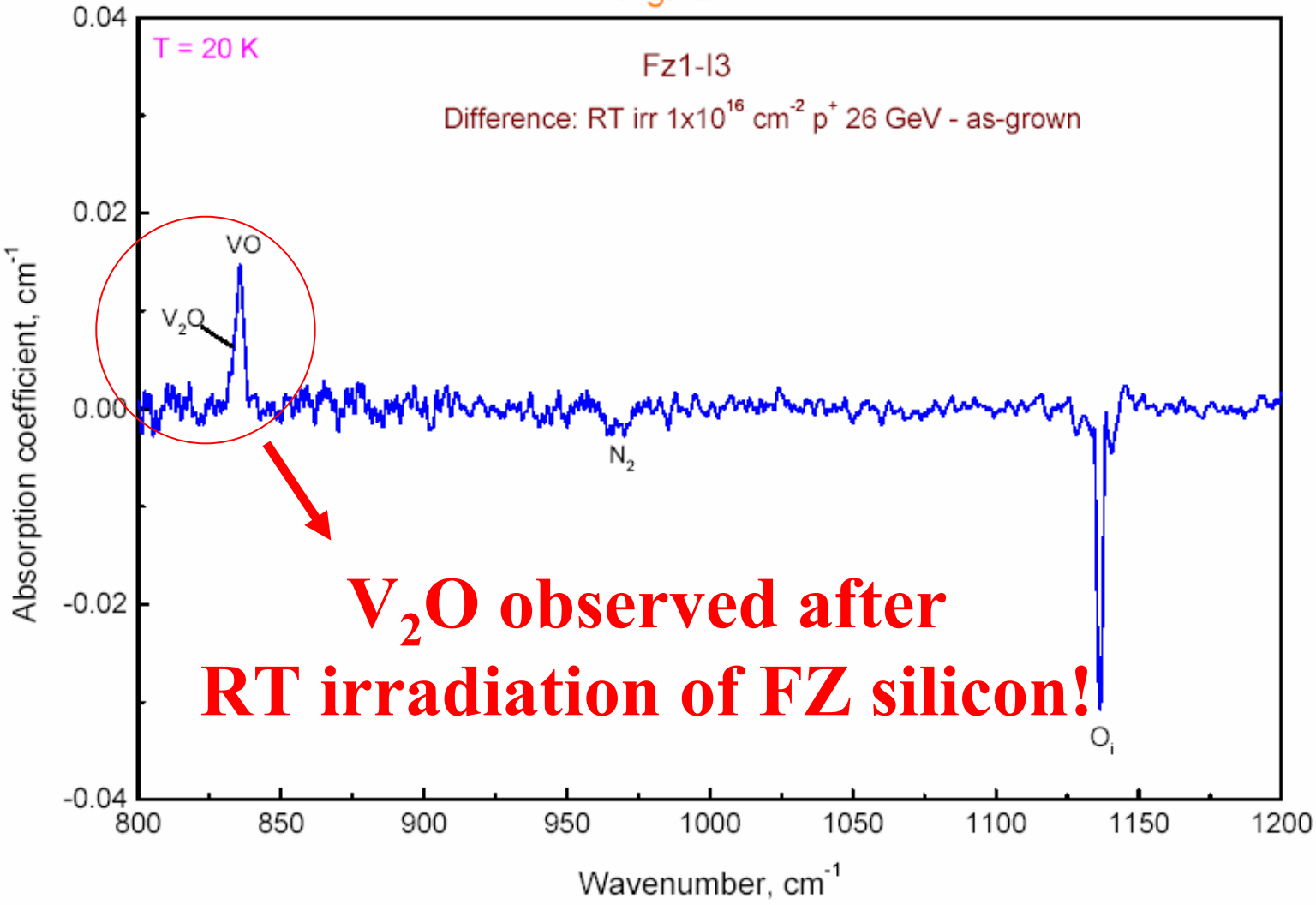
IO_2, I_2O

[VO]~5x10^{15} cm^{-3}

Data: Leonid Murin, National Academy