Ionizing organic compound based nanocomposites for efficient γ–ray sensor

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composites have great potential for low cost alternatives to semiconductor approach

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Outlines..

- Objectives
- Previous studies
- Current approach
- Thin film approach (Well established by Arshak and his group)
- Composite approach
- Results
- Summary

Ionizing organics have some advantages

Ionizing organic based nanocomposites for efficient γ–ray sensor

Our previous work in this field:

- **Semiconductor crystals**
  - Bulk CZT and CdTe crystals
  - Ternary selenide crystals
- **Heavy metal haides**
  - Mercurous Halides
  - Thallium lead halides
- **Thin film unusual oxides**
  - Pure and doped oxides
- **Nanoengineered Indium (**Cherinkov radiation**)**
- **Ionizing organic composites**

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Objectives:

Develop nanoengineered composites for radiation sensors

Approach:

Base Material: Nickel oxide

Ionizing organic for matrix: Ethylene carbonate

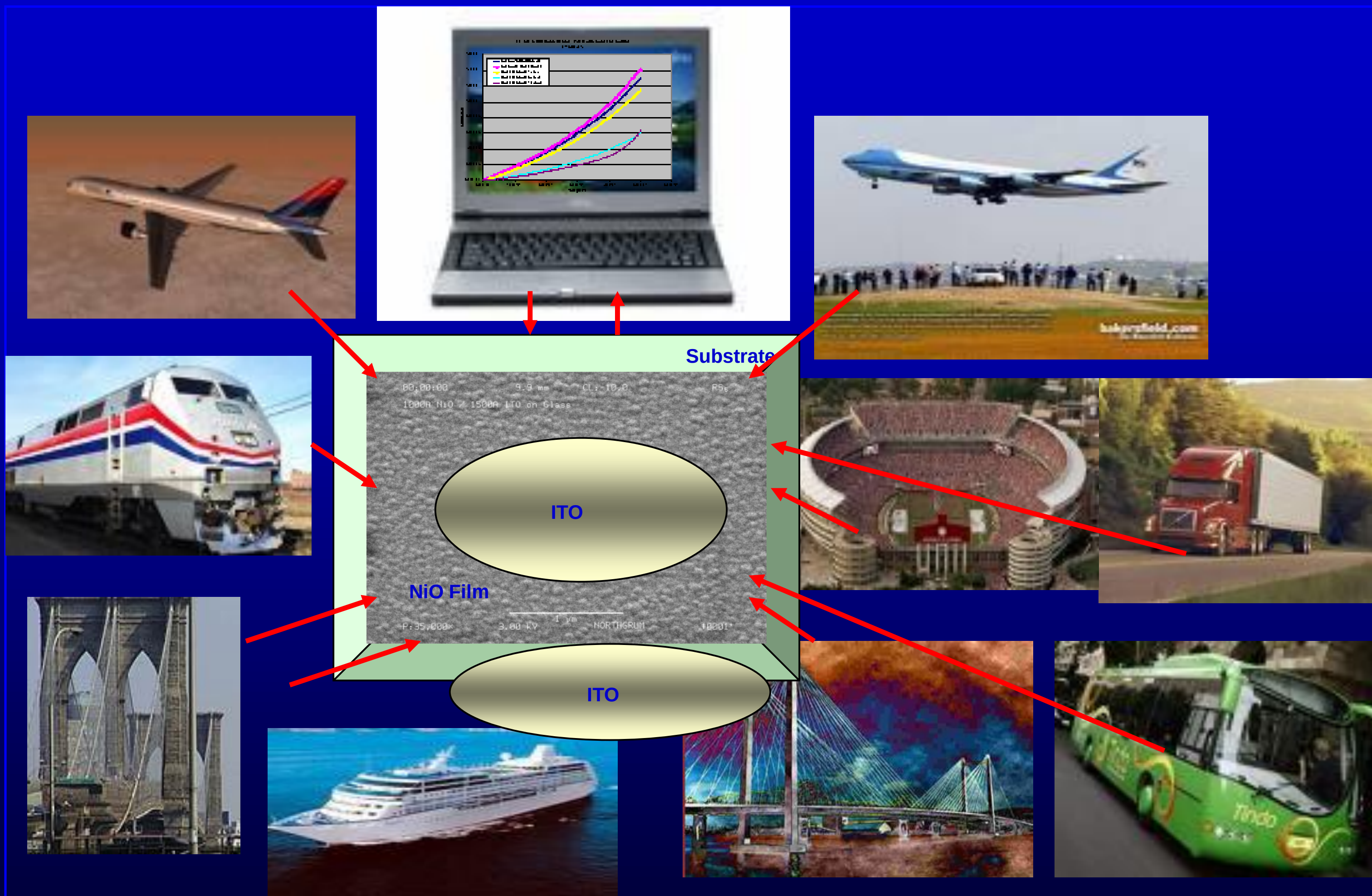
Dopants: TiO_2

Other materials under investigation: MnO_2, $KMNO_4$, $K_2Cr_2O_7$

Approach: Determine I-V curve as grown and radiation exposed composite

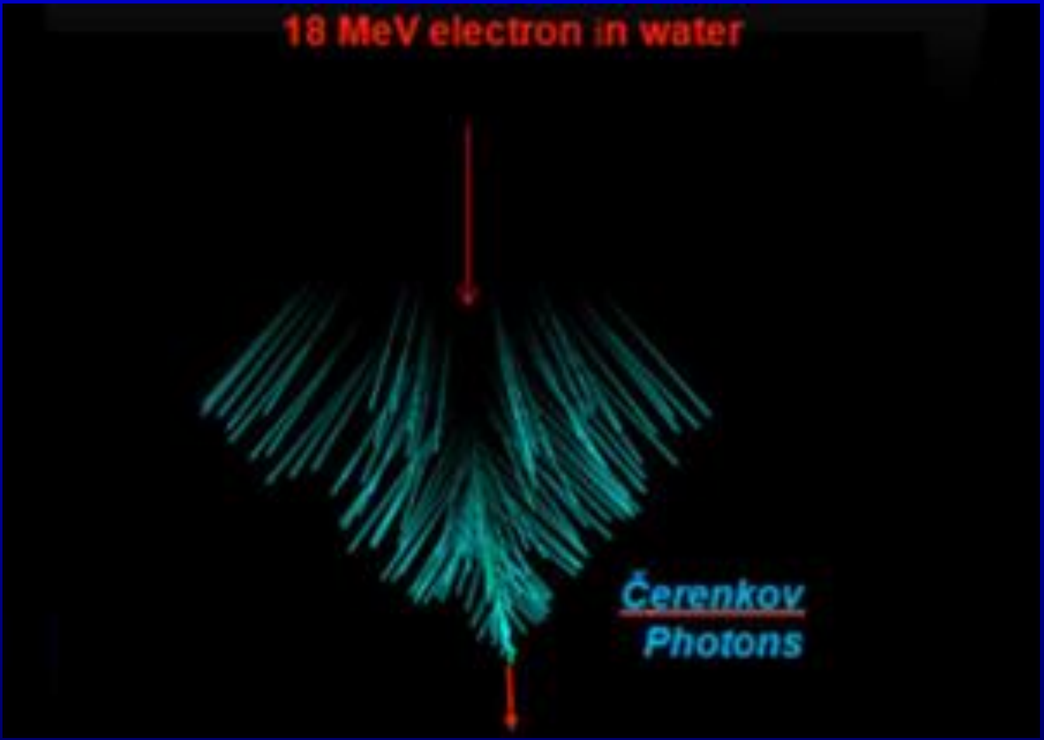
Monolithic NiO_2 has been utilized for instrumentation

