Terahertz Polarimetric Sensing for Linear Encoder Based on a Resonant-Tunneling-Diode and CFRP polarizing plates

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Abstract

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***Abstract*—We report the first experimental results on the linear encoder based on a resonant-tunneling-diode (RTD) and a periodic linear array of carbon-fiber reinforced plastic (CFRP) plates as a scale. By using polarization dependent reflection signal, we were able to detect the incremental position in a non-contact manner.**

I. INTRODUCTION AND PROPOSAL

Linear encoder, a sensor paired with a scale, has been used for positioning in various measurement and motion systems. Optical encoders are the most commonly used in industrial applications, but performance degradation occurs under poor ambient conditions such as dust and fine particles. Magnetic encoders have resistance to such conditions, but their accuracy is sensitive to the vibration, because the working distance between a sensor and a scale must be small. Our motivation is to realize an encoder with environmental resistance and tolerance to wide gap. To this end, we focus on using THz wave and polarization information, since THz wave has the robustness to the ambient condition [1], and the use of polarization prevents the influence of change in received signal strength indication (RSSI) and phase due to the gap fluctuation. Therefore, we expect this encoder has the potential to use as position sensor for motion system and mobile body system in severe heavy-duty environment.

Recently, we reported the principle of THz encoder in [2]. Fig. 1 shows its schematic diagram. The encoder consists of a THz transceiver and a periodic linear array of polarizers. By scanning the reflected intensities of two orthogonal waves along the scale, we can obtain two RSSI traces, which can then be converted into differential RSSI. The position can be determined by extracting the change of sign in the differential RSSI. To verify this concept, we had built a test bench using THz-TDS system and wire-grid film polarizers. Then, we had found that the encoder can operate at wide gap distance on the order of 100 mm and the use of polarization information prevents performance degradation due to the gap fluctuation. In this paper, we first demonstrated the encoder using solid-state semiconductor THz device and low-cost polarizing plates to further reduce the size and cost of the encoder.

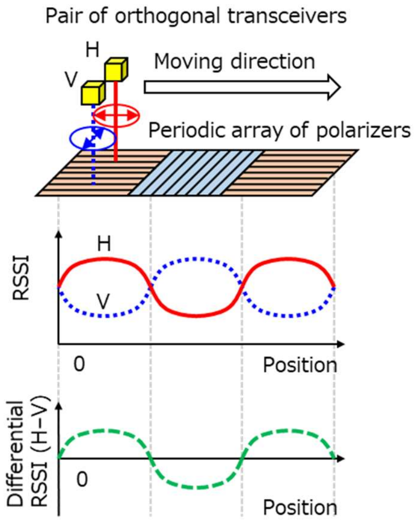

Fig. 1 Schematic diagram of THz encoder and RSSI traces scanned by transceivers and differential RSSI trace

II. EXPERIMENT AND RESULTS

We used a resonant-tunneling-diode (RTD) oscillator emitting at 0.46 THz as a light source and a zero bias Schottky-barrier diode detector (QOD, Virginia Diodes Inc.) as a detector. Since RTDs are compact, solid-state coherent source, and able to operate at room temperature, they have been expected to be used in future industrial application [3]. As a polarizer, we employed uni-directional carbon-fiber reinforced plastic (UD-CFRP) plates. Because the carbon fibers have a relatively small resistance along the fiber direction, UD-CFRP is known to behave like a wire-grid polarizer [4]. CFRP plates have benefits for industrial applications, because of their cheap cost, high rigidity and rust-free feature.

Fig. 2 shows the schematic diagram of measurement system. The RTD and the SBD were placed with 50 mm separation and their directions were optimized using an Au mirror placed at 100 mm gap distance from the RTD and the SBD. A DC bias for RTD oscillator was modulated at 1 kHz and the SBD output signal was measured by a lock-in amplifier. The output beam from the RTD is extracted through a hemispherical silicon lens and its effective 3-dB beamwidth was approximately 2.5 degree.

To confirm the beam propagation property in our setup, we measured and simulated RSSI by varying the gap distance and the tilt angle. Figs. 3 (a) and (b) show the gap distance and tilt angle dependence, respectively. Because the beam is not collimated and the incident angle is not vertical, the RSSI varied with gap distance and the tilt angle. Dashed lines show simulated RSSI profile using ray tracing method assuming the RTD as a point light source. We found that the measured results were well reproduced with the effective beamwidth. Therefore, we thought that the beam propagation channel for reflection measurement was correctly achieved.

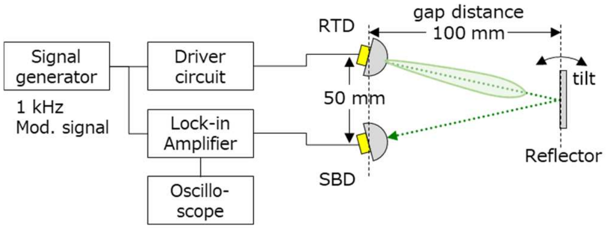

Fig. 2 Schematic diagram of measurement system

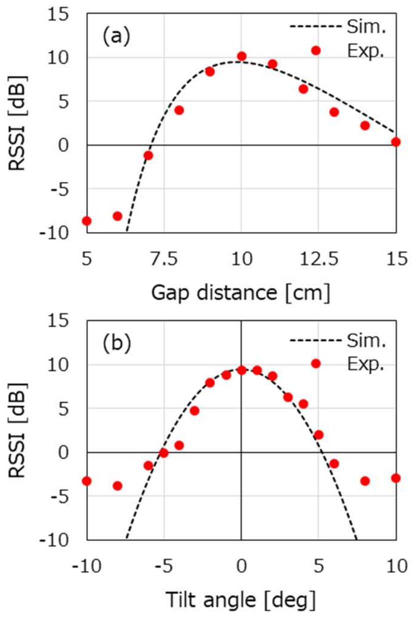

Fig. 3 (a) RSSI dependence on gap distance, (b) RSSI dependence on tilt angle

We characterized polarization dependence of reflection in our UD-CFRP plate (40 mm×40 mm×0.1 mm). We defined orientation of UD-CFRP plate θ as the angle between the fiber direction and electric field direction. We observed strong reflection at $\theta = 0°$ in contrast to weak reflection at $\theta = 90°$. The difference of RSSI between the two orthogonal polarizations is approximate 4 dB. Hence, we expect that the direction of the UD-CFRP plate can be distinguished by the measured RSSI when the gap distance is in between 90 to 110 mm and the tilt angle is in between -2 to 2 degree in our reflection setup

