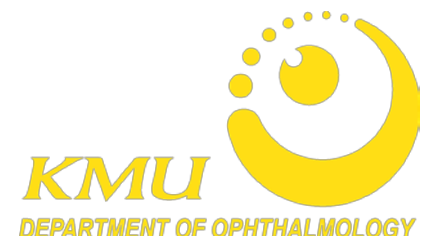


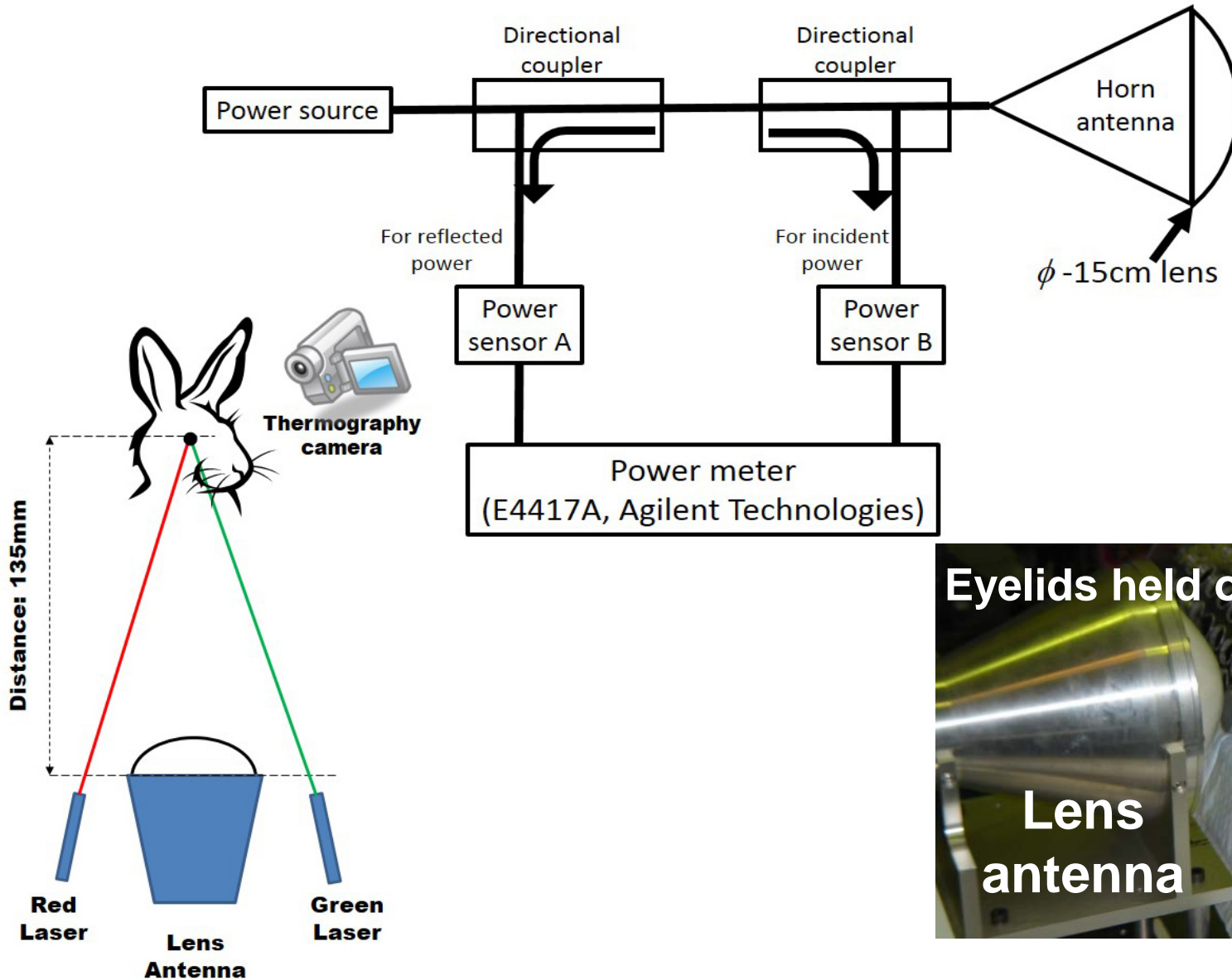
# Ocular Studies of EMF Exposure at the MMW

**M. Kojima <sup>1,2,3)</sup>, Y. Suzuki <sup>4)</sup>**

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2. Department of Ophthalmology, Kanazawa Medical University
3. School of Nursing, Kanazawa Medical University
4. Department of Electrical Engineering and Computer Science, Tokyo Metropolitan University



# MMW Exposure System



Eyelids held open with tape

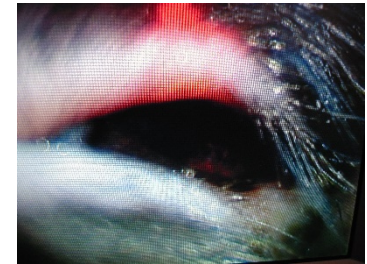
Lens antenna

# Exposure Conditions (aversive behavior control)

## ➤ Eyelids unrestrained



Before exposure



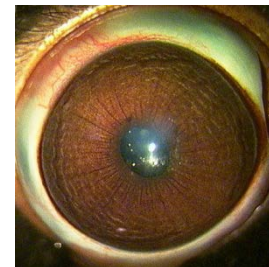
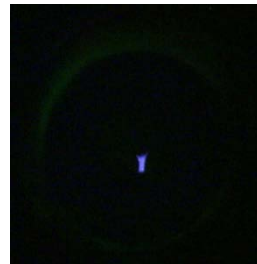
After start of exposure

## ➤ Eyelid edema occurs, but no ocular damage

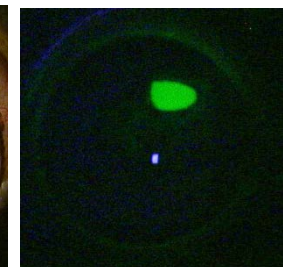
(Ex. 75 GHz 200 mW/cm<sup>2</sup> 6 min 1 day after exposure)