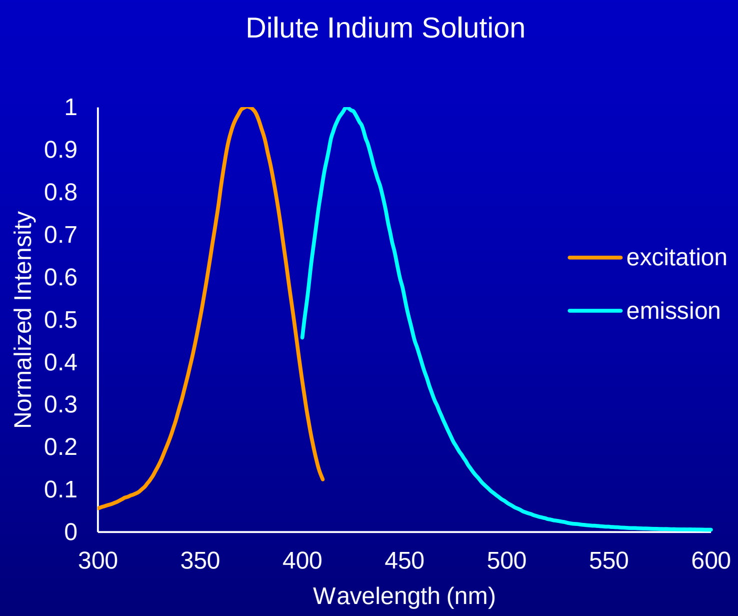
Composites have potential for applications where low cost large volume is required



Chip based detector can be used on every platform

Cerenkov radiation (emission) is based on nano particles





- Idea is to prepare desired size of nanoparticles so that emission is in region where we can observe.
- Emission will depend on particle size

Cerenkov radiation can be used for detection using emission in near IR region

Several novel features will improve performance of detectors

- <u>What is lacking to make it reality</u>
  - Materials Red-Ox characteristics must be studied for improvement
  - Materials with different nano- and micro morphology should be evaluated to see effect of morphology
  - Materials with different transparent substrates should be evaluated to enhance sensitivity
  - Electrodes effect is unknown, it will affect sensitivity
  - No data is available for Low cost PVD vs sputtering methods for pure and doped NiOx performance
  - Novel design of diodes may also enhance sensitivity
  - NiOx based devices with at least three modified characteristics will provide better selection for performance

Current status of NiO_x based technology.

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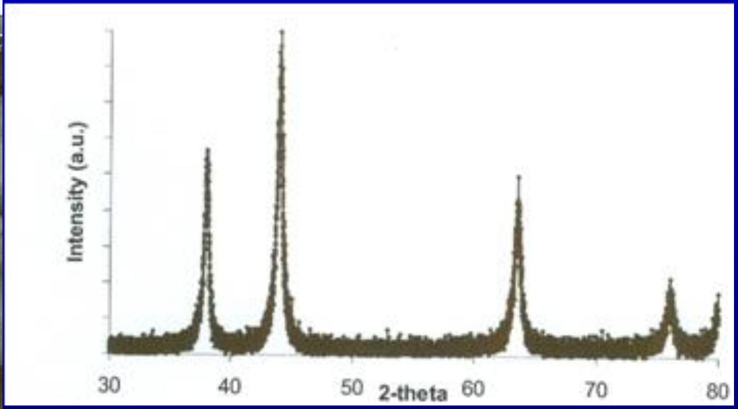
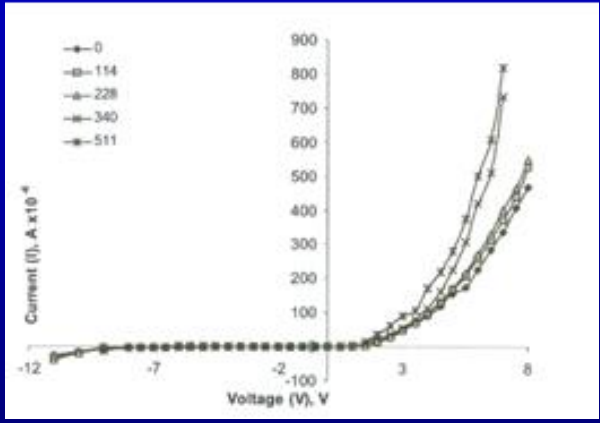
- Work done by Prof. Khalil Arshak: Published famous paper Nickel oxide as gamma ray sensor
  - He was the first one to show that NiO_x works





Microstructres have pronounced effects,
There data shows that NiOx does work,

No attempt was made to understand and enhance materials parameters for device and sensor performance

NiOx must be engineered and improved to enhance efficiency

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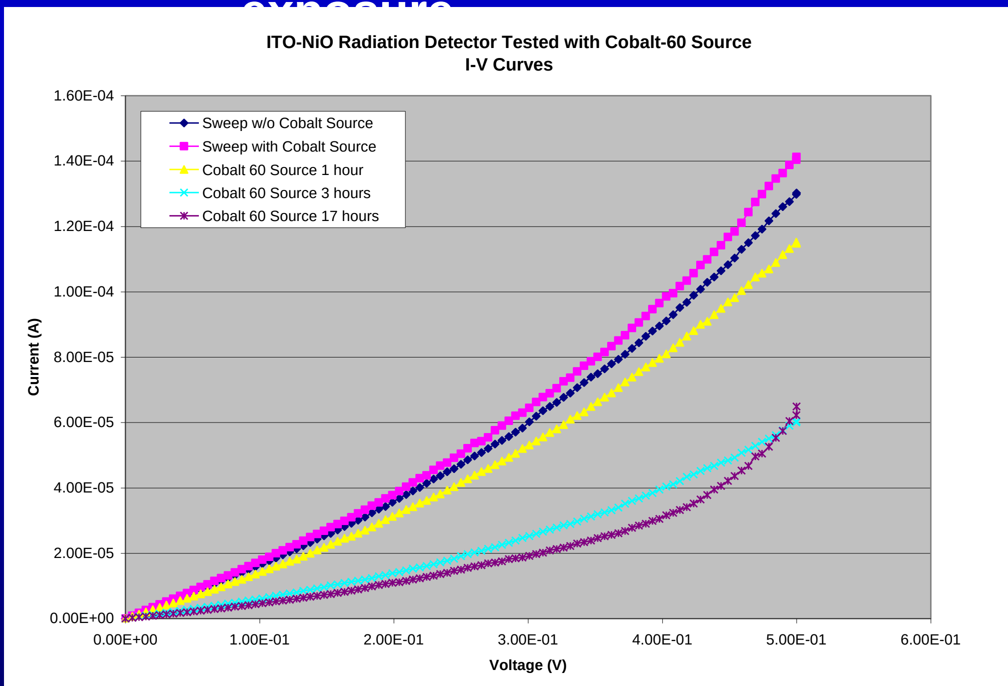
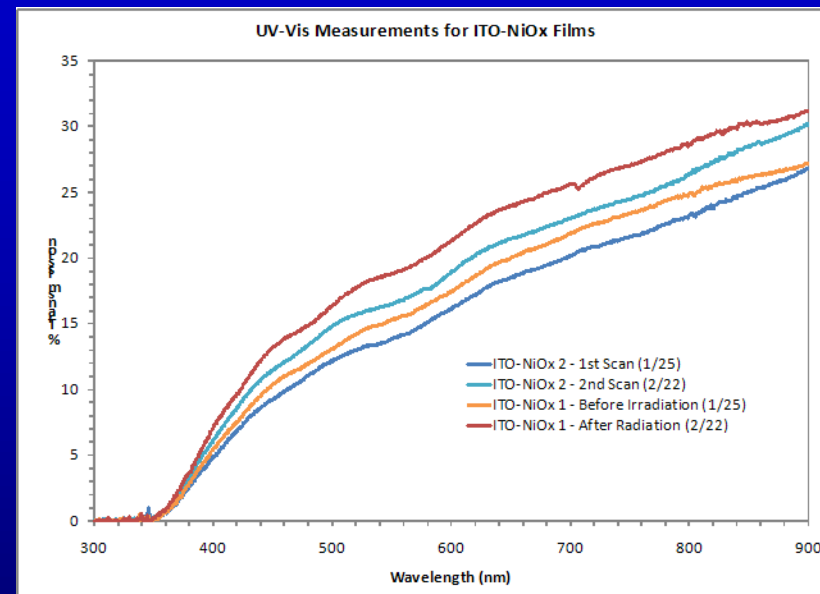
Preliminary work showed feasibility of NIOx based devices, but properties, process to control microstructures and fabricate diodes must be investigated and improved to make a practical detector

