Application of T-Ray Gyrotron Developed for Real-Time Non-Destructive Inspection to Enhanced Regeneration of Cells

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***Abstract*—Active real-time THz imaging system (ARTIS) for non-destructive inspection (NDI), requires a powerful T-ray source capable of illuminating large inspection area at a time. A sub-THz gyrotron satisfying such a unique requirement is proven to be effective not only for NDI but also for bio-medical application such as enhanced regeneration of cells.**

I. INTRODUCTION

CONVENTIONAL terahertz imaging systems employing a tightly focused point-beam scanned over the object point by point, are not practical in the real world because of the long image-acquisition time to take a single frame of image. As an alternative, active real-time THz imaging system (ARTIS) was proposed, especially aiming for non-destructive inspection (NDI) of foreign bodies in food [1].

In ARTIS, instead of scanning object point by point, expanded T-ray beam is illuminated over entire inspection area at a time maintaining the power density above the detection level of a camera at focal plane. Consequently, a powerful T-ray source capable of illuminating large area by means of quasi-optical guidance is essential in realizing an ARTIS.

The author with Korea Electrotechnology Research Institute (KERI) developed a compact T-ray gyrotron system, which was successfully deployed to the ARTIS for NDI of foreign bodies in food. The ARTIS employed with the KERI gyrotron shows promise of security applications as well as NDI of food [2].

To examine the availability of the T-ray gyrotrons capable of producing high output power in the 0.2-THz to 1-THz range for diversified fields such as bio-medical application, the author tried applying this unique THz source to enhanced regeneration of cells.

II. T-RAY GYROTRON FOR REAL-TIME NDI

Having the capability of generating superior output power with good spatial pattern, a compact ($0.5\times0.84\times1.6$ m^3) gyrotron capable of producing 0.2 THz ($TE_{4,2}$ mode) and 0.4 THz ($TE_{9,3}$ mode) was implanted as a source in an ARTIS for food inspection.

Owing to the high-power capability of the T-ray gyrotron to illuminate over the broad area of many tens square centimeters while maintaining the power density, real-time NDI is attained for the objects moving on the conveyor belt (200-mm width) with the speed of 500 mm/s.

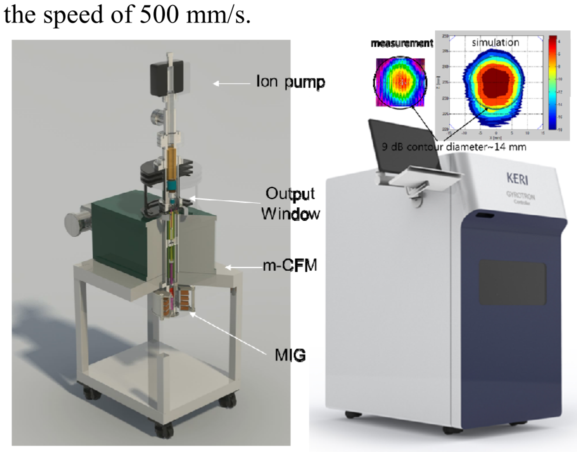

Fig.1. Developed T-ray gyrotron and control system. Measured and simulated patterns of 0.4 THz beam from the gyrotron are depicted.

Fig.2. Captured images from the videos demonstrating the capability of the active real-time T-ray imaging system for food inspection (left) and security screening (right). Gaussian beam from the T-ray gyrotron is transformed into a line shape crossing the conveyor belt, where a line array detector placed beneath take the shadow images of the samples moving along the conveyor belt.

The ARTIS is well suited for the inspection of soft (low-density) foreign bodies hidden in food (for example, worms and plastics), which are not clearly identified with conventional modalities. At the same time, it is demonstrated that the ARTIS is adaptable to security inspection for dangerous substance such as knives and blades.

III. ENHANCED REGENERATION OF CELLS

To examine the availability of the T-ray gyrotron for bio-medical application, we tried studying THz-induced effects at cellular level because many important biomolecules, including DNA and proteins, may have intrinsic vibrational resonances in the THz range.

