



# **Whisker growth on Sn thin film accelerated under gamma-ray induced electric field**

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# Outline

- Introduction
- Preliminary studies
- Experimental details
  - Samples
  - Irradiation source  $^{192}\text{Ir}$  specs
- Results: SEM images, whisker density, and whisker length
- Conclusions

# Introduction

- We have previously investigated the effect of high-energy electron beam irradiation on whisker kinetics
- Evaluate the effect of  $\gamma$ -ray irradiation on whisker kinetics
  - One report of whisker growth on Sn-plated surface irradiated under 50keV x-rays, published ~50 years ago
- Possibility of developing non-destructive accelerated life-testing tool

# Previous results: irradiation with 6MeV electron beam

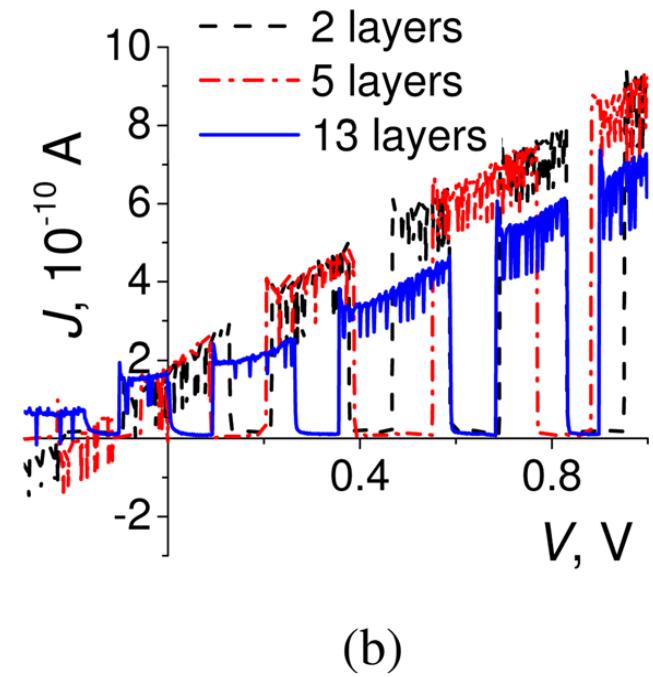
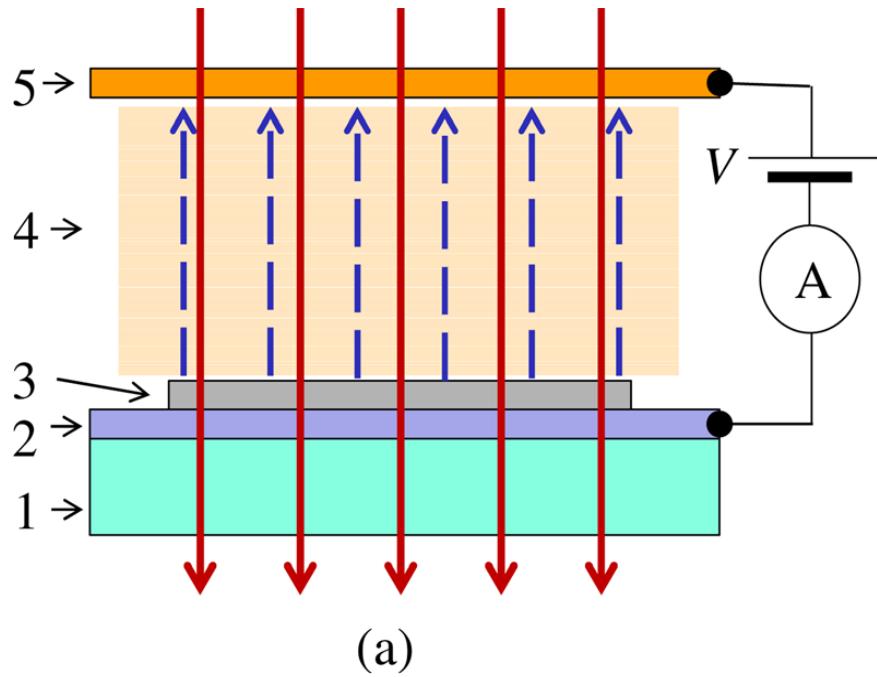