Eyelids unrestrained



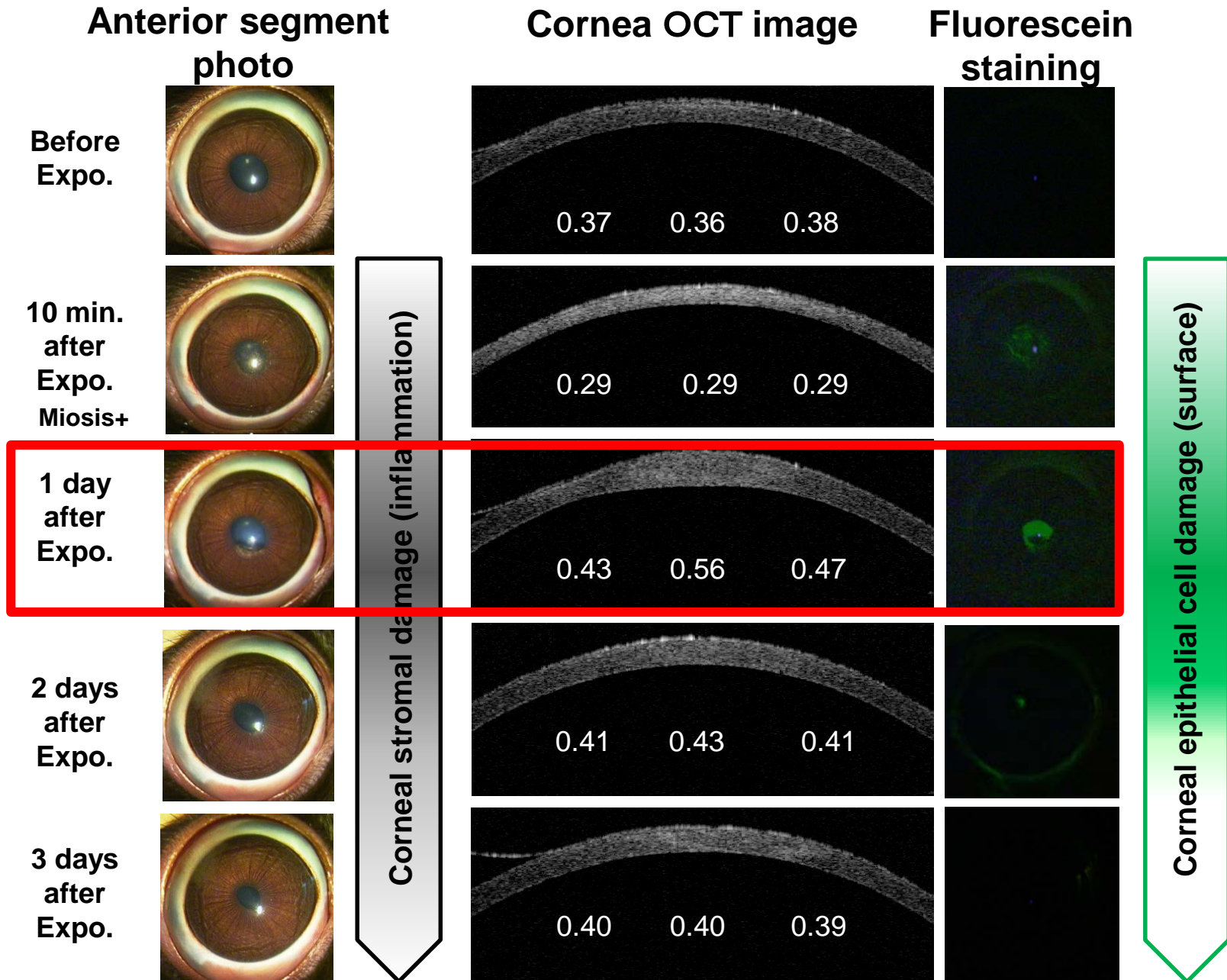
Eyelids held open with tape



## ➤ Without control of aversive behavior

Without control of aversive behavior, ocular the damage threshold depends on by the skin hazard threshold.

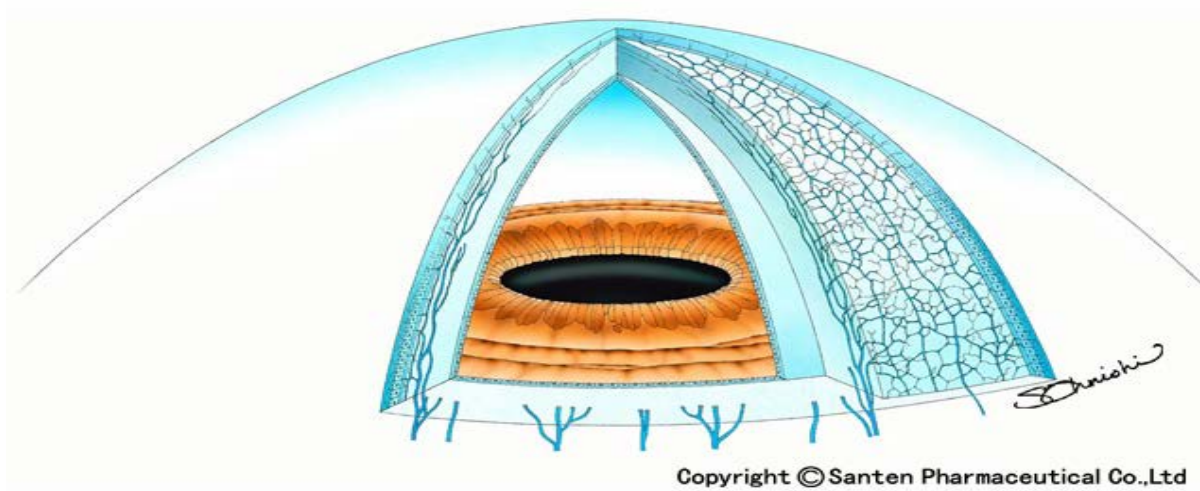
# Representative Ocular Damages by 75 GHz 200 mWcm<sup>2</sup> Exposure



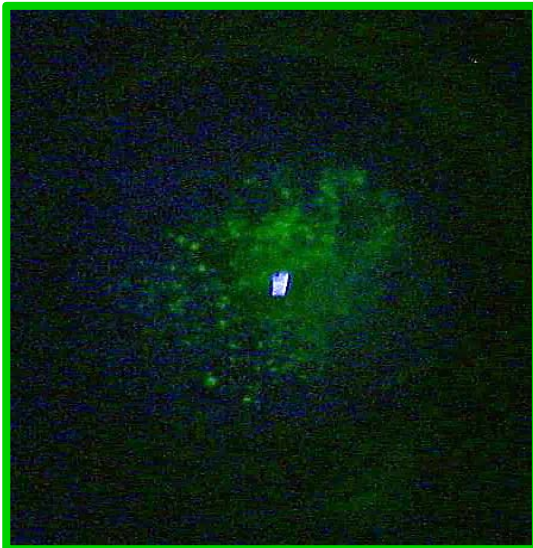


# Confocal Laser Scanning Microscopy Findings

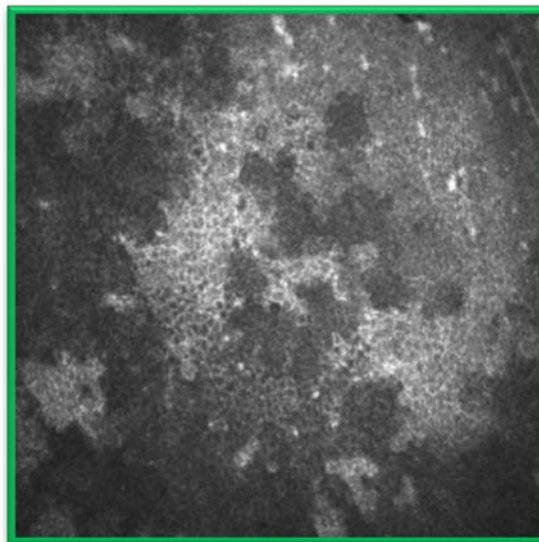
Immediately after 40 GHz, 600 mW/cm<sup>2</sup> exposure