Preliminary one shot data on effect of thickness and time of exposure





Measurement of different exposure time showed feasibility, but sensitivity with pure NiOx was low and higher exposure was required

Measurement of different thickness did not show pronounced enhancement

Design of materials (Red-OX), film quality enhancements, design of electrodes and diodes ill enhance performance suitable for system

Preliminary work showed feasibility of NIOx based devices, but properties, procees to control microstructures and fabricate diodes must be investigated and improved to make a practical detector

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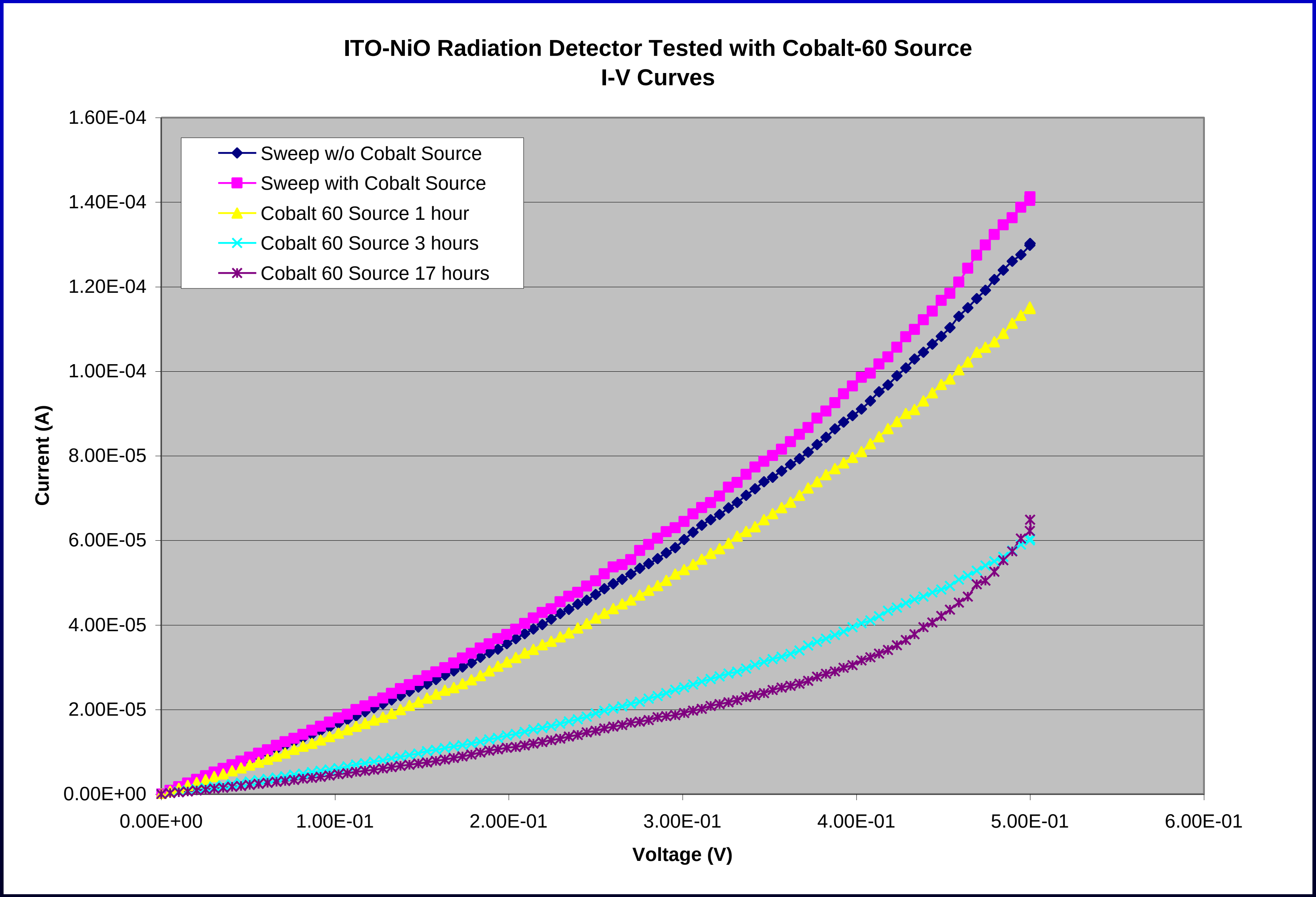
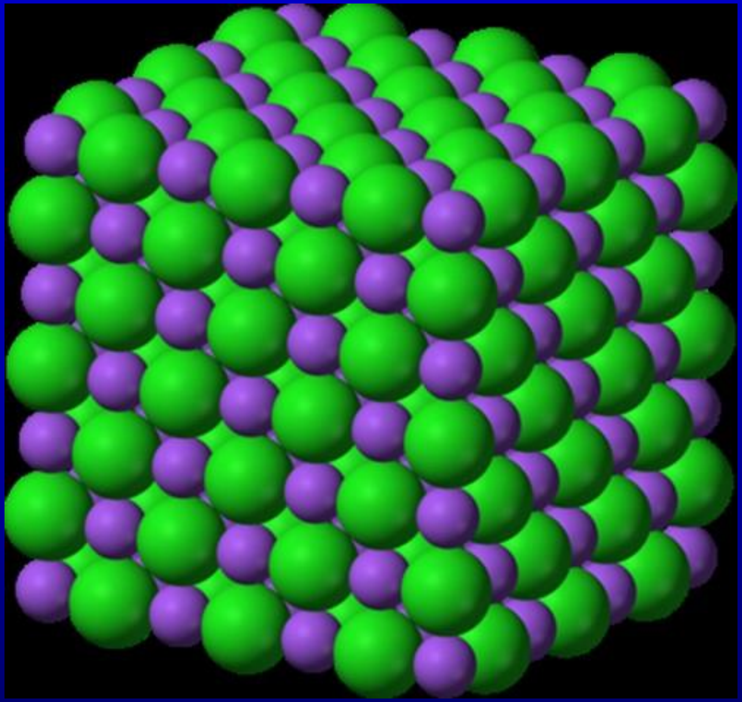