- Samples irradiated under 6MeV electron beam of clinical linear accelerator
  - Sn thin films (~300 nm) on glass
  - Zn-plated steel floor samples (NASA computation center, courtesy of J. Brusse) placed on acrylic slab

# Previous results: irradiation with 6MeV electron beam

- Irradiation time 10-20 hours in sessions, to achieve dose 10-20kGy (SI unit of dose 1 Gy=1J/kg)
- Observed enhancement in whisker growth and whisker lengths in irradiated samples compared to control samples
- Acceleration ratios ~200 found
- Main mechanism: substrate charging under electron beam
- Electrical measurements showed **charging present only during irradiation**

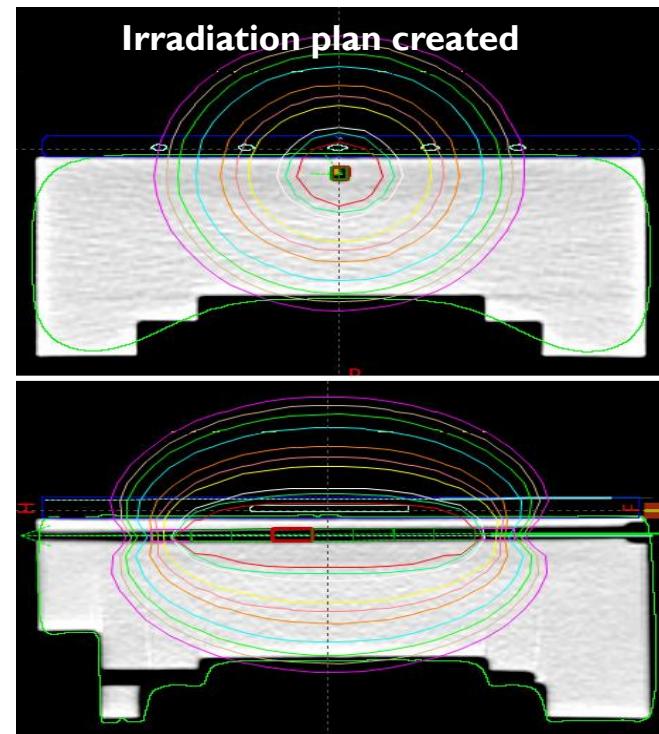
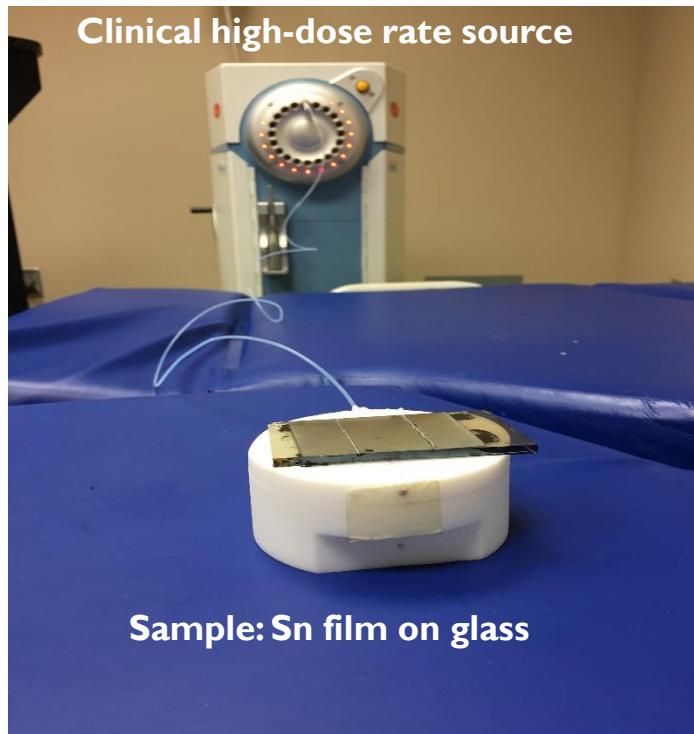
# Previous results: irradiation with 6MeV electron beam



(a) Sketch of the experimental setup for electrical characterization of sample charging: downward arrows represent the primary electron beam; upward arrows show the measured current of secondary electrons from the sample. The layers represent: 1-glass substrate, 2-conductive oxide, 3-tin, 4-spacer filled with plastic sheets, and 5-second (foil) electrode.