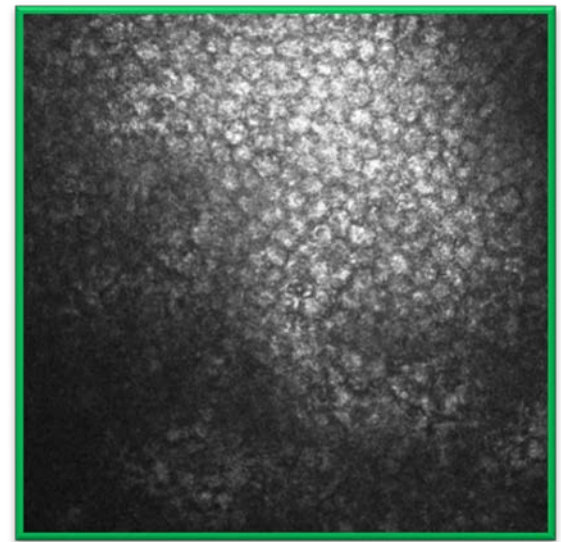
**Fluorescein  
Staining**



**Corneal Epithelial  
Layer**



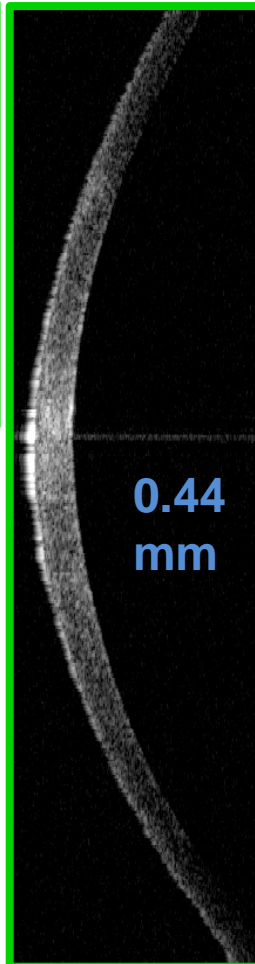
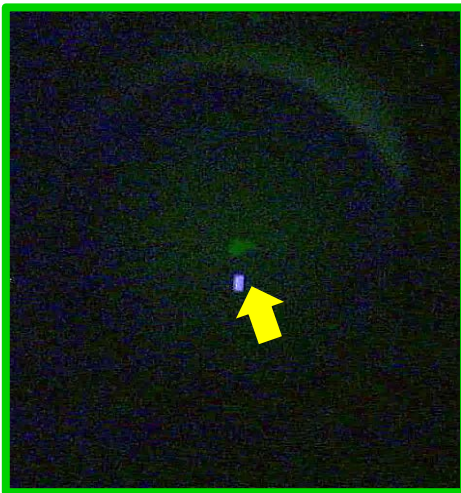
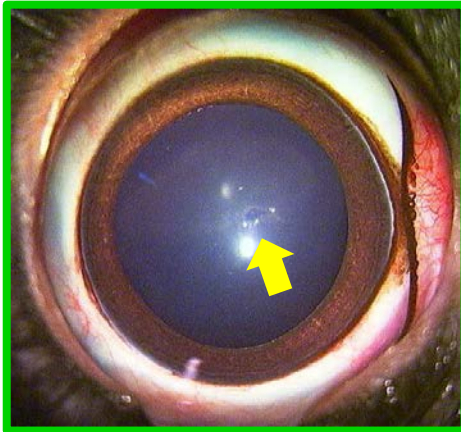
**Corneal Endothelial  
Layer**



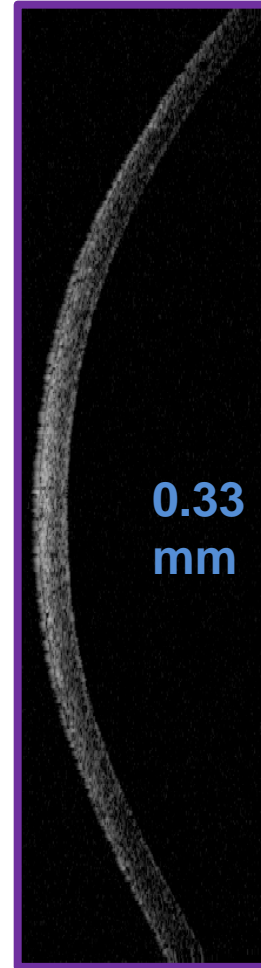
# Four Days after 40 GHz, 600 mW/cm<sup>2</sup> Exposure

**Exposed**

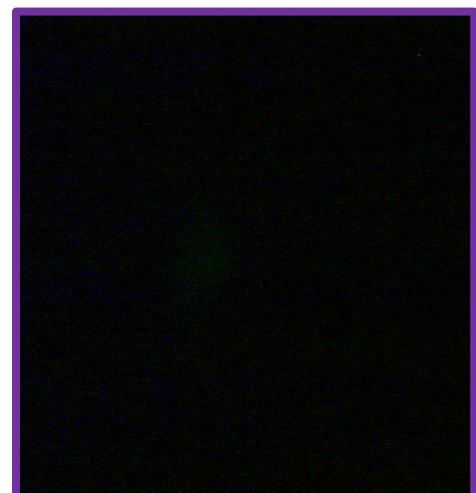
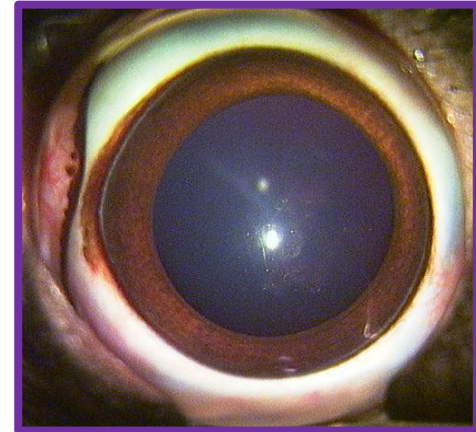
**Non-exposed**