of Sciences of Belarus

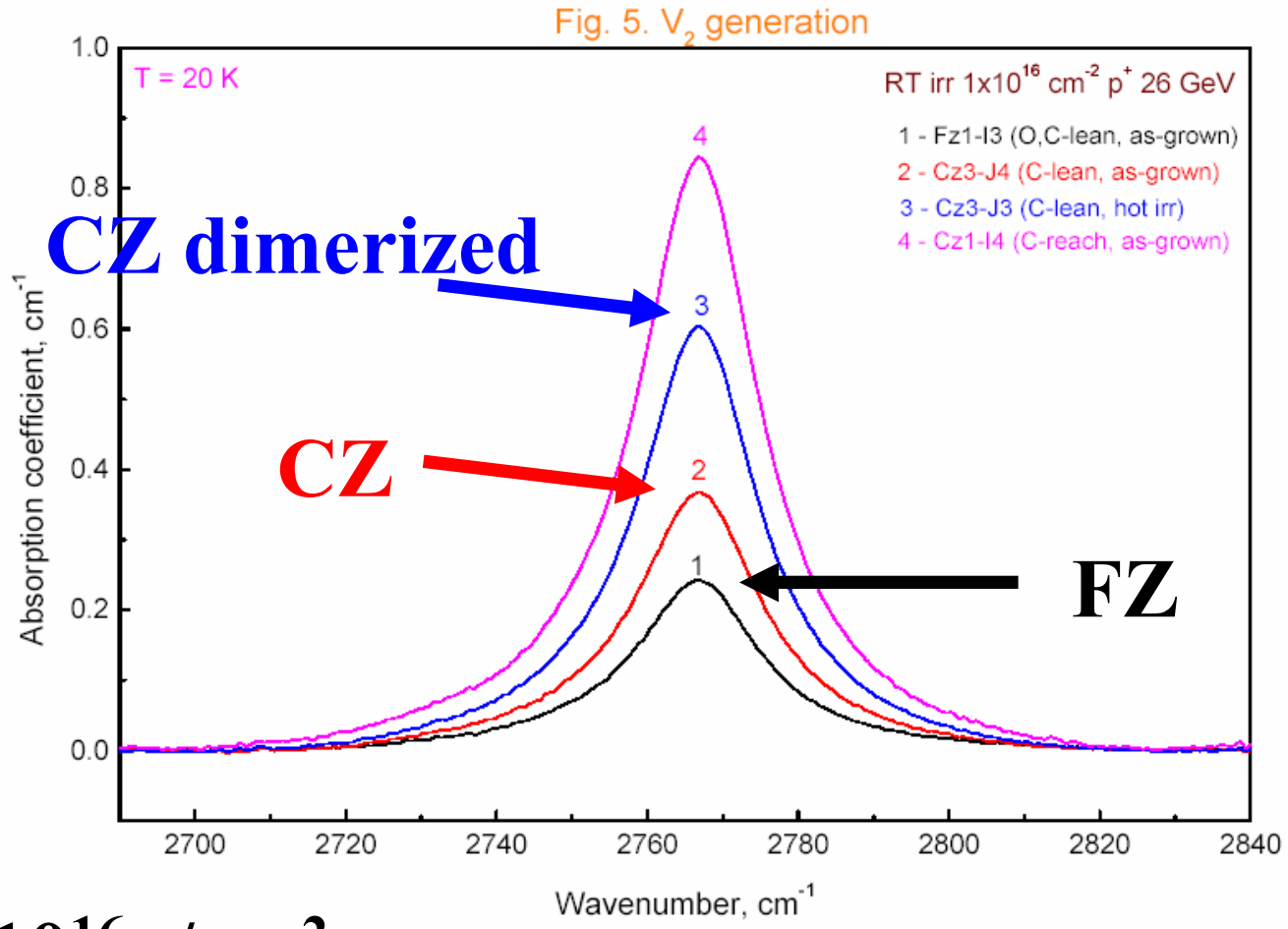
V_2O in proton irradiated FZ silicon

Fig. 4.



