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Development of a Long-Focal-Range Annular Array Ultrasonic Transducer
広域焦点可変アニュラアレイセンサの開発

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1. Introduction

High resolution and high sensitivity are important requirements for inspections of integrated circuits (ICs) and semiconductors. We have been developing high-frequency electronic scanning apparatuses (ES5100) and inspection techniques using 25/50/75 MHz linear array transducers. Recently, there are growing needs for power device ICs with high environmental performance. Since these ICs are thicker than conventional ones, it is necessary to develop a higher performance ultrasonic transducer which has a long focal distance and a high spatial resolution.

Annular array ultrasonic transducers have been developed for nondestructive testing or medical uses [1, 2]. Those transducers usually have equal-area transducer elements. For example, the transducer in Ref. [2] has 100-μm fine spatial resolution at F=15 mm (F: focal distance). However, there is a limitation for enlarging the diameter of the transducer due to element widths from the outer side. Therefore, higher resolution over F=20 mm has not been obtained.

In this paper, we designed and fabricated a prototype of a new annular array transducer. Then, we evaluated performances of the prototype at different focal distances (F=10 mm to 30 mm).

2. Array Design

Spatial resolution of an annular array transducer is represented as eq.(1):

$$B = \frac{F\lambda}{\pi\phi} \quad (1)$$

where B [μm] is spatial resolution at the full width at half maximum (FWHM), F [mm] is focal distance, λ [μm] is wave length, and ϕ [mm] is transducer diameter. A higher spatial resolution is obtained with a larger diameter transducer from eq. (1). Targeted spatial resolution of the prototype was decided as 100 μm at F=30 mm. To achieve this goal at 50 MHz, the outermost diameter must be above ϕ 10 mm from eq. (1). Then, the innermost diameter must be below ϕ 1.1mm to get proper focusing with all transducers. Considering these conditions, we designed a new annular array pattern, which consists of elements of equal areas for the inner side, and equal stroke widths for the outer side as shown in **Fig. 1**. The prototype has 32 elements, and inner side is divided into 16 equal areas elements and the outer side is divided into 16 equal stroke width elements.

Fig. 1 Illustration of the new annular array pattern (a case with 6 elements).

3. Experiments

The designed annular array pattern was printed using copper on a flexible printed circuit (FPC) for the electrode. The prototype (**Fig. 2 (a)**) was manufactured with the FPC and copolymer piezoelectric film (P(VDF/TrFE)).

The prototype transducer was evaluated using the high-frequency electronic scanning apparatus, ES5100 (**Fig. 2(b)**). This apparatus is suitable for frequencies to 100 MHz, and it is able to control transmission and receiving timing of 32 channels simultaneously. A 25-μm diameter tantalum wire was used as a reflector. Spatial resolution was measured by scanning the prototype transducer across the reflector in 5 μm steps in the horizontal

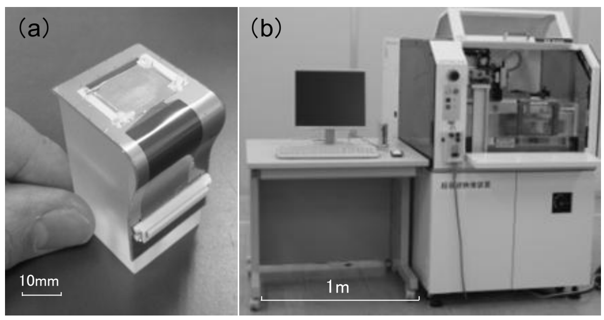

Fig. 2 Photograph of (a) the prototype transducer and (b) high-frequency electronic scanning apparatus (ES5100).

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direction and in 5 mm steps in the vertical direction. The sensitivity characteristics of this pattern were verified in advance by a finite element method.

4. Results and Discussion

Fig. 3 shows spatial resolution results at each focal distance, where the calculated value was evaluated using eq. (1) at 50 MHz. The measured values corresponded to the calculated values. This agreement indicated that all transducer elements contributed to focusing on the surface of the reflector. Therefore, high spatial resolution was obtained with below 100 μm between F=10 mm and F=30 mm.

Relative sensitivity results of the prototype transducer are shown in **Fig. 4**, where measured and calculated sensitivities were normalized by each maximum value. The calculated relative sensitivities varied within 6.4 dB, while the measured values varied within 6.5 dB. The focal distance dependence tended to be approximately the same except for the peak point of focal distance.