Composites of Nickel Oxide



Structure of Nickel Oxide

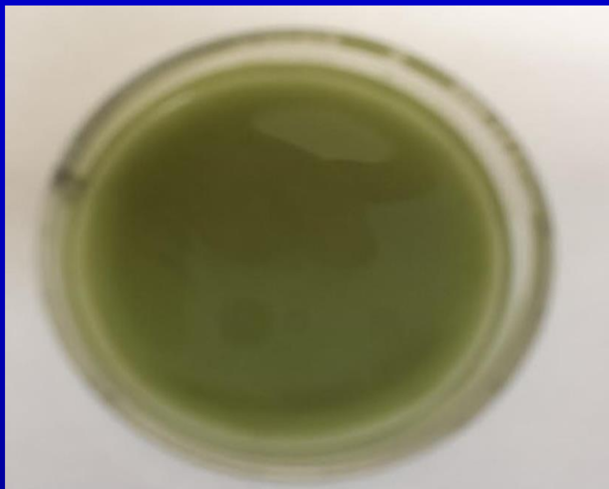
- **NiO_x mixed in matrix of Ethylene carbonate**
- **Effect of TiO_2**
- MnO_2, $KMnO_4$ or $KMnO_4$
- Both together MnO_2 + $KMnO_4$ together
- **Sample 1:**
  - **Ethylene Carbonate: 9.52g**
  - **Nickel Oxide: 1.28 g**
- **Sample 2:**
  - **Ethylene Carbonate: 10.96g**
  - **Nickel Oxide: 0.8 g**
  - **Titanium Oxide: 0.57**

- Mixed in molten $ETCO_3$ by melt freeze method
- Evaluate C-V behavior
- Exposed to gamma ray and determine C-V
- Morphology of both pre and post exposed

Relevance for applications of composites

- The significant difference in the I-V characteristics due to radiation source of monolithic and composites based on ionic organics can be explained based on contribution of organic ionic matrix.
-
- Pair production due to ionization is the major mechanism in organic compounds. The γ- and β-radiations easily break the chemical bonds and prevent bond recombination.
- The radiation, γ-rays or other charged particles lead to ionization process and hence can alter the current-voltage characteristics compared to monolithic oxides.
- This results in larger change in current (high resistance) for the composites compared to monolithic film. Most of the film based NiO_2 sensors involve growth of film by high temperature process on desired substrates.

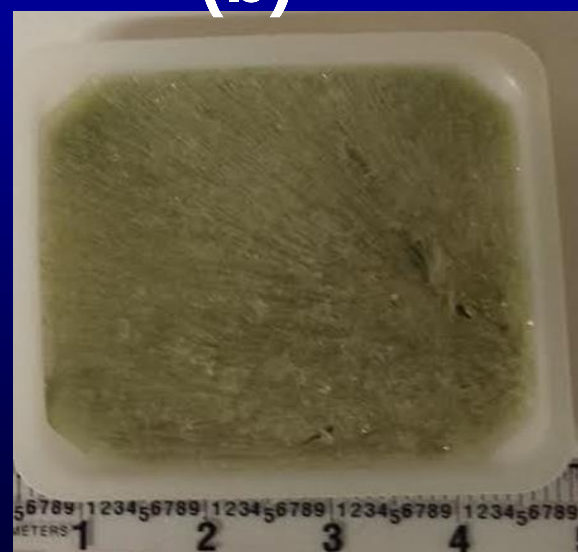
Shaped composites can be designed



(a)

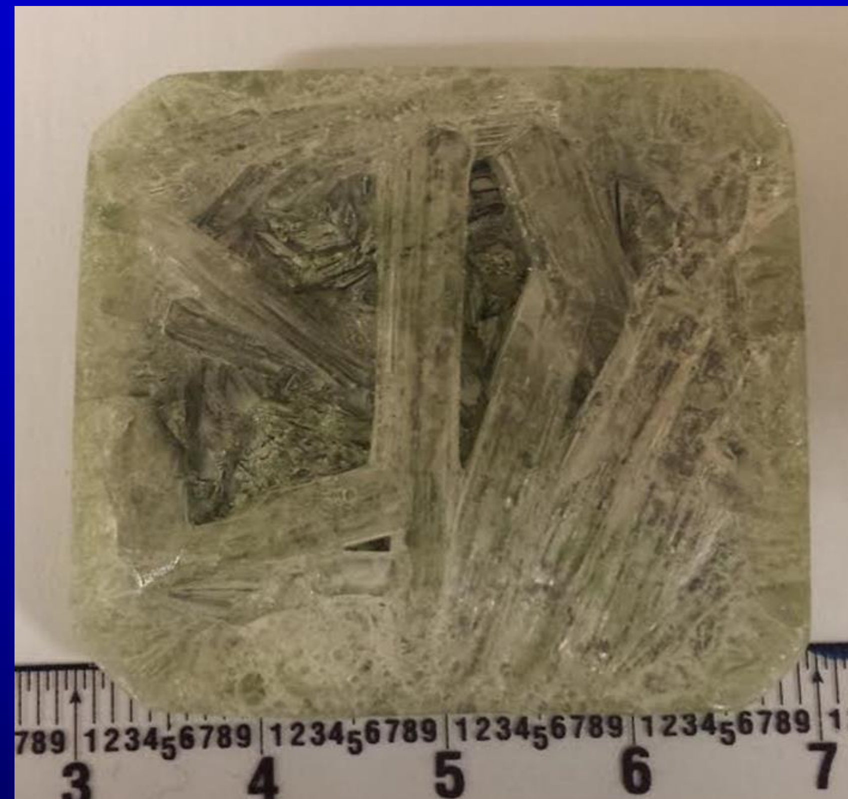
(b)

Ethylene carbonate composites containing (a) NiO_2 and (b)NiO_2 and TiO_2



Shaped composites containing (a) NiO_2 and (b)NiO_2 and TiO_2

Processing has significant effect on morphology



- NiO_2 and TiO2 doped ETC composites processed at slow cooling rate
- Large crystals are possible at slow cooling

Morphology controls the performance

Sources used in present study

Alpha, beta and gamma source

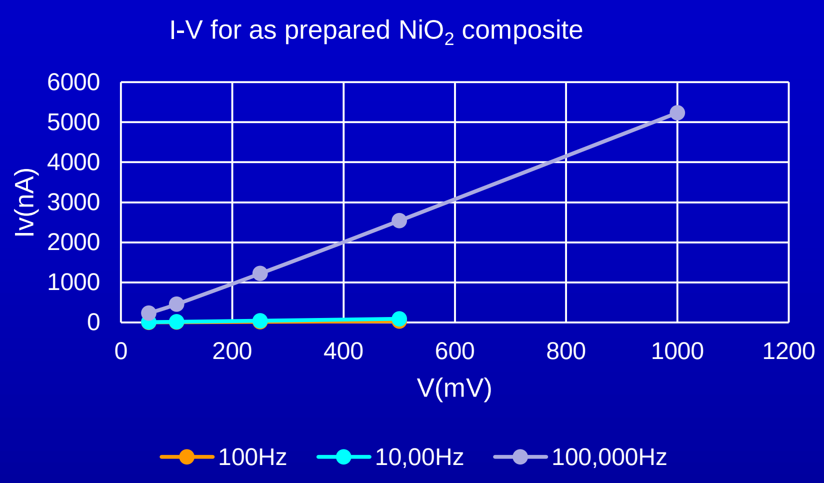
Cs-137: 0.25 µCi, 30.2 years, β, γ radiation