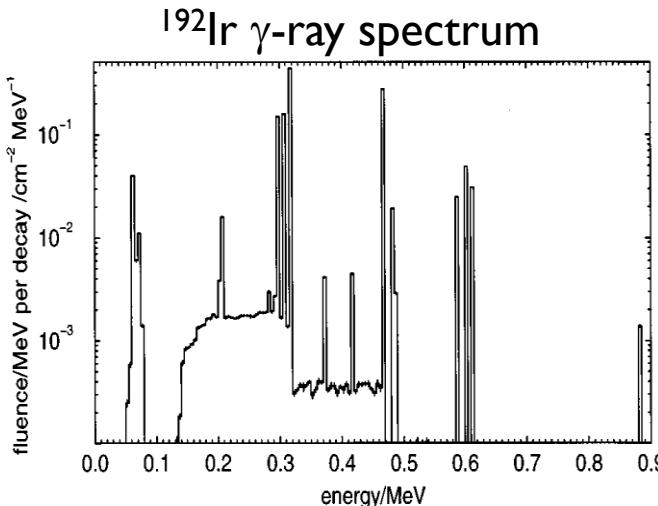
(b) Current-voltage characteristics of the structure in (a) for different insulating spacers. The beam was repeatedly turned on and off, leading to the gaps (beam off) in the plots.

# Irradiation under Ir-192 source

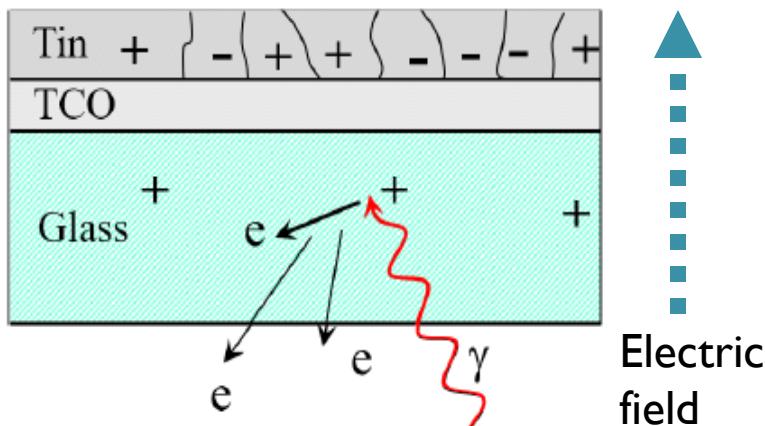


- A small (~5mm) encapsulated radioactive source is attached to a wire and moves along a catheter
- Dwells in pre-planned locations, a line source irradiation geometry
- The dose (10 to 20kGy) was delivered in multiple irradiation sessions of 2-4 hours per 1kGy

# Irradiation under Ir-192 source



$^{192}\text{Ir}$  also emits  $\beta$ -particles, which are absorbed in source encapsulation



- Source average energy  $\sim 380\text{keV}$
- Sn film thickness is too small to have significant number of interactions
- In 3mm thick glass  $\sim 7\%$  of  $\gamma$ -rays interact
  - Compton scattering is predominant
  - Some photoelectric effect processes
- Result: substrate charging and electric field in direction perpendicular to the film surface

# Irradiation under Ir-192 source: are atomic displacements possible?

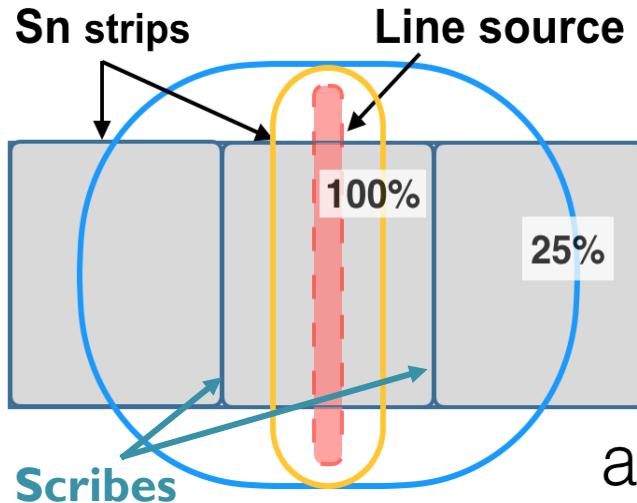
- The gamma rays average energy  $\sim 0.38$  MeV, maximum energy  $< 1$  MeV
- The average Compton electron energy is  $\sim 40\%$  of the maximum photon energy
- The energy transferred to an atom (mostly due to the Compton effect) is lower than the electron energy by  $\sim 4 \times 10^{-6}$  (the ratio of the electron to atom masses). Consequently, the atom receives  $< 4$  eV
- The energy is well below the displacement threshold energy estimated for Sn as 22.2 eV
- Other mechanisms of energy transfer are even less efficient