The performances of the prototype and commercial 50-MHz single transducers were compared by imaging a part of the engraved scene on a 10-yen coin as shown in **Fig. 5**. The amplitude values were converted into a gray scale and plotted. The measurement range was 5 mm × 5 mm in 5 μm steps. One single transducer was used for F=13 mm, and another one was used for F=25 mm. Images obtained by the prototype transducer were much clearer than those by the two single transducers at both focal distances. Furthermore the prototype resolved the three-convex shapes at a door (shown in ovals), which are lined with a 100-μm pitch, not only at F=13 mm but also at F=25 mm.

5. Summary

We designed and evaluated the new large-diameter annular array ultrasonic transducer which consists of elements of equal areas for the inner side, and equal stroke widths for the outer side. We achieved the spatial resolution below 100 μm and a 6.5-dB variation width of relative sensitivity between F=10 mm and F=30mm for the prototype. Moreover, the prototype had higher performance than commercial transducers when tested by imaging the engraving on a 10-yen coin.

References

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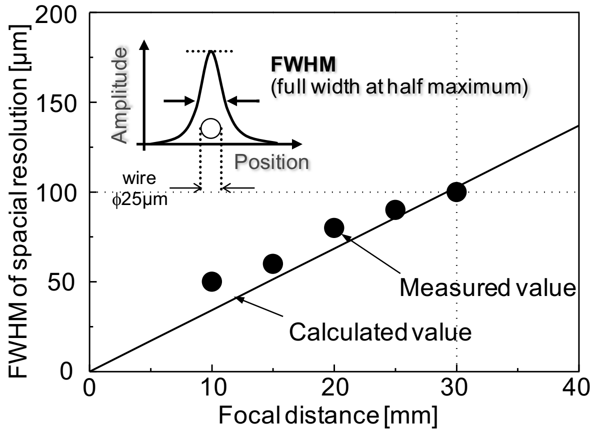

Fig. 3 Spatial resolution dependences on focal distance.

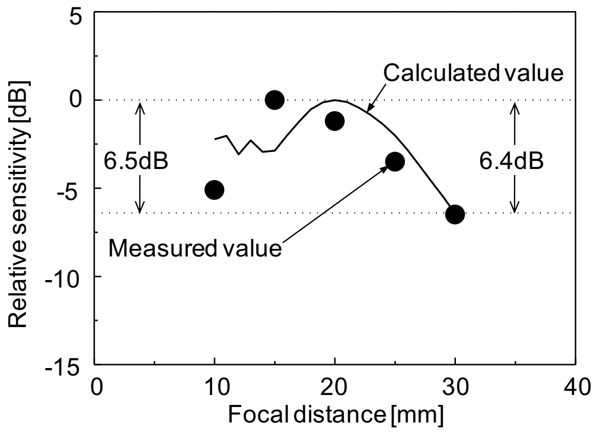

Fig. 4 Relative sensitivity dependences on focal distance.

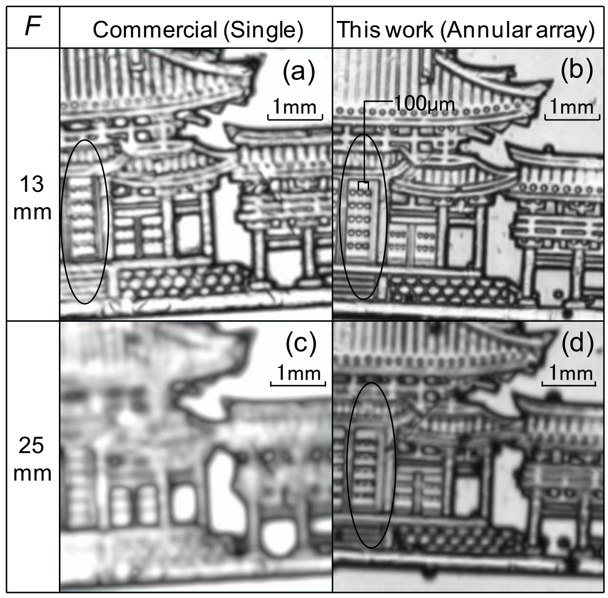

Fig. 5 Images of the engraving on a 10-yen coin. (a) Commercial transducer (F=13 mm). (b) Prototype transducer (F=13 mm). (c) Commercial transducer (F=25 mm). (d) Prototype transducer (F=25 mm).