0.44  
mm



0.33  
mm

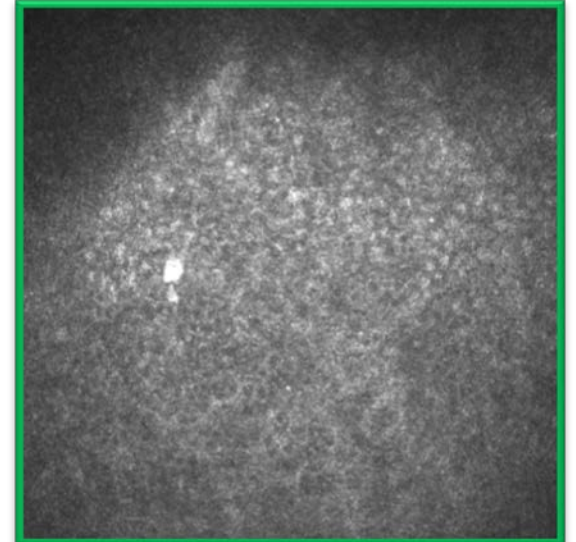
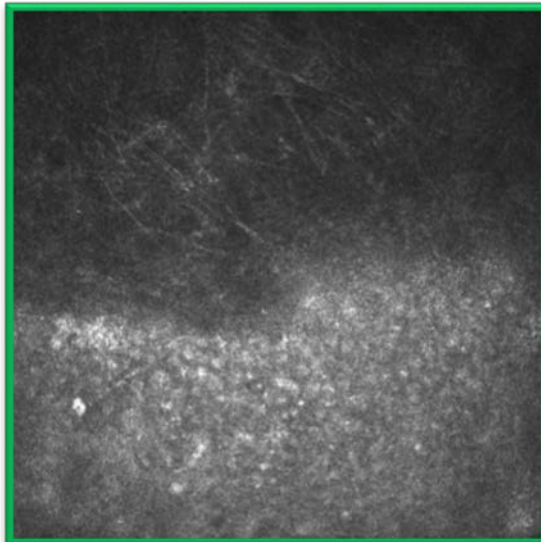
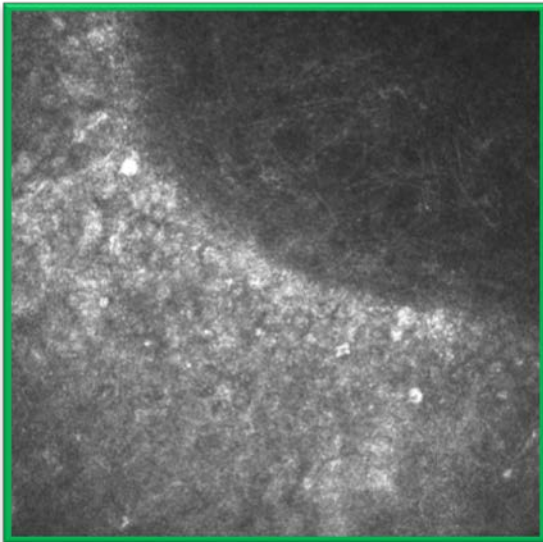
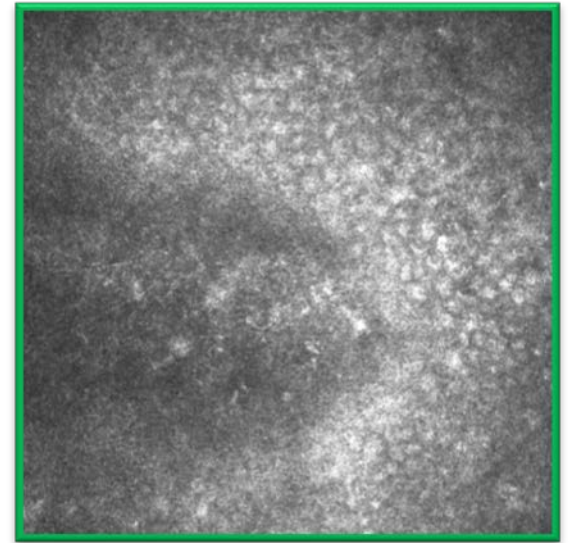
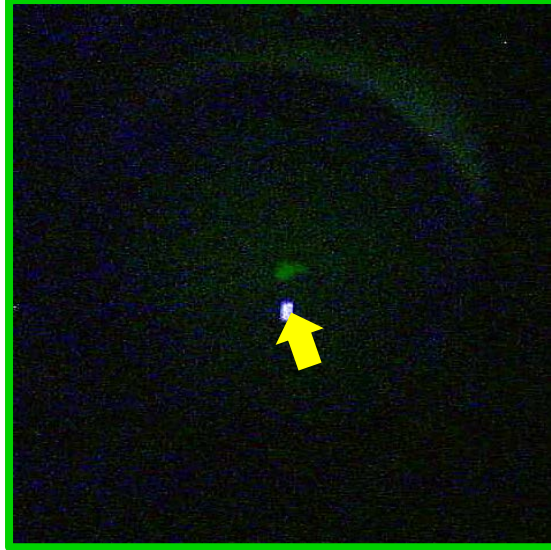




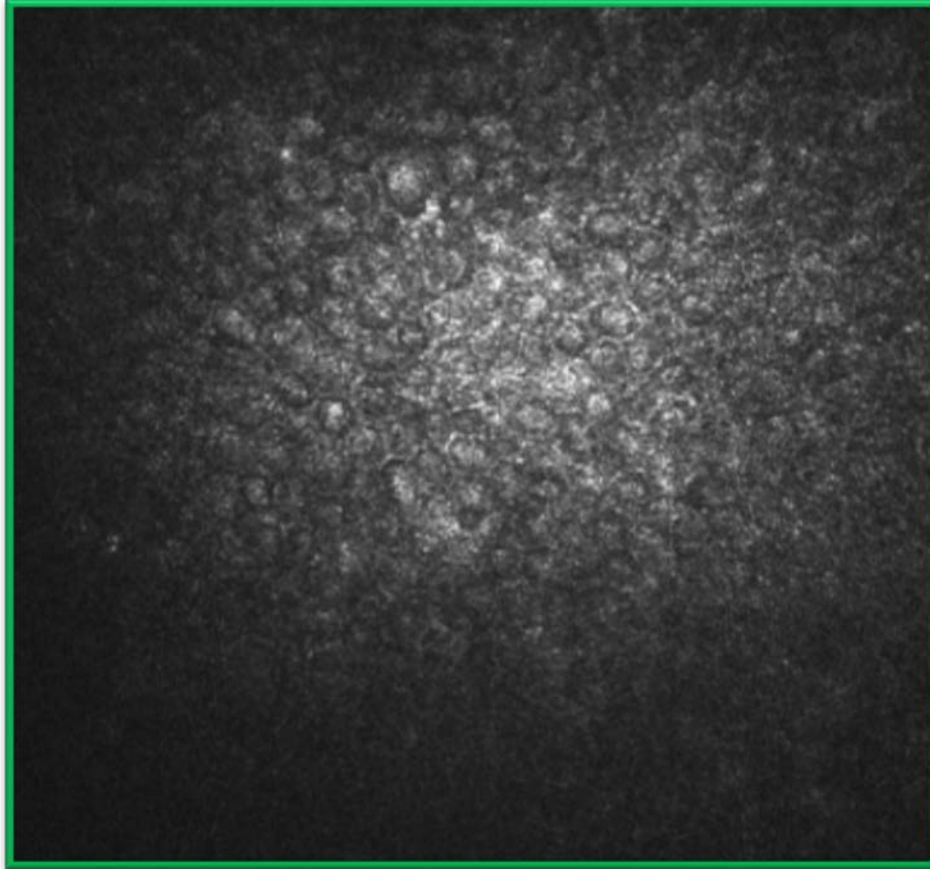
# Confocal Laser Scanning Microscopy Findings