**No atomic displacements in Sn film  
under  $\gamma$ -ray irradiation**

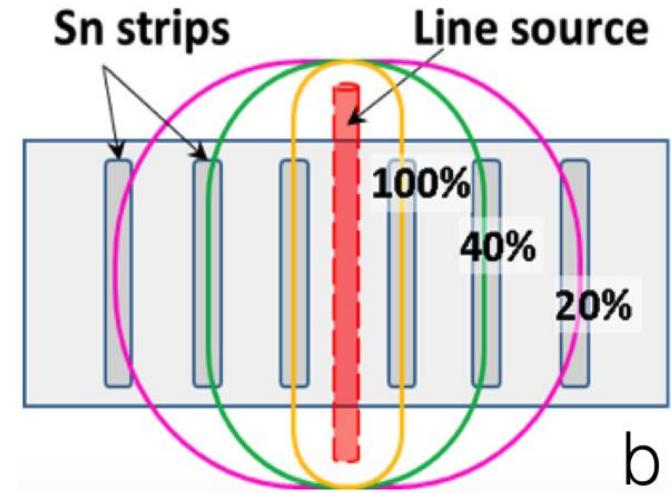
# Sn film samples

- Two Sn thin film samples studied
  - Vacuum evaporated at RT
  - RF-sputtered at RT
- Sn thickness ~250-300 nm
- Deposited on 3mm-thick soda-lime glass covered with transparent conducting oxide (TCO, specifically,  $\text{SnO}_2:\text{F}$  with nominal 15 Ohm/square sheet resistance; TEC-15 glass from Pilkington)