Data: Leonid Murin, National Academy of Sciences of Belarus

V_2 generation after 10^{16} p/cm^2

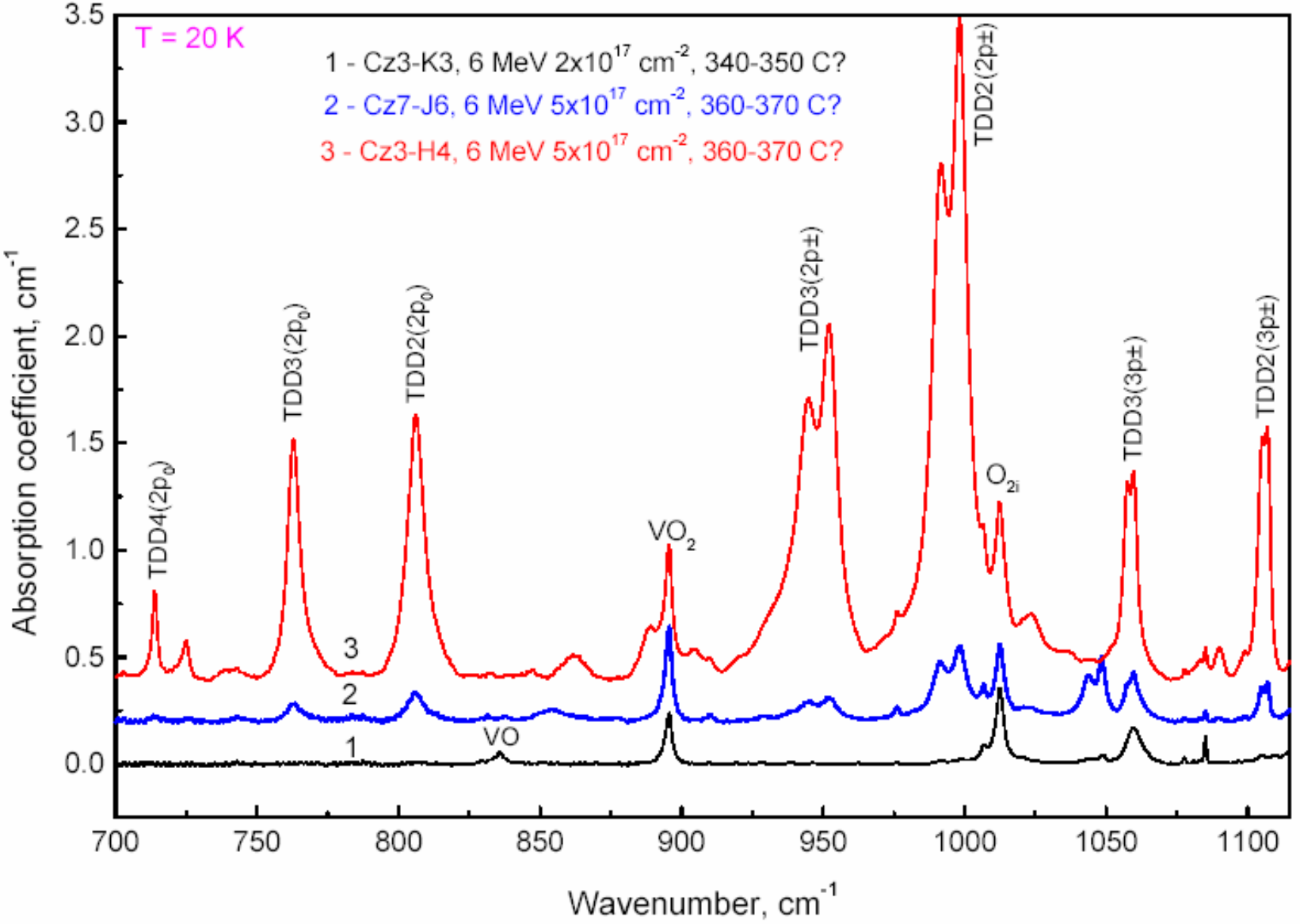


After 10^{16}p/cm^2:

Strong annihilation of V_2 via interstitials in FZ

Data: Leonid Murin

Thermal Donor Generation



Data: Leonid Murin

Conclusions

- **Dimerization process (as done by us) creates too many charged defects in silicon diodes could not be depleted after "dimerization"**
  - **… we could go down in the electron pre-irradiation fluence, but then we would even produce less dimers**
  - **….could use thin detectors?**

- **It is not possible to create a significant amount of dimers in CZ silicon (not more than 5% of the [O] concentration).**
  - **Also only a small amount of dimers in DOFZ and FZ after dimerization process**
    …. below detection limit (~10^{15}cm^{-3})

- **Novel ground for defect studies!**
  - **Identification and characterization of many defects**
  - **Tuning of simulations**
    - Could potentially lead to a usable material?
  - **FTIR – A microscopic tool that works after an irradiation with 10^{16} cm^{-2} !**

- **RD50 dimer task force**
  - **Formed on RD50 Workshop in October 2002…**
    … after first promising dimer tests of the Brunel group
  - **Analyses of latest dimerization experiment currently under way**
    (preliminary result: diodes can not be depleted even after the lowest fluence of 2x10^{17} cm^{-2})
  - **Finalize the work with a publication within the coming 3 months**
  - **Give final conclusion in next status report**