Although the possibility of terahertz interaction with biological systems had been discussed by Frohlich [3] about 50 years ago, researchers had to wait till appropriate terahertz sources become available for their experimental investigations. Doster *et al.* proved indirectly by inelastic neutron scattering in-between that the timescale related to the dynamics of biomolecules is 0.1-100 ps, which strongly implies that THz radiation is uniquely suited to affecting on the collective modes of molecular systems for living organisms, such as proteins and DNA [4]. Recently, owing to the development of fs lasers, terahertz effects on stem cell could be experimentally investigated. *In-vitro* results [5-6] support that gene expression in stem cell is definitely affected in response to terahertz radiation. By extension, *in-vivo* experiments conducted on mice paved the path for therapeutic applications of intense terahertz pulses including possible side-effect as well [7-9].

Now that we have acquired the powerful, continuous wave terahertz source developed for real-time non-destructive inspection, expansion of the T-ray gyrotron application toward bio medical area where only fs pulses are available up to now for intense terahertz source should be reasonable sequence of moves.

Focus was given to hair follicles since hair follicle is located in outmost layer of skin tissue which is the niche in potential clinical applications of terahertz waves due to their limited penetration. In addition, hair follicle is well-defined organ to monitor the regeneration of stem cell responsible for hair proliferation by immunofluorescence staining methods [10-11]. Hair regeneration cycling consists of growth (anangen), cessation (catagen), and rest (telogen) phases [12]. And each phase shows specific anatomical characteristics: During anagen phase hair follicles are elongated to the hair shaft by the rapidly dividing stem cells. Consequently, active regeneration can be identified by the elongated shape of the follicles dyed by Hoechst. Also, it can be identified by the number of stem cells marked by Ki-67 indicating high growth rate.

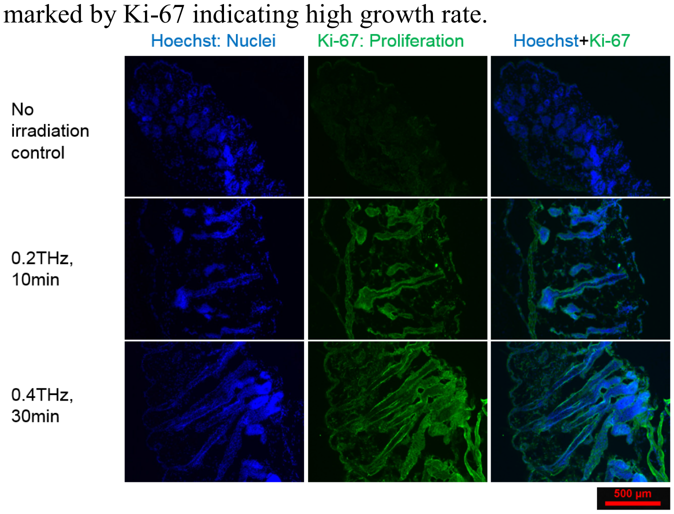

Fig.3. Proliferation enhancement by T-ray illumination at both 0.2 THz and 0.4 THz. Increase of longitudinal length of the hair follicles of mice (Balb/c, Male, 4weeks) is identified by Hoechst (blue). And significant enhancement of proliferation is also observed by staining with Ki-67 (green).

By the both staining methods, we identified that exposure to T-rays both at 0.2THz and 0.4THz promotes cell proliferation and hair follicle growth. This preliminary observation may indicate potential of THz irradiation to enhance the regeneration of hair by affecting cellular and molecular functions.

IV. Conclusion

A compact T-ray gyrotron satisfying the requirement of high-power capable of illuminating large inspection area at a time in the active real-time THz imaging system for non-destructive inspection, is proven to be effective not only for NDI but also for bio-medical application.

We evaluated the influence of a continuous terahertz waves on the regeneration of stem cells in the hair follicles of mice *in vivo*. Based on our results we argue that development of new therapeutic strategy to treat dermatological conditions, such as cutaneous abrasions, burns, and lipsotrichia will be attainable by using the T-ray gyrotron capable of illuminating over broad area. More detail discussions as well as quantitative analysis will be presented in the conference.

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