# Sample and irradiation geometry



For a line source dose falls off with distance  $r$  as  $1/r$



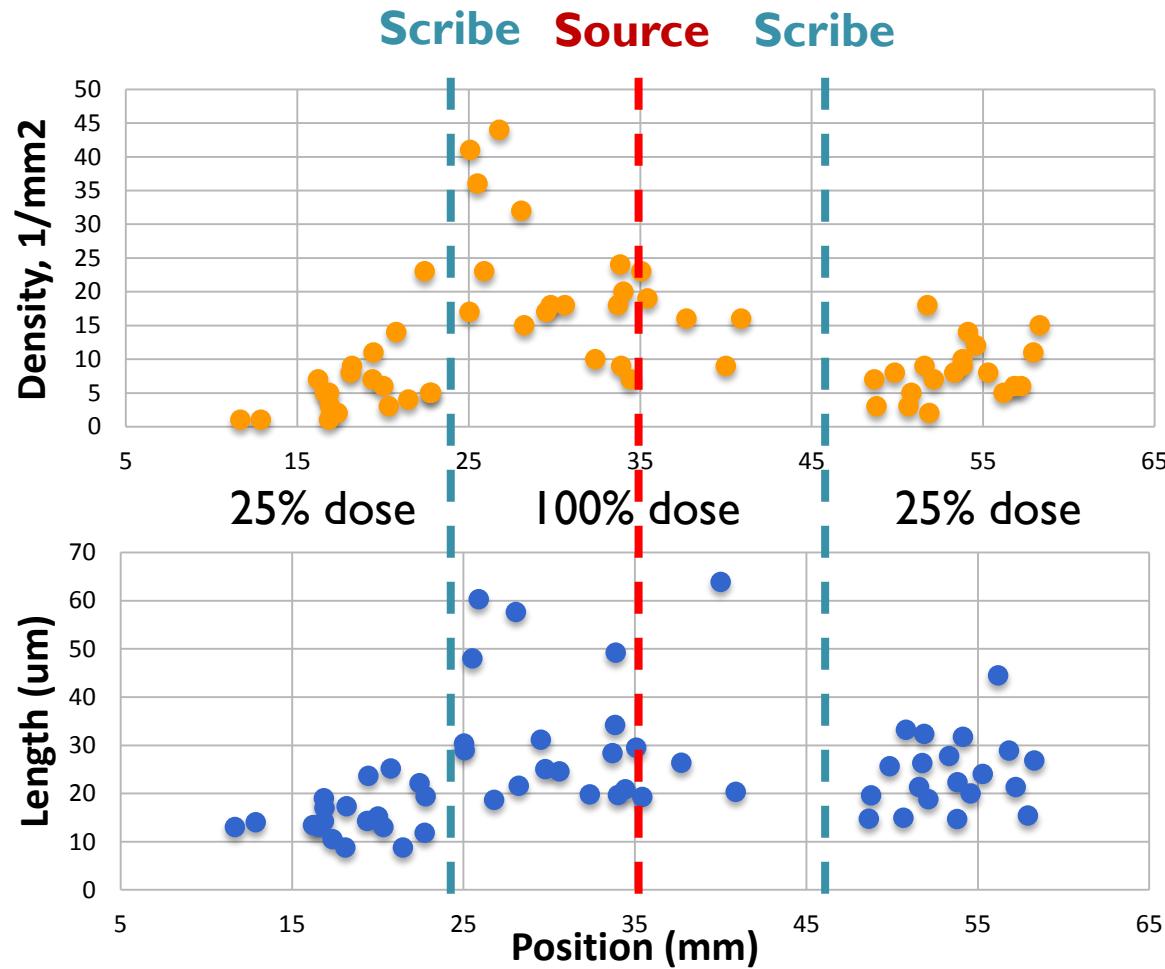
## Sample 1 – disconnected strips

- Continuous Sn film/TCO scribed
- Scribe lines define central area exposed to 100% dose and two side areas 25% dose

## Sample 2 – connected strips

- Sn film deposited in strips/TCO continuous
- Sn strips exposed to 100%, 40%, and 20% dose levels

# Results: Sample I on glass/ scribed TCO



Whisker density  
after 10kGy

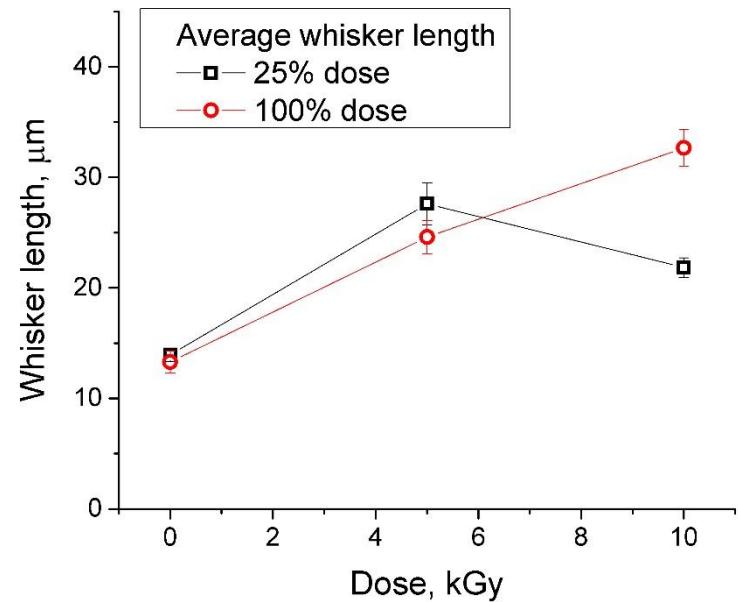
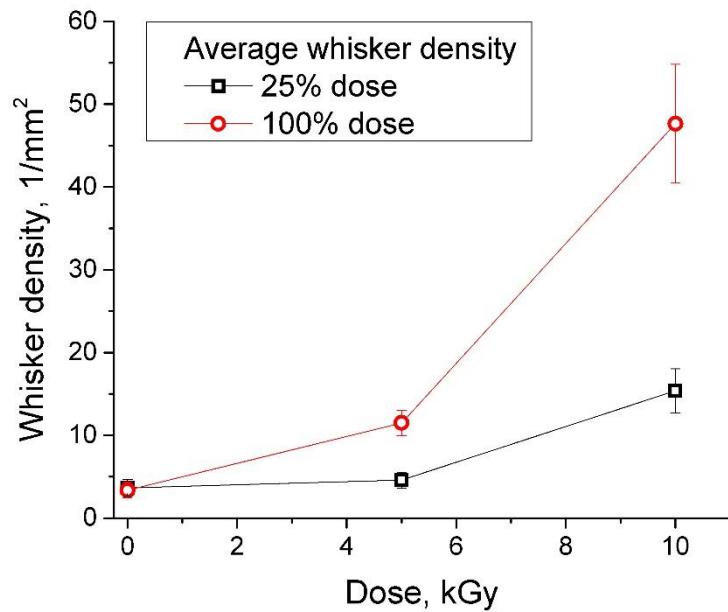
Whisker length  
after 10kGy