Four days after 40 GHz, 600 mW/cm<sup>2</sup> exposure: epithelial layer

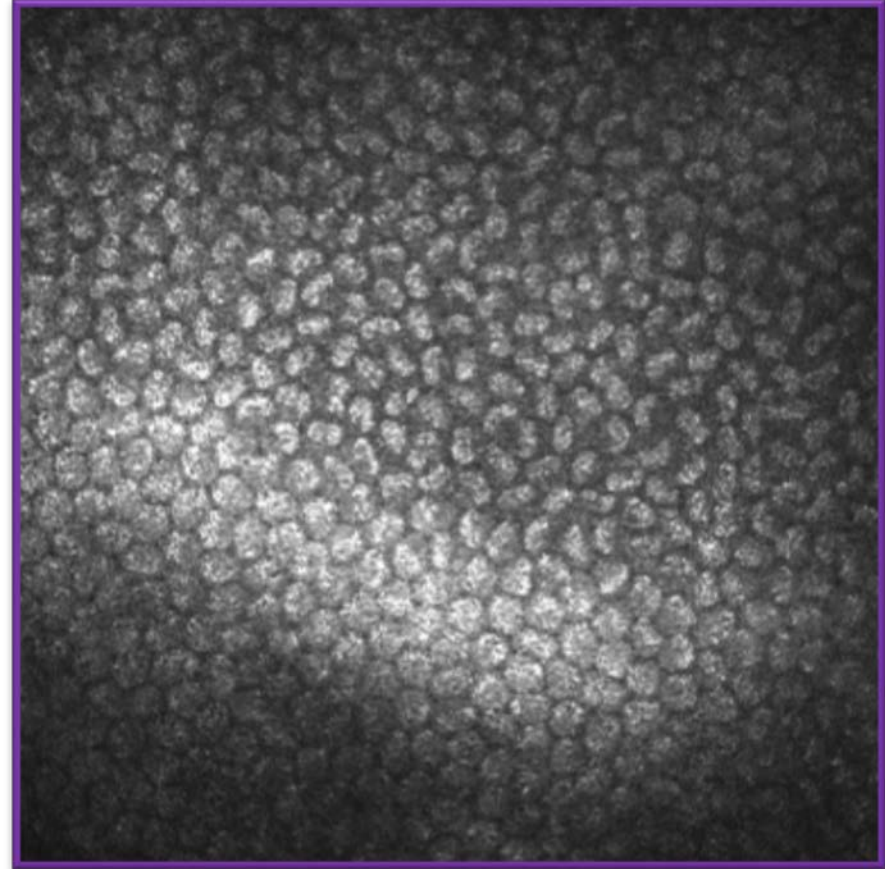
**Exposed**



# Four Days after 40 GHz, 600 mW/cm<sup>2</sup> Exposure : endothelial layer



Exposed

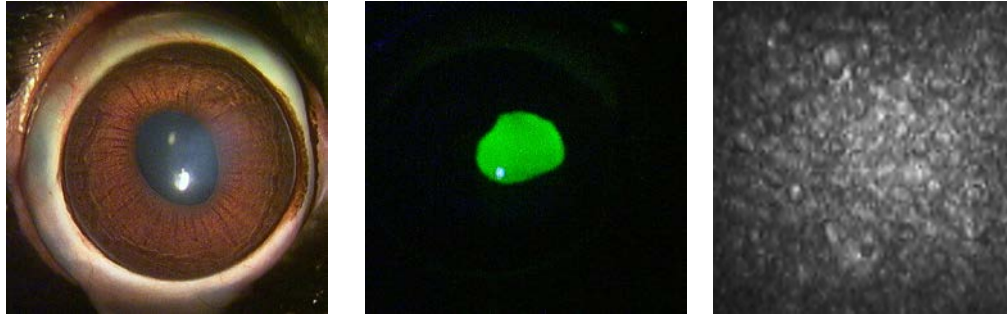


Non-exposed



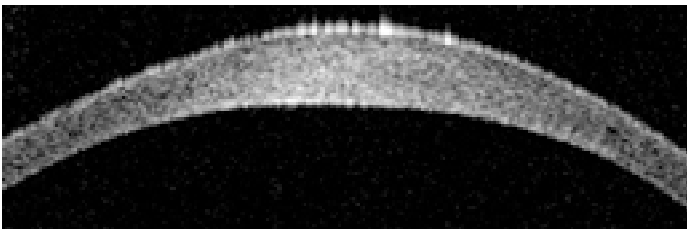
# Summary of MMW Induced Corneal Damages

- **MMW (40 GHz, 600 mW/cm<sup>2</sup>, 6 min) did not induce any marked corneal endothelial cell damage.**



**Corneal disorder resulted primarily from corneal epithelial cell death induced by MMW exposure.**

- **Epithelium and endothelium damage showed different directions of corneal swelling.**



**MMW exposure:  
Convex to epithelium side**



**Glaucoma attack:  
Convex to endothelium side**

# Ocular Effects of Exposure to 40, 75, and 95 GHz Millimeter Waves

**M. Kojima <sup>1,2,3)</sup>, Y. Suzuki <sup>4)</sup>, K. Sasaki <sup>5)</sup>, M. Taki <sup>4)</sup>  
K. Wake <sup>5)</sup>, S. Watanabe <sup>5)</sup>, M. Mizuno <sup>5)</sup>  
T. Tasaki <sup>6)</sup>, H. Sasaki <sup>1,2)</sup>**

**J Infrared Milli Terahz Waves**  
**DOI 10.1007/s10762-018-0497-z**



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4. Department of Electrical Engineering, Tokyo Metropolitan University
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6. Division of Protein Regulation Research, Medical Research Institute, Kanazawa Medical University

# Methods

- Rabbits were exposed to MMWs at frequencies of 40, 75, and 95 GHz for 6 minutes.
- One day after exposure, morphological changes in the cornea were assessed by slit-lamp microscopy (including fluorescence staining) and optical coherence tomography.
- Dose-response data of corneal injury (corneal epithelium damage, corneal opaque, and corneal edema) at each frequency were obtained by experiments in the range of power density.



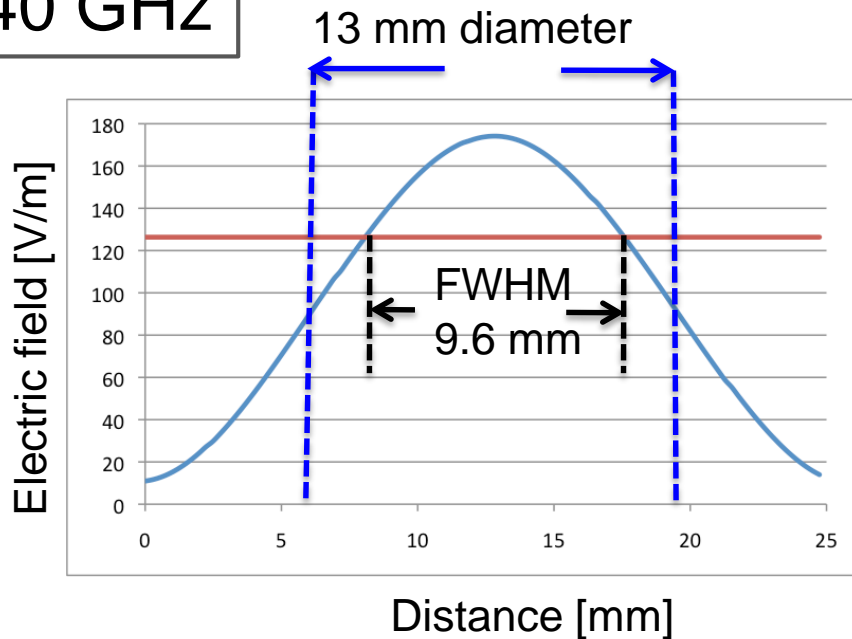
# MMW Exposure

Incident power density: Power density averaged over a 13-mm-diameter circle corresponding to the area of the ocular surface exposed to the ambient air.

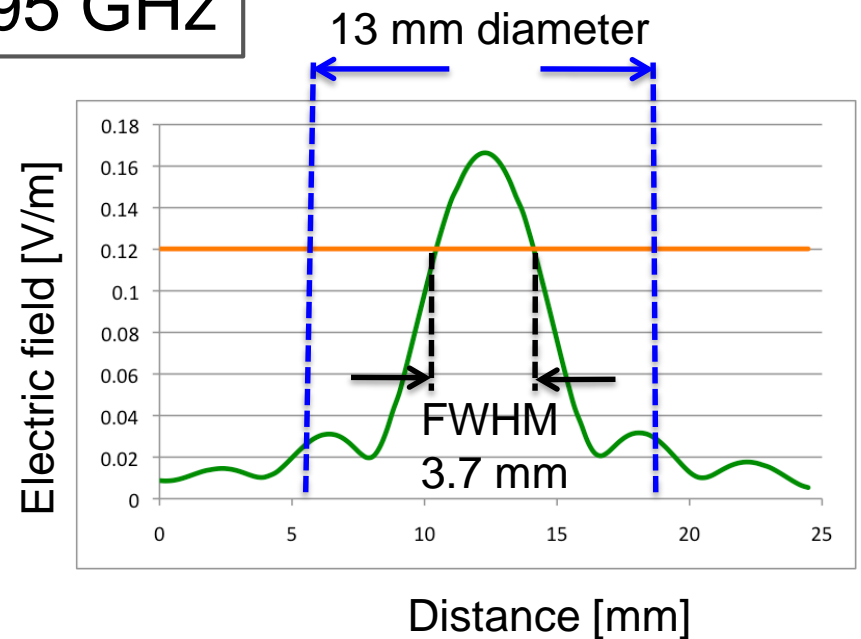
## Beam profile

FWHM: full width at half maximum

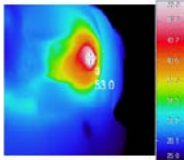
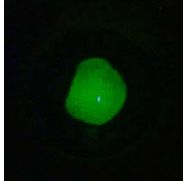

