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Increasing the frequency of surface acoustic waves generated by phase velocity scanning of laser interference fringes

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To nondestructively detect surface defects that reduce the strength of ceramics and structural materials of micromachines, we previously developed the phase velocity scanning method. By using scanning interference fringes generated by two laser beams whose frequencies are shifted, the method can generate a 110 MHz surface acoustic wave (SAW). However, the frequency of the SAW depends on the frequency of the Bragg cell used, thus making the upper-limit frequency about 110 MHz. In this study, we propose multiple use of Bragg cells in series, and successfully generated a 200 MHz SAW. © *1999 American Institute of Physics.* [S0034-6748(99)02911-1]

Surface defects of micrometer sizes reduce the strength of ceramics and structural materials of micromachines. To maintain the integrity of such materials, it is necessary to detect these defects nondestructively with a detection sensitivity on the order of microns. Therefore, researchers have studied the use of surface acoustic waves (SAW) with a frequency above 100 MHz, which is not used in conventional nondestructive evaluation. For example, a method using interference fringes of leaky SAW, which are reflected from a crack, has been developed in scanning acoustic microscopy.[1] However, these methods cannot be used to detect distant cracks because they use a liquid coupler, such as water, and because the attenuation of SAW is large due to the leaky loss. Conventional laser-ultrasonic methods have difficulty in evaluating small cracks because the directivity of SAW is low for such measurements. Therefore, we previously developed the phase velocity scanning (PVS) method in which a laser beam is scanned with a velocity equal to a phase velocity of a specimen.[2] The PVS method does not use a coupler and has excellent directivity. By PVS of laser interference fringes, this method can generate a 110 MHz SAW.[3–5] We previously used the SAW to detect Vickers indentation cracks[1] and microstandard defects on a Si (100) surface.[6,7] However, the frequency of the SAW that the PVS method can generate depends on the Bragg cell used, and therefore has an upper-limit frequency of about 110 MHz. An approach to increase the frequency of SAW would be to develop higher frequency Bragg cells. However, there is a certain difficulty in doing this. For example, a 200 MHz shear wave of TeO_2, used for highly efficient anisotropic Bragg diffraction, which we use to shift the frequency of the yttrium–aluminum–garnet (YAG) laser beam, suffers 3 dB attenuation by 3 nm propagation.[8] Consequently, an intensity distribution of the diffracted laser beam becomes asymmetric. Therefore, we propose another approach of multiple use of moderate frequency Bragg cells in series. As a preliminary demonstration, we successfully generated a 200 MHz SAW by using two 100 MHz Bragg cells.

When the scanning velocity of the scanning interference fringe (SIF) is equal to the phase velocity of a SAW on a specimen, the amplification effect of the PVS method is maximum and the largest SAW is generated (Fig. 1).[4] Furthermore, the largest amplitude SAW is generated when the difference in the frequency ($\Delta f = f_2 - f_1$) of the YAG laser beams is equal to the frequency ($f \simeq vk \sin\theta/\pi$) determined by the incidence angle (θ) of each YAG laser beam, the magnitude ($k \simeq k_1, k_2$) of the wave number of the YAG laser, and the SAW velocity (v) of the specimen. Therefore, the

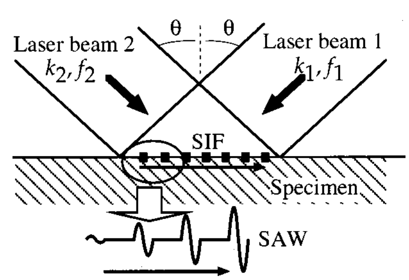

FIG. 1. Principle of PVS of laser interference fringes. When the scanning velocity of the SIF is equal to the phase velocity of the specimen, the amplification effect of the PVS method is maximum and the largest SAW is generated.