# Results: Sample I on glass/scribed TCO

	Irradiated sample, 25%		Irradiated sample, 100%	
Dose, kGy	Whisker density, #/mm <sup>2</sup>	Whisker length, µm	Whisker density, #/mm <sup>2</sup>	Whisker length, µm
0	3.63±1.02	13.94±0.62	3.36±0.95	13.30±1.01
5	4.60±0.97	27.60±1.90	11.49±1.52	24.59±1.51
10	15.39±2.66	21.84±0.89	47.65±7.18	32.65±1.67

- Sample had whiskers before irradiation (stored on the shelf for several months)
- Correlation between dose and whisker enhancement

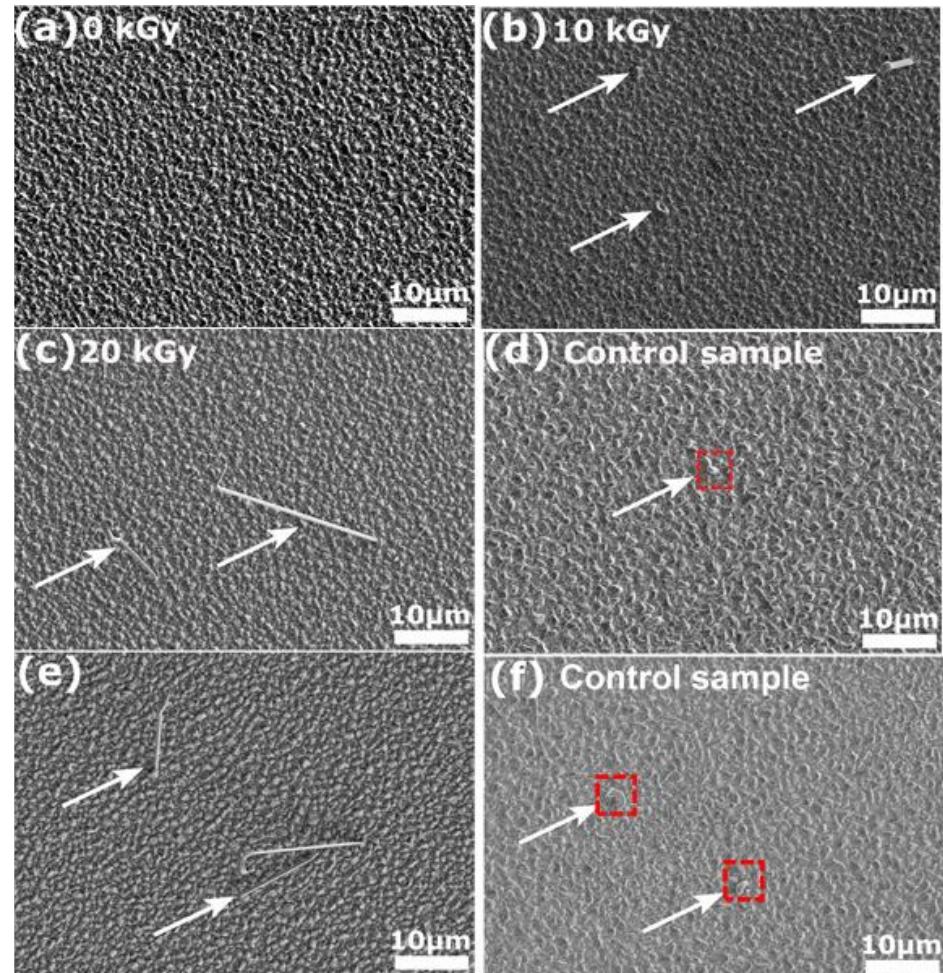
# Results: Sample I on glass/scribed TCO