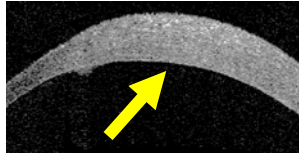
40 GHz



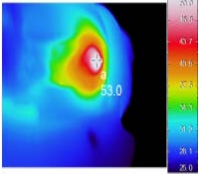
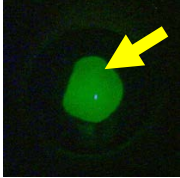
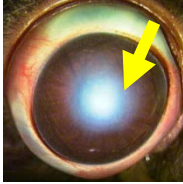
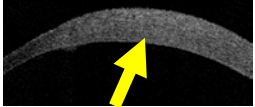
95 GHz



# Damage by 40 GHz Exposure

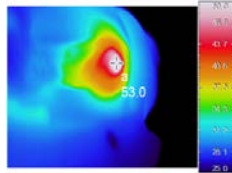
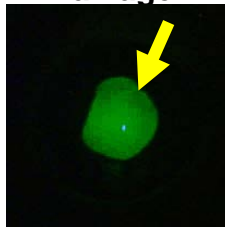
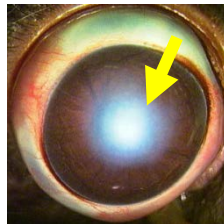
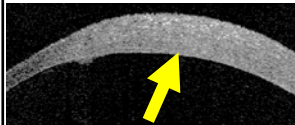
<b>40 GHz</b> <b>One day after exposure</b>	<b>Corneal Surface Temp. (°C)</b> 	<b>Corneal Epithelium Damage</b> 	<b>Corneal Opaque</b> 	<b>Corneal Edema</b> 
400 mW/cm <sup>2</sup> _6 min	43.9±3.6	<b>Damage + (6/8)</b>	<b>Damage + (5/8)</b>	<b>Damage + (5/8)</b>
300 mW/cm <sup>2</sup> _6 min	41.3±1.3	<b>Damage + (5/6)</b>	<b>Damage + (1/6)</b>	<b>Damage + (1/6)</b>
200 mW/cm <sup>2</sup> _6 min	41.3±1.5	<b>Damage+ (2/4)</b>	<b>No damage (0/4)</b>	<b>No damage (0/4)</b>
100 mW/cm <sup>2</sup> _6 min	37.1±2.7	<b>Damage+ (1/7)</b>	<b>No damage (0/7)</b>	<b>No damage (0/7)</b>
50 mW/cm <sup>2</sup> _6 min	33.6±1.8	<b>No damage (0/8)</b>	<b>No damage (0/8)</b>	<b>No damage (0/8)</b>

# Damage by 75 GHz Exposure

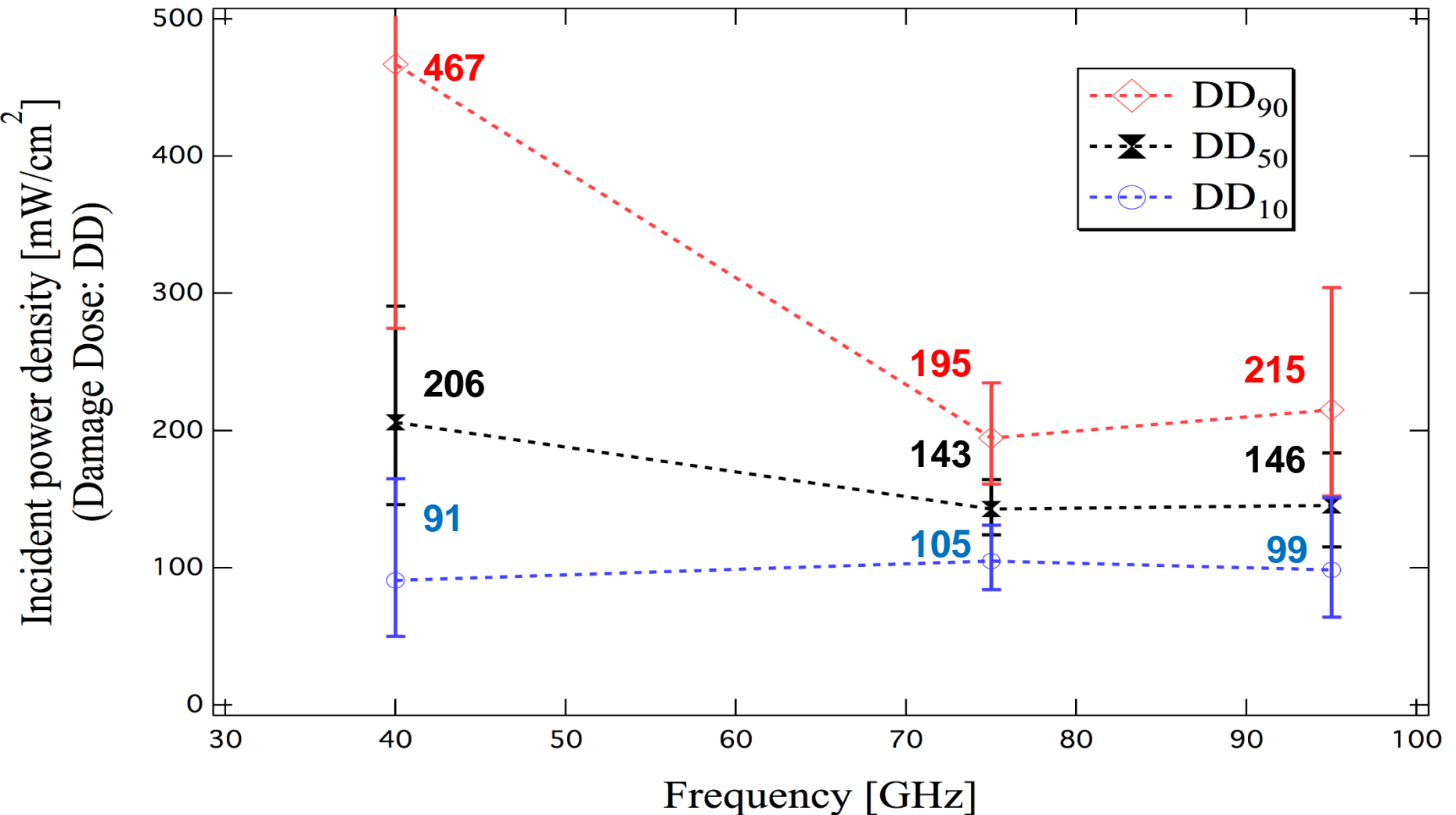
<b>75 GHz</b> <b>One day after exposure</b>	<b>Corneal Surface Temp. (°C)</b> 	<b>Corneal Epithelium Damage</b> 	<b>Corneal Opaque</b> 	<b>Corneal Edema</b> 
300 mW/cm <sup>2</sup> _6 min	50.7 ± 1.9	<b>Damage + (3/3)</b>	<b>Damage + (3/3)</b>	<b>Damage + (3/3)</b>
200 mW/cm <sup>2</sup> _6 min	43.8 ± 4.9	<b>Damage + (14/15)</b>	<b>Damage + (13/15)</b>	<b>Damage + (13/15)</b>
150 mW/cm <sup>2</sup> _6 min	43.1 ± 1.9	<b>Damage + (3/6)</b>	<b>Damage + (3/6)</b>	<b>Damage + (3/6)</b>
100 mW/cm <sup>2</sup> _6 min	40.2 ± 0.5	<b>Damage + (1/12)</b>	<b>No damage (0/12)</b>	<b>No damage (0/12)</b>
50 mW/cm <sup>2</sup> _6 min	37.6 ± 1.5	<b>No damage (0/7)</b>	<b>No damage (0/7)</b>	<b>No damage (0/7)</b>