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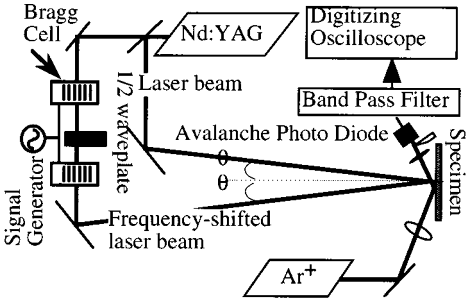

FIG. 2. Schematic of the improved PVS method used to generate 200 MHz SAW. SAW was generated by using the second-harmonic wave (532 nm) of a *Q*-switched Nd:YAG laser, whose power and stability had been improved by using two image-relay lenses. The SAW was detected by using an optical knife-edge method with an Ar^+ laser probe. By using two Bragg cells, we generated a SAW whose frequency was higher than that generated by each Bragg cell.

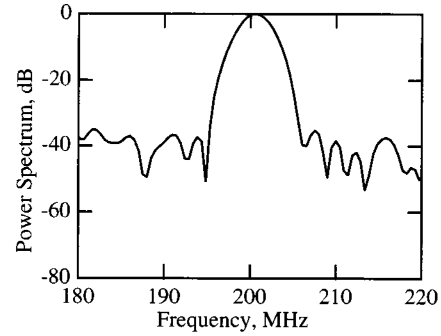

FIG. 4. Power spectrum of a 200 MHz SAW. Peak is at 200.6 MHz and the *Q* value is 60.6.

generation of higher frequency SAW without having to change k requires both a larger Δf and θ.

In this study, our goal was to use two Bragg cells, each producing a frequency difference Δf between laser beams, to double the synchronized frequency difference $(=2\Delta f)$ in the PVS method, and thus generate a $2\Delta f$ Hz SAW. In the optical system that we used (Fig. 2), the second-harmonic wave (532 nm) of a *Q*-switched Nd:YAG laser was used to generate the SAW. The pulse energy of the YAG laser was 9–14 mJ and its pulse width was 50 ns. An etalon was used to improve the coherent length of the YAG laser beam, and two image-relay lenses in the resonator were used to improve the power and stability of the beam. The laser beam was split into two beams by a beam splitter. The frequency difference Δf between the two laser beams was introduced by a Bragg cell. The SAW was generated by using the SIF formed by the intersection of the laser beams on a specimen. The SAW was detected by using an optical knife-edge method with a 120 mW Ar^+ laser probe. Furthermore, we used 60–100 MHz Bragg cells to generate 120–200 MHz SAW on a Si (001) surface.

We successfully generated a 120–200 MHz SAW on the Si (001) surface by using two 60–100 MHz Bragg cells. Wave forms of the generated 200 MHz SAW propagating along [110] direction (Fig. 3) show the signal-to-noise ratio of about 23 dB with 20 times averaging. Figure 4 shows the power spectrum of the wave form in Fig. 3. The resulting power spectrum had a peak at 200.6 MHz. The *Q* value calculated from this spectrum was 60.6. On the other hand, the theoretical *Q* value is estimated to be 63.9 by using a theoretical wave form assuming a gaussian function envelope, $\exp(-7\times10^{13}t^2)\sin(4\pi10^8 t)$. The relatively small difference between the theoretical and experimental *Q* values, about 5%, demonstrates that the experimental and theoretical wave forms are similar. This similarity indicates that the generated SAW has a single frequency and that the intervals of the SIF are uniform. These results confirm that we successfully generated a single frequency 200 MHz SAW by using two 100 MHz Bragg cells in series. Then, we conclude that higher frequency SAW can be generated by combined use of efficient Bragg cells operating at moderate frequencies without developing a higher-frequency Bragg cell.

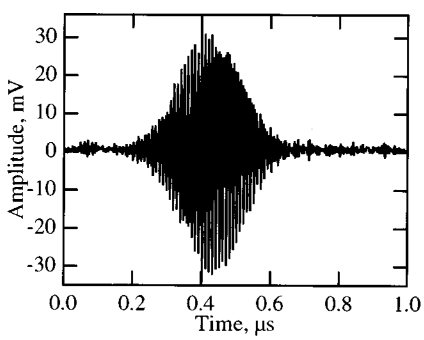

FIG. 3. Averaged 200 MHz SAW generated by two 100 MHz Bragg cells.

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