- Data from the table are plotted
- Correlation between dose and whisker enhancement

# Results: Sample 2 on glass/continuous TCO

- Irradiated sample imaged
  - after deposition (before irradiation)
  - after 10kGy
  - after 20kGy
  - after 20kGy+30 days on the shelf
- Control sample imaged
  - after deposition,
  - after 30 days shelf
  - and 60 days shelf



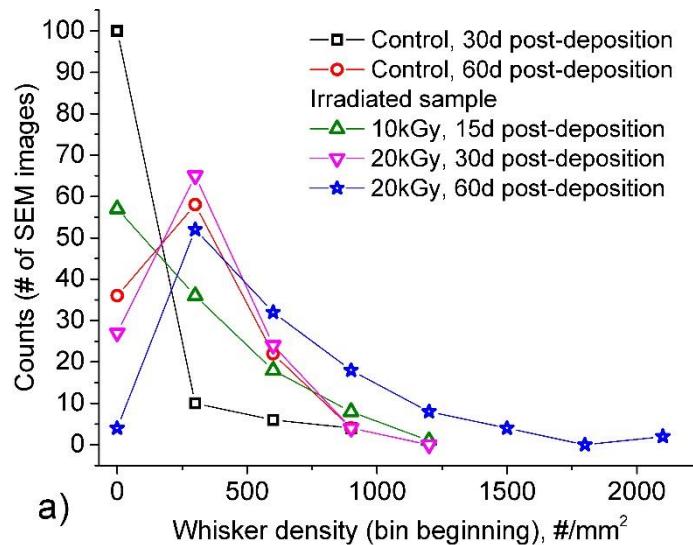
# Results: Sample 2 on glass/continuous TCO

Irradiated sample				Control sample		
Time	Dose, kGy	Whisker density, #/mm <sup>2</sup>	Whisker length, μm	Time, days	Whisker density, #/mm <sup>2</sup>	Whisker length, μm
30 hrs	10	282.65±31.74	2.57±0.12	0	0	0
60 hrs	20	377.86±25.35	4.98±0.42	35	101.16±32.69	0.75±0.02
60 hrs +30days	20	696.22±40.54	6.5±0.47	60	339.18±36.12	1.99±0.12

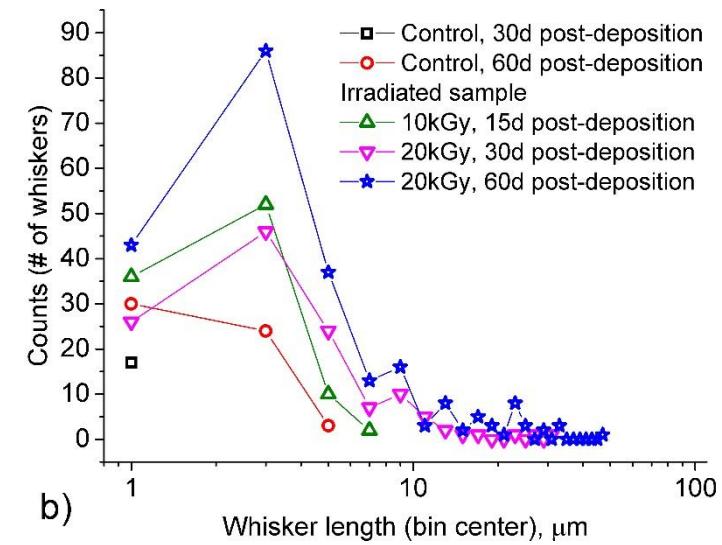
- Both whisker density and lengths were accelerated under irradiation
- No correlation between dose distribution and whisker enhancement