# Damage by 95 GHz Exposure

95 GHz One day after exposure	Corneal Surface Temp. (°C)	Corneal Epithelium Damage	Corneal Opaque	Corneal Edema	
					
	300 mW/cm <sup>2</sup> _6 min	46.5±1.3	Damage+ (3/3)	Damage+ (2/3)	Damage+ (1/3)
	200 mW/cm <sup>2</sup> _6 min	43.7±1.7	Damage+ (11/13)	Damage+ (5/13)	Damage+ (6/13)
	100 mW/cm <sup>2</sup> _6 min	37.0±3.3	Damage+ (1/9)	No damage (0/9)	No damage (0/9)
50 mW/cm <sup>2</sup> _6 min	34.1±2.3	No damage (0/4)	No damage (0/4)	No damage (0/4)	

# Probability of Ocular Damage by Maximum Likelihood Estimation with Probit Analysis



# **Characteristics of Ocular Temperature Elevations after Exposure to Quasi- and Millimeter Waves (18-40 GHz)**



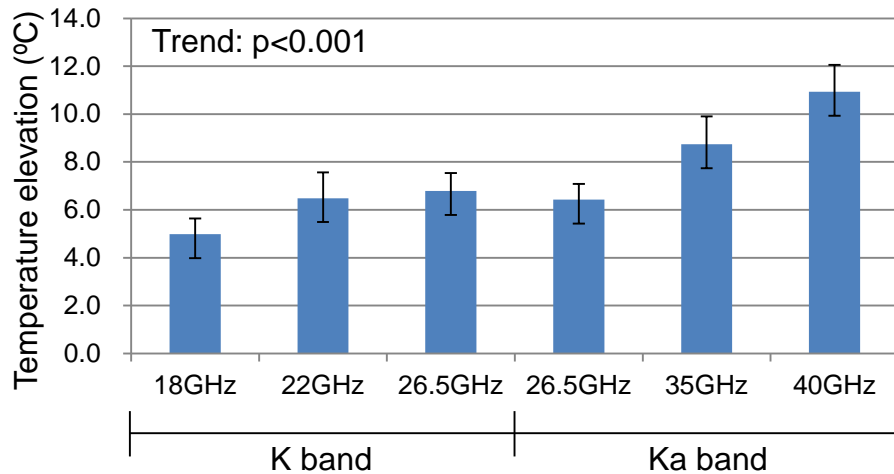
**M. Kojima, Y. Suzuki, C-Y, Tsai, K. Sasaki  
K. Wake, S. Watanabe, M. Taki,  
Y. Kamimura, A. Hirata, K. Sasaki, H. Sasaki**

**J Infrared Milli Terahz Waves  
DOI 10.1007/s10762-014-0142-4**

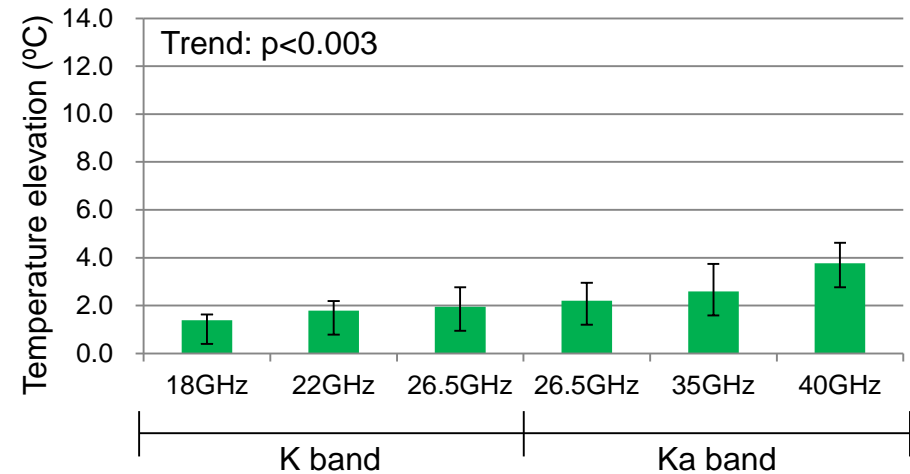


# Difference in Intraocular Temperature Rise by Frequency (200 mW/cm<sup>2</sup> exposure)

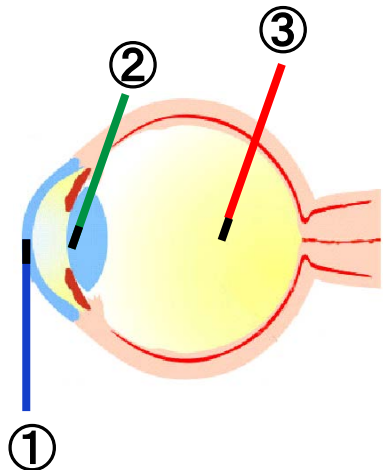
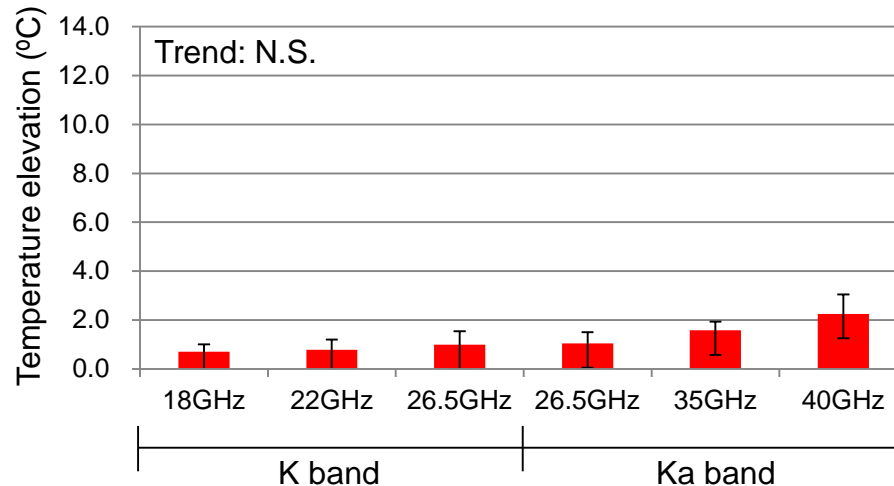
## Cornea