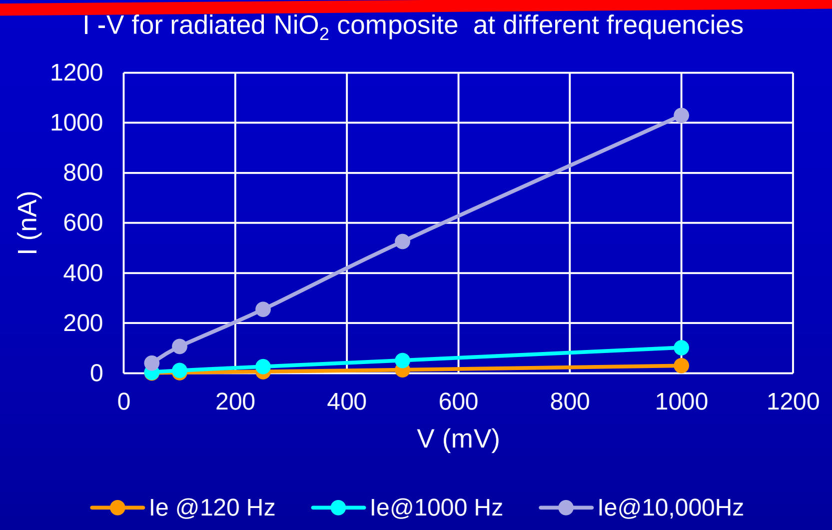
https://www.pasco.com/prodGroups/radioactive-sources/index.cfm

- **Silver pastewas used as electrode**
- **LCR meter was used for electrical characterization**
- **Measurements were taken at 50, 100. 250, 500 1nd 1,000mV**
- **100, 120, 1,000 10,000 100, 000 and 1000,000 Hz was used for each bias voltage**
- **Radiation exposure of 48 hours was used with commercial Cs-137 source**

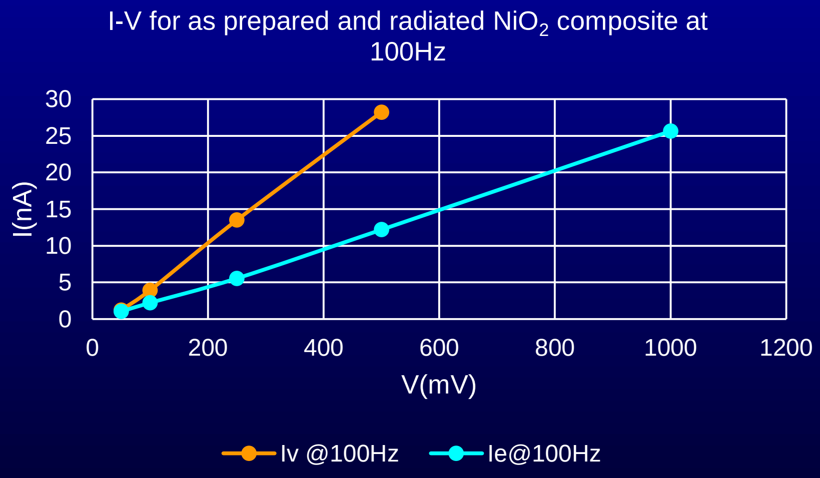
Radiation source was placed within mm distance

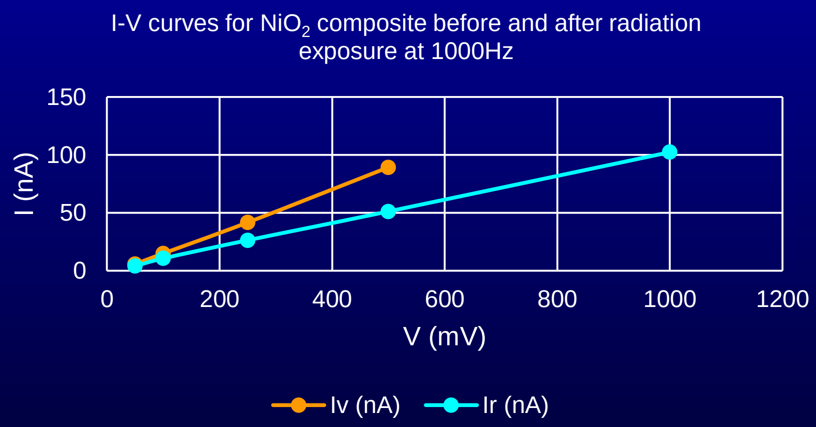
I-V curve showed large difference in slope of virgin and radiated samples





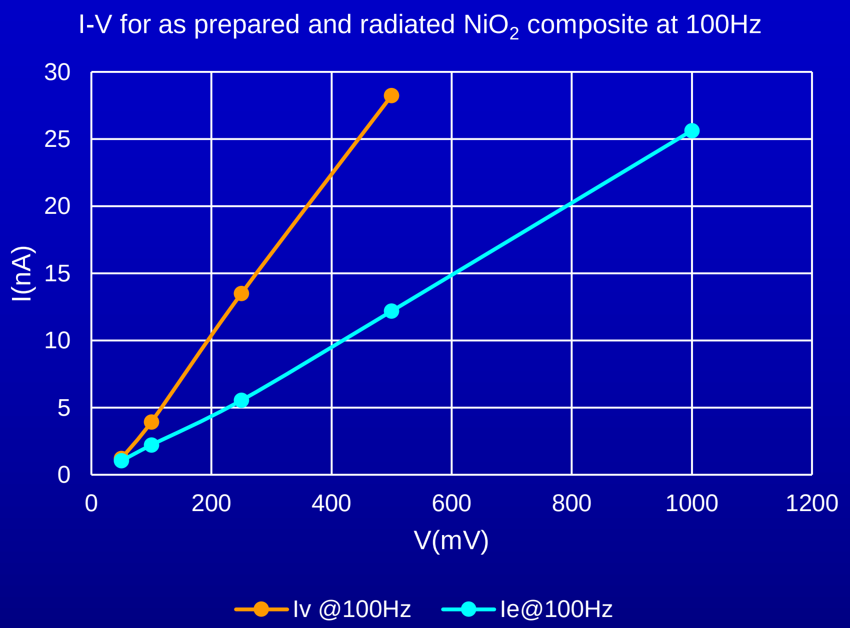
I-V for different frequencies: Radiated composite had lower current