# Results: Sample 2 on glass/continuous TCO

Whisker density



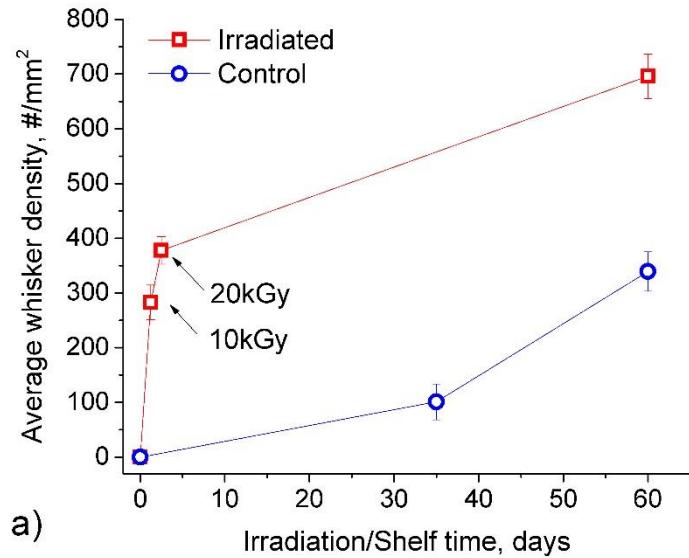
Whisker length



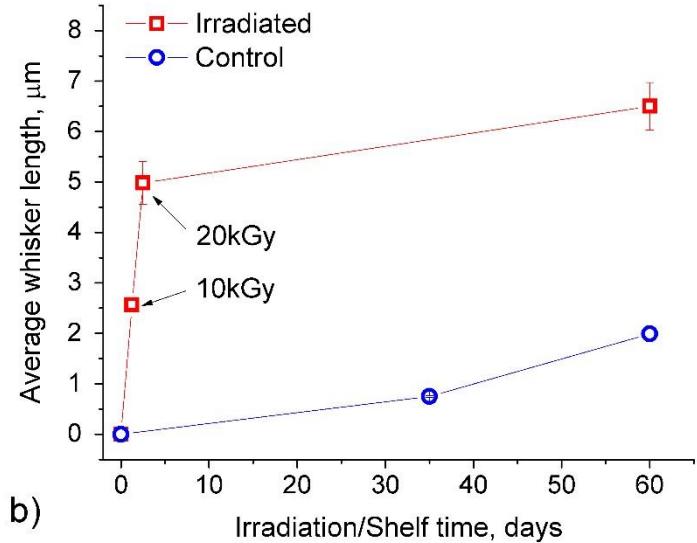
- Frequency counts irradiated vs. control
- Both whisker density (a) and whisker lengths (b) were significantly enhanced under irradiation

# Results: Sample 2 on glass/continuous TCO

Whisker density



Whisker length



- Temporal evolution irradiated vs. control
- Both whisker density (a) and whisker lengths (b) were significantly enhanced under irradiation

# Acceleration factor

- To quantify the effect of electric field on whisker growth we use whisker creation rate

$$R = \frac{\text{whisker density}}{\text{time}}$$

- Distinguishing between E-field stimulated  $R_{STIM}$  and spontaneous  $R_{SPON}$  whisker growth rates, define *acceleration ratio*

$$a \equiv \frac{R_{STIM}}{R_{SPON}}$$

- For our experiment irradiation time to 20kGy dose  $t_R=60\text{hrs}$ , and shelf time for control  $t_S=35\text{days}=840\text{hrs}$ ,  
 $a=(378/60)/(101/840) \approx 52$

# Summary of observed correlations vs. sample type

Sample	Radiation dose	
	Local dose	Average dose
Connected strips	No	Yes
Disconnected strips	Yes	Yes

- Average radiation dose correlates with whisker growth through induced electric field
- Field distribution depends on sample: connected cells/strips are equipotential

# Conclusions

- Observed effect of accelerated Sn whisker growth under  $\gamma$ -ray irradiation: both whisker densities and lengths are greatly enhanced
- Attributed to generation of electric charges in the insulating glass substrate supporting the Sn thin films. The charges create an electric field perpendicular to the film surface, providing conditions conducive to electrostatically driven whisker growth
- Field distribution depends on the sample: connected (e.g., through TCO underneath) cells/strips are equipotential
- The field acts mostly at the nucleation stage by diminishing the whisker nucleation barrier
- The observed acceleration factor of  $\sim 50$ ; higher values are achievable
- Promising as a non-destructive readily implementable accelerated life testing tool for whisker propensity

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