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