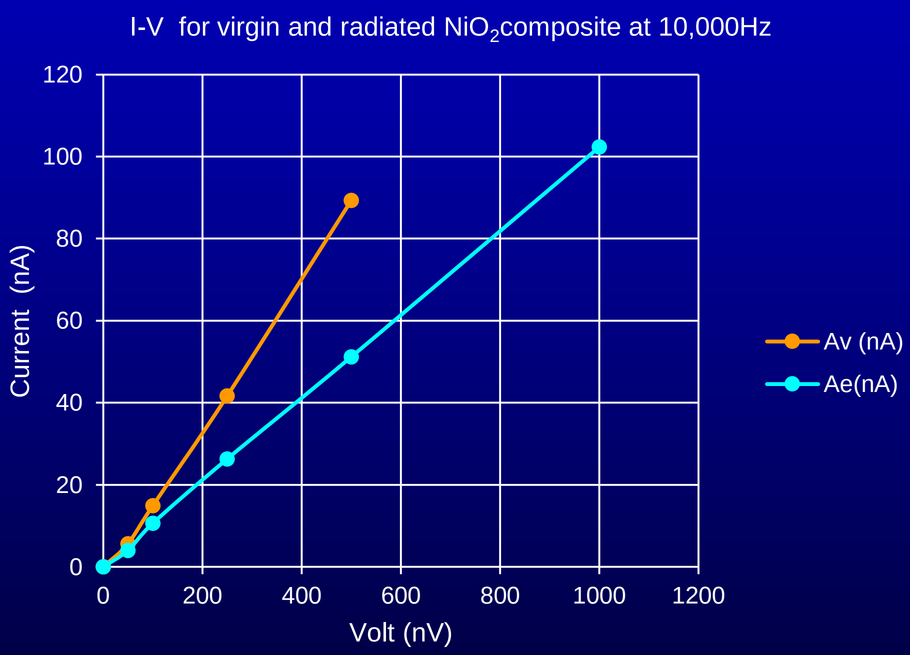




Frequency and radiation had higher resistivity and lhence ower current

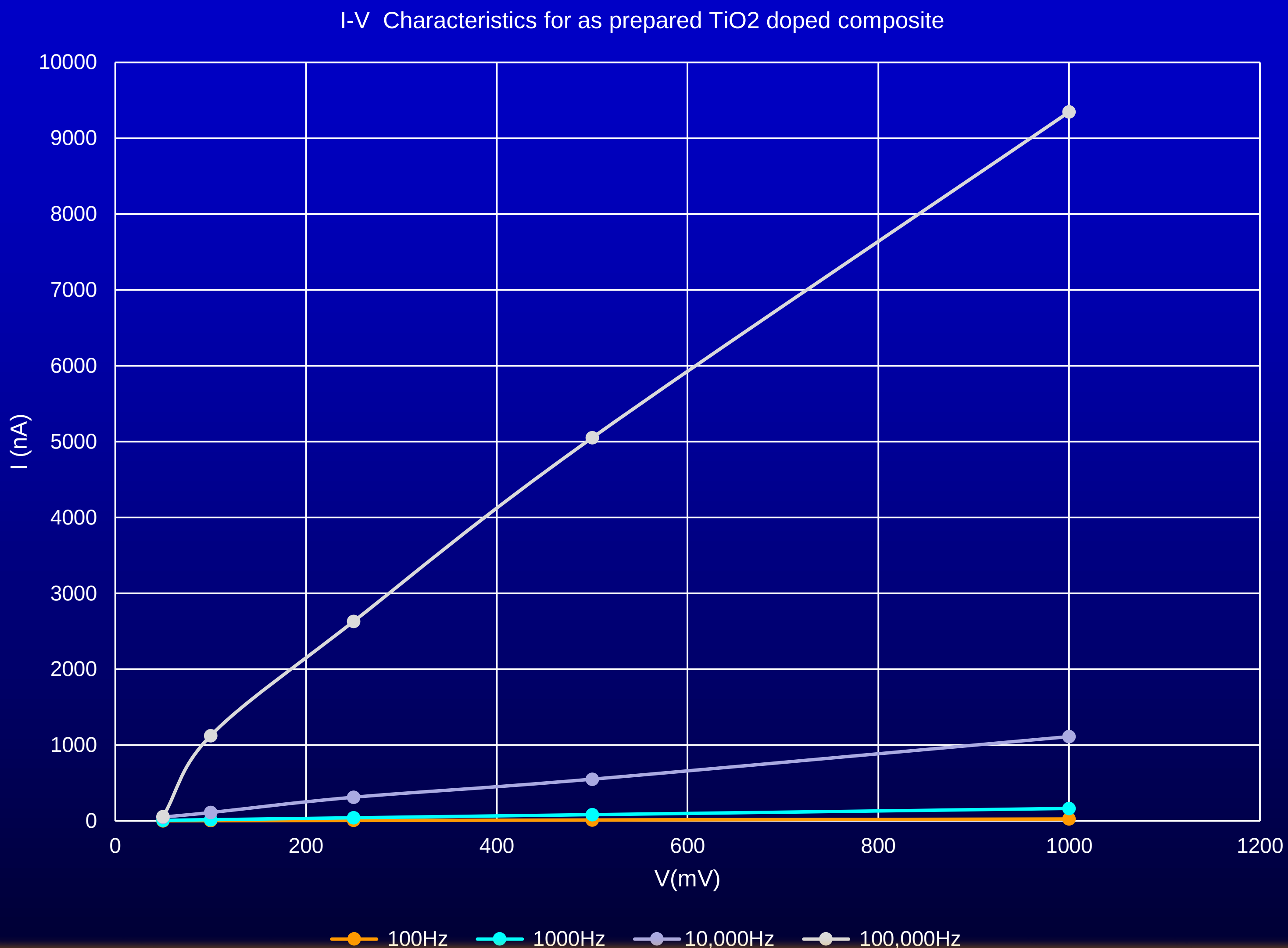
I-V curves at all frequencies showed that radiation had similar effect at all frequencies





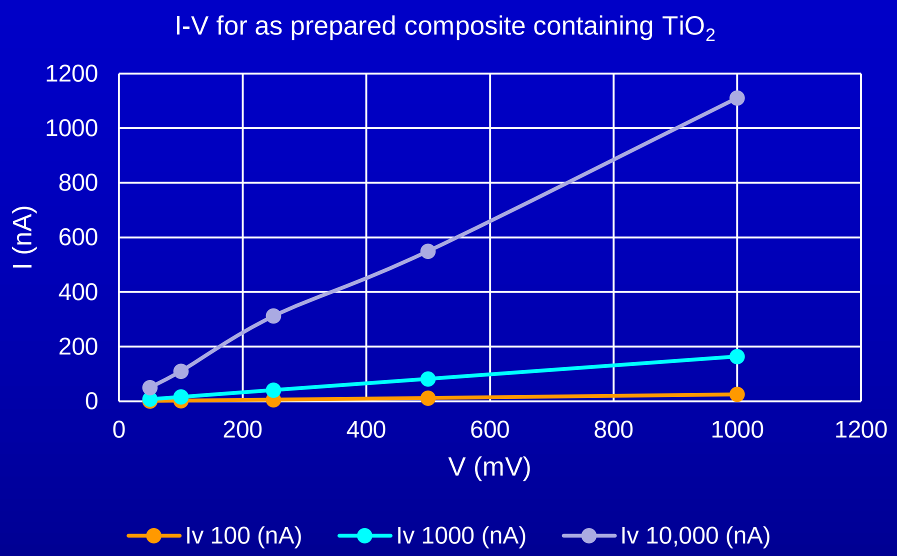
Performance of composite at 100 and 10, 000Hz