To verify the possibility of linear encoder, we built a periodic array of UD-CFRP plates on a linear translation stage and placed at a gap distance of 100 mm. Figs. 4 (a) and (b) show photograph and the schematic drawing of the periodic array of UD-CFRP plates. To evaluate RSSI traces with two orthogonal polarization using a single pair of the RTD and the SBD, the array consists of two linear tracks with three UD-CFRP plates. The orientation of adjacent UD-CFRP plates are orthogonal to each other as illustrated in Fig. 4 (b). We measured RSSI traces along the scale at each 5 mm step by using translating stage. Here, we note that the beam spot diameter at the scale position is estimated to be 9.3 mm, which is enough small comparing to the dimension of the UD-CFRP plate, so that reflection from the next track does not affect to our measurement. Fig. 4 (c) shows the measured RSSI traces for two tracks with orthogonal polarizer arrangements. Fig. 4 (d) shows the converted differential RSSI. Although we found interference induced signal fluctuation, the transitions of the differential RSSI were clearly observed. The width of rise and fall area is approximate 10 mm, which is consistent with the estimated beam spot diameter. We were able to determine the incremental position by extracting transition position from the differential RSSI trace. Here, the estimated scale width from the transition position of the differential RSSI was 41.6 mm. We also evaluated the scale width at gap distances of 90 and 110 mm, the error of the scale width were within ±2 mm.

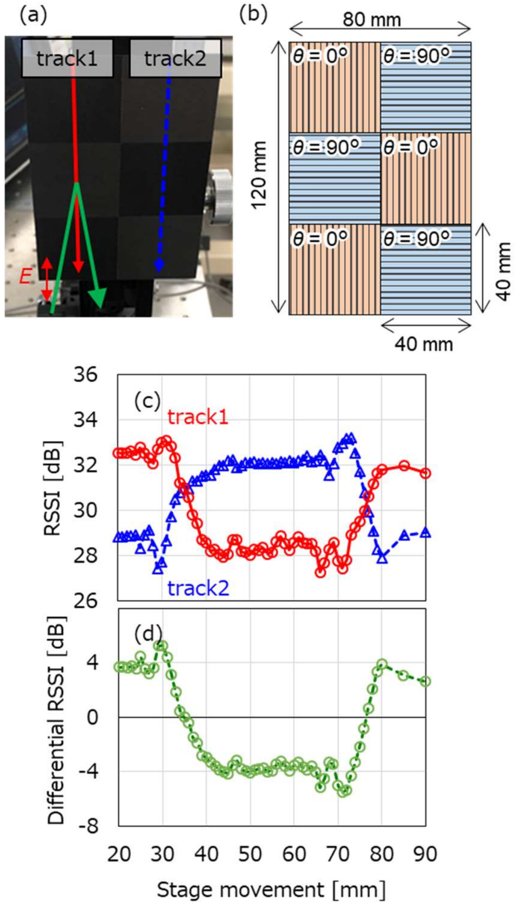

Fig. 4 (a) Photograph and (b) Schematic diagram of periodic array of UD-CFRP plates, (c) Measured RSSI traces of two tracks with orthogonal polarizer arrangements, (d) Calculated differential RSSI trace

Therefore, the THz encoder based on solid state semiconductor source and CFRP plates has possibility to the position by utilizing THz wave and polarization information.

III. CONCLUSION

We report the first experimental results on the THz polarimetric sensing for linear encoder using the RTD oscillator and periodic linear array of UD-CFRP plates. Experimental results show potentials of encoders using solid-state semiconductor THz devices and low-cost polarizing plates. In future works, we plan to evaluate the performance of the encoder under various environmental conditions.

REFERENCES

[1]. K. Su, L. Moeller, R. B. Barat, and J. F. Federici, “Experimental comparison of terahertz and infrared data signal attenuation in dust clouds,” *J. Opt. Soc. Am. A*, vol. 29, no. 11, pp. 2360-2366, 2012.

[2]. K. Sadamoto, W. Tsujita, Y. Sawa, B. Wang, R. Ma, P. Wang, K. H. Teo, P. V. Orlik, K. Kato, and M. Nakajima, “Terahertz Polarimetric Sensing for Linear Encoder,” *The 43rd International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz)*, Mo-POS-10, 2018.

[3]. M. Asada and S. Suzuki, “Room-Temperature Oscillation of Resonant Tunneling Diodes close to 2 THz and Their Functions for Various Applications,” *J. Infrared, Millimeter, Terahertz Waves*, vol. 37, no.12, pp. 1185-1198, 2016

[4]. J. Zhang, C. Shi, Y. Shi, Y. Ma, X. Han, W. Li, T. Chang, D. Wei, C. Du, and H.-L. Cui, “Spectroscopic study of terahertz reflection and transmission properties of carbon-fiber-reinforced plastic composites,” *Optical Engineering*, vol. 54, no. 5, pp. 054106, 2015.