## Lens

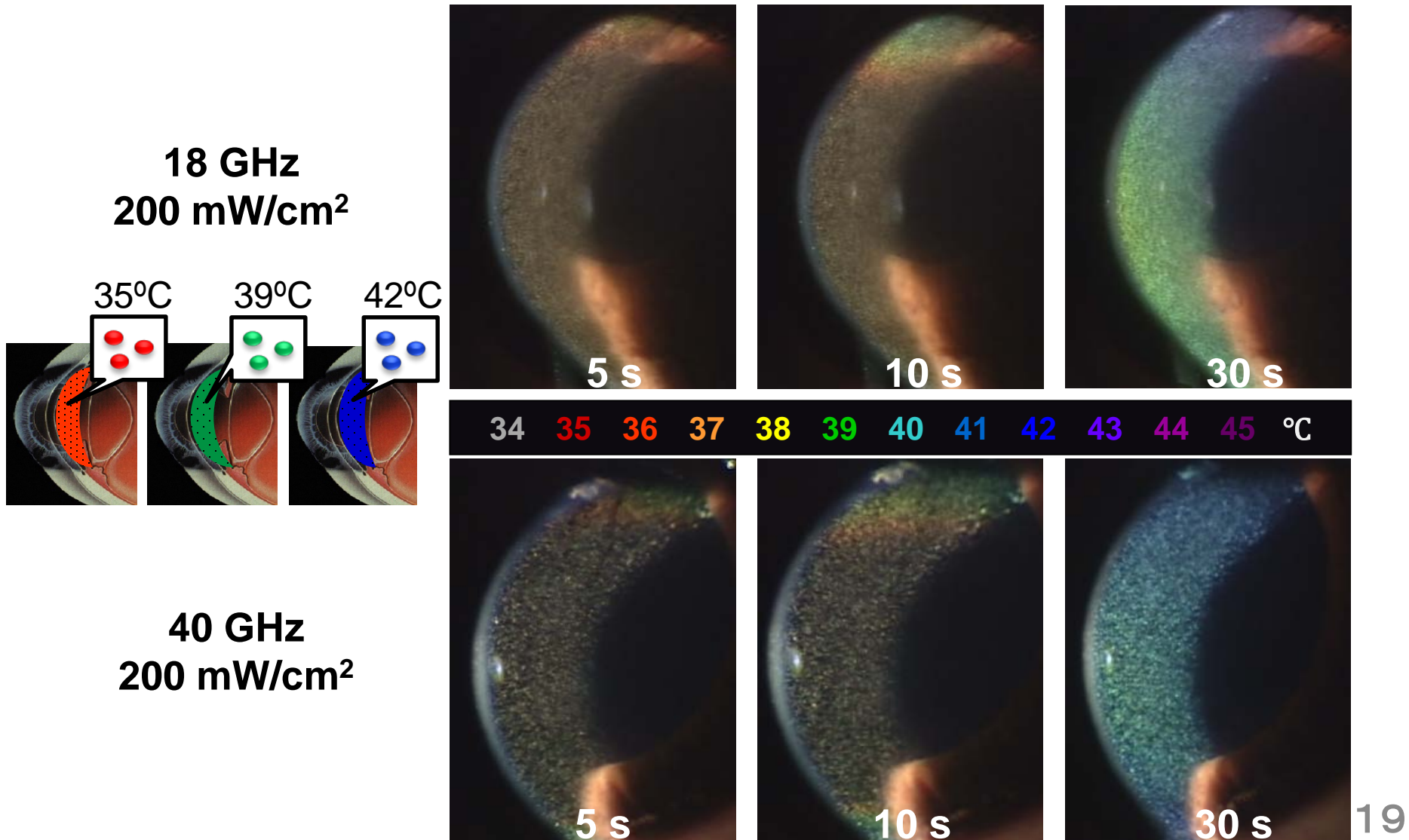


## Vitreous



# Comparison of Temperature Rise in the Anterior Chamber by Quasi-MMW & MMW (18 vs. 40 GHz)

Microencapsulated Thermochromic Liquid Crystals (MTLC) change color with temperature



# Summary

- Although ocular damage induced by 40 and 75 GHz did not differ greatly, ocular damage induced by 95 GHz was more localized and milder.
- Ocular damage thresholds among 40, 75 and 95 GHz in rabbit eye are affected by the following factors: MMW penetration depth, and heat transport in the eye including dissipation from the cornea.
- The highest ocular temperature was induced by 40 GHz MMW, followed by 35 GHz. The 26.5 and 22 GHz corneal temperatures were similar. The lowest temperature was recorded at 18 GHz.
- Corneal disorder resulted primarily from corneal epithelial cell death induced by MMW exposure, whereas corneal edema and corneal opacity were secondary findings to corneal epithelial cell death.

# **Acknowledgment**

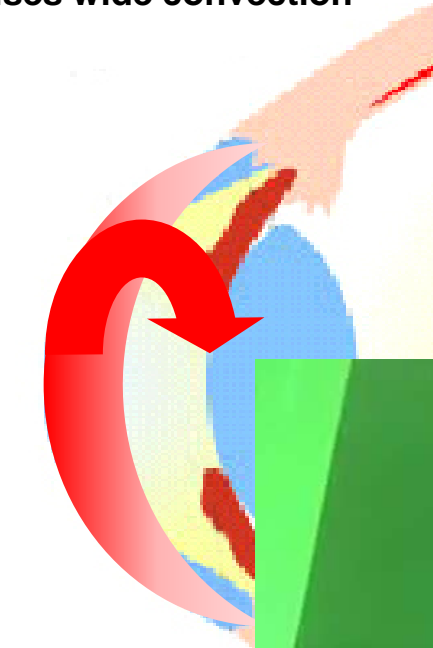
**This work was supported by the Ministry of Internal Affairs and Communications, Japan.**





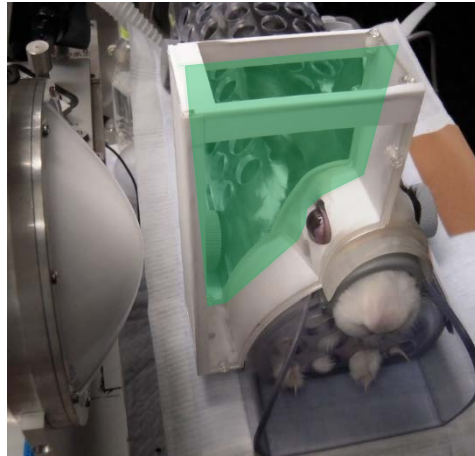
# Discussion

Broad and deep  
temperature elevation  
causes wide convection

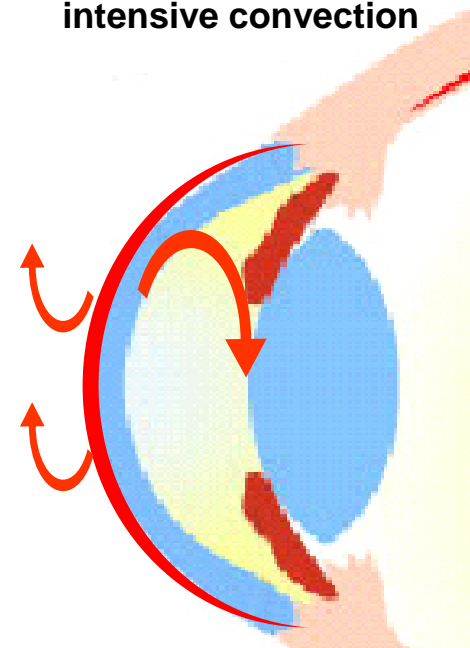


Skin depth: 0.5

MMW (40 GHz)



Corneal surface heat  
generation causes an  
intensive convection



Skin depth: 0.31 mm

MMW (95 GHz)