Effect of TiO_2 doping on performance



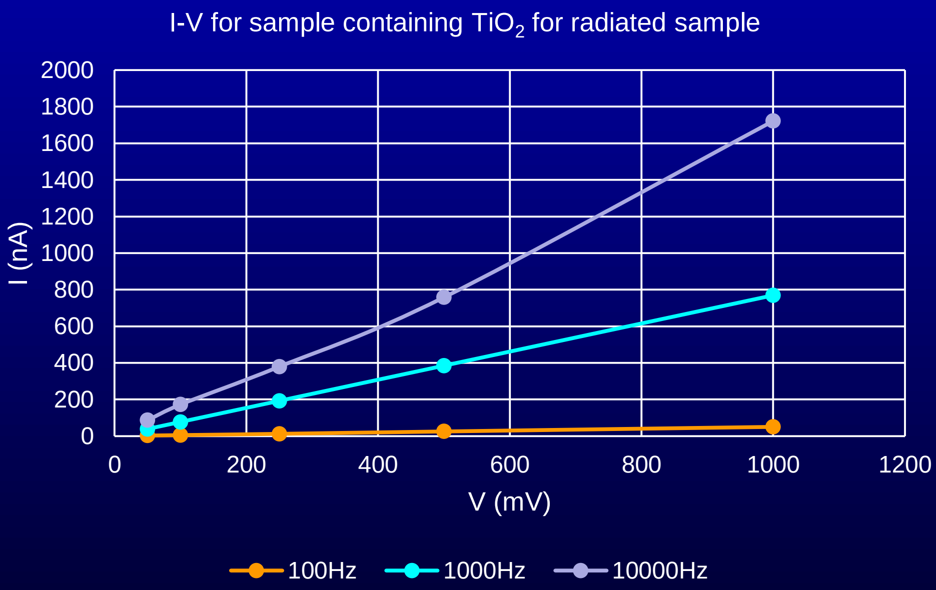
As prepared TiO_2 containing composite showed lower current

Effect of TiO_2 doping on performance



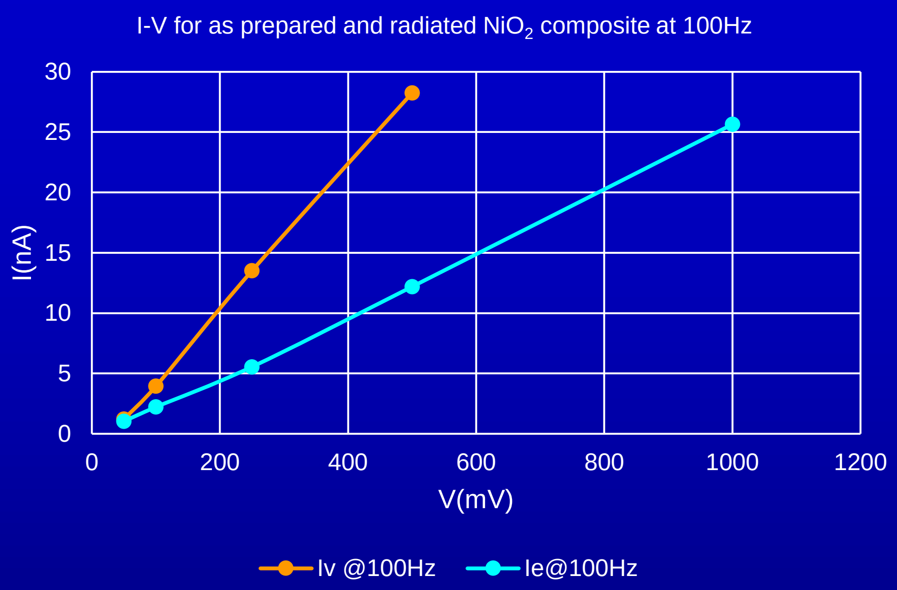
I-V characteristics of TiO_2 composite before γ-ray radiation exposure

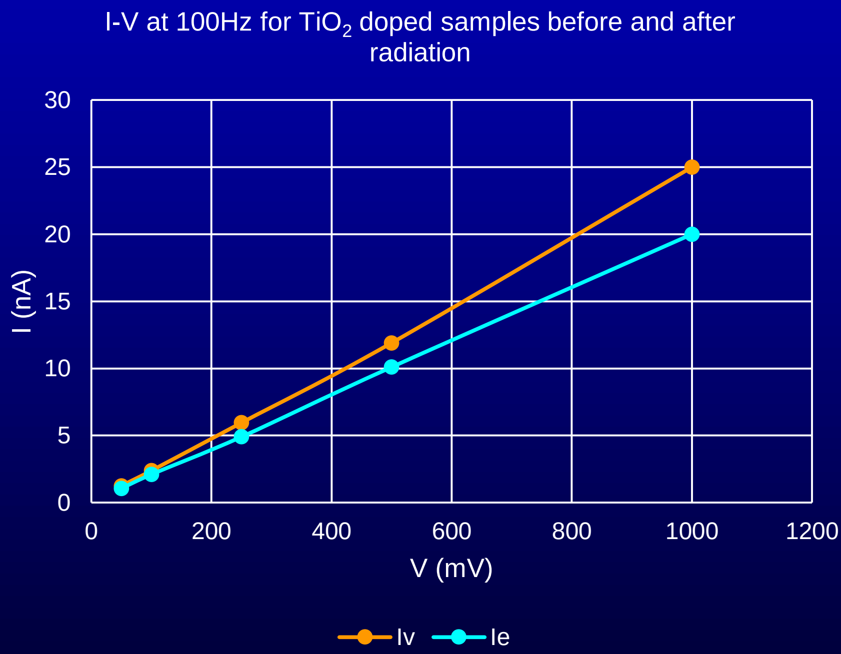
I -V characteristics of TiO_2 composite after g-ray radiation exposure



As prepared and radiated samples showed identical behavior at all frequencies

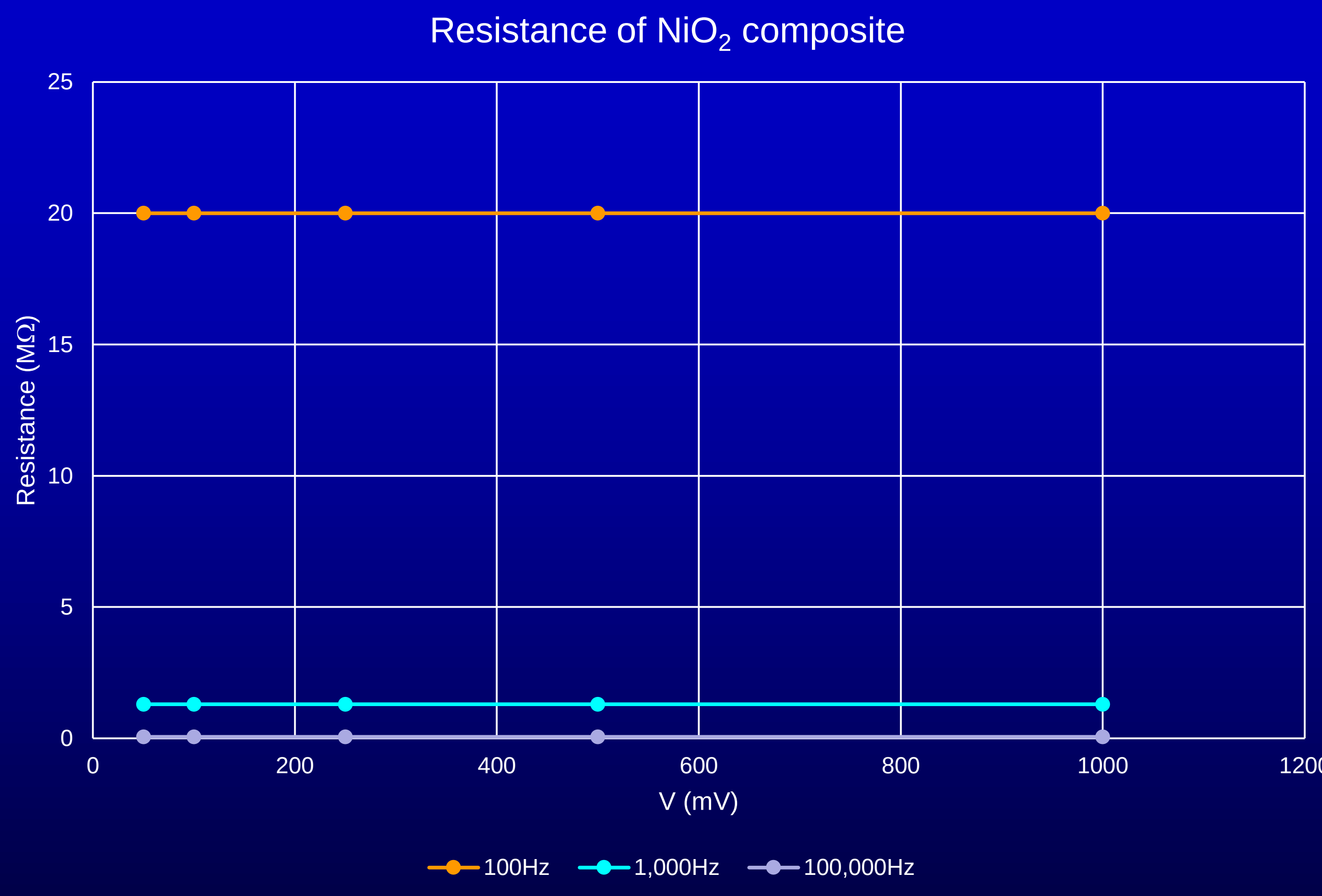
I-V characteristics for pure NiO_2 TiO_2 doped samples





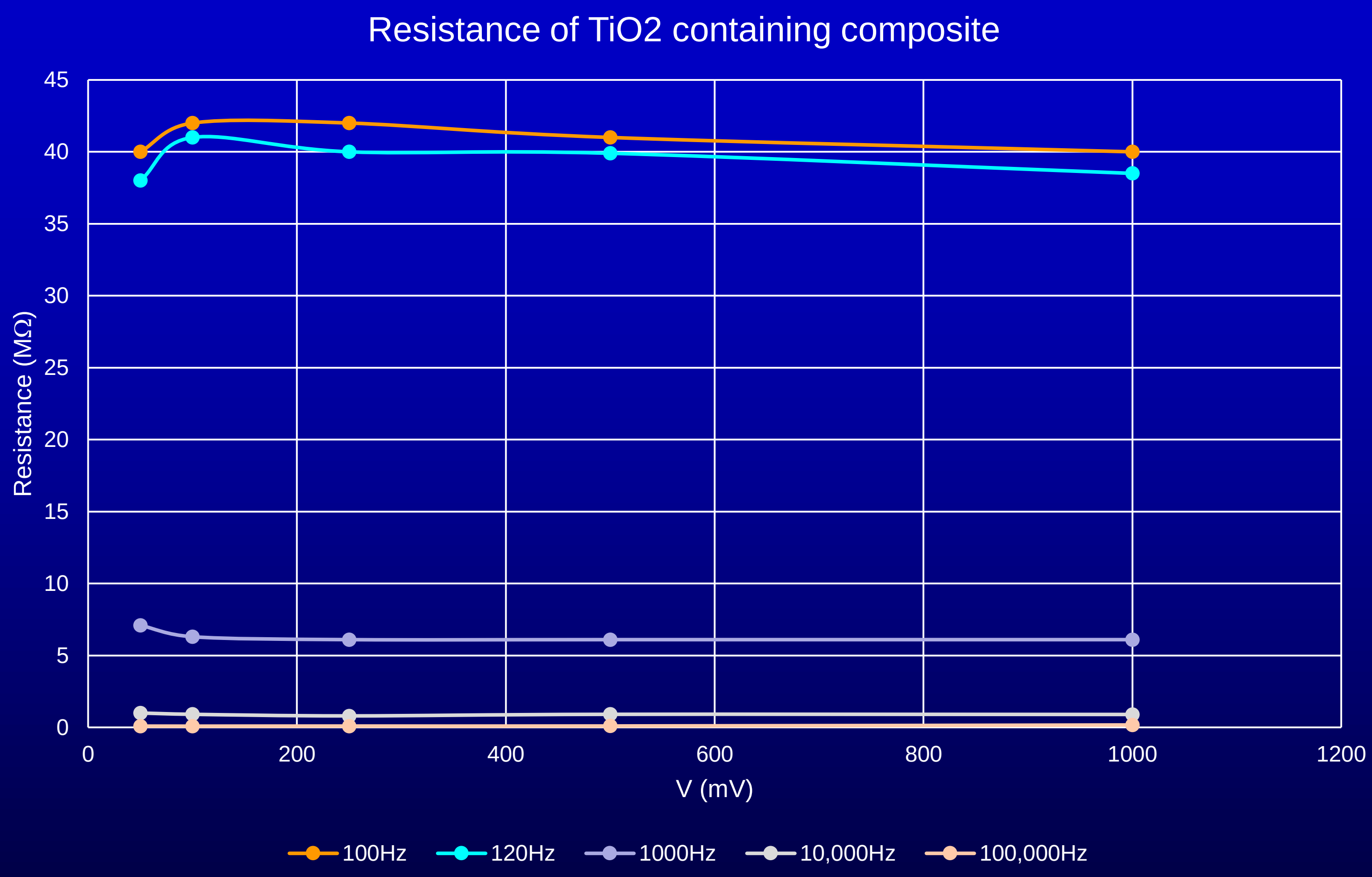
Addition of TiO_2 increased the hardness, but decreased the sensitivity

Resistivity of NiO_2 composite



There is no tunability as function of voltage

Resistivity of TiO_2 doped composite: TiO_2 raises the resistivity and hence lowers the sensitivity



There is no tunability as function of voltage

Effect of organic matrix and dopants

- TiO_2 had pronounced effect on performance
- I-V curves showed similar behavior at all frequencies
- Current at certain voltage were higher for frequencies
- Ionizing organics have different sensitivity for identical doping
- Processing is very important for the sensitivity
- Effect of particle size on sensitivity is to be studied

Effect of parameters are unknown on sensitivity

Summary

- Ionizing organics have significant advantage
- Commercial source Cs-137 for was used radiation for testing the composite
- It was clear that we observed very significant difference in as prepared sample and radiated sample.
- The data on γ-radiation interaction with the composite showed that I-V exhibits a linear response that can be used in the development of real-time radiation sensors for the low γ-ray dose range.
- All samples showed higher resistivity after γ-radiation.
- The ionic organic ethylene carbonate is a low melting material and has some problems for applications above 38^{o}C.
- We are performing experiments with other organic matrix materials suitable for applications above 50^{o}C and increase mechanical hardness of the composite.

Other ionic organics show similar effect with better mechanical propertie

Thank you for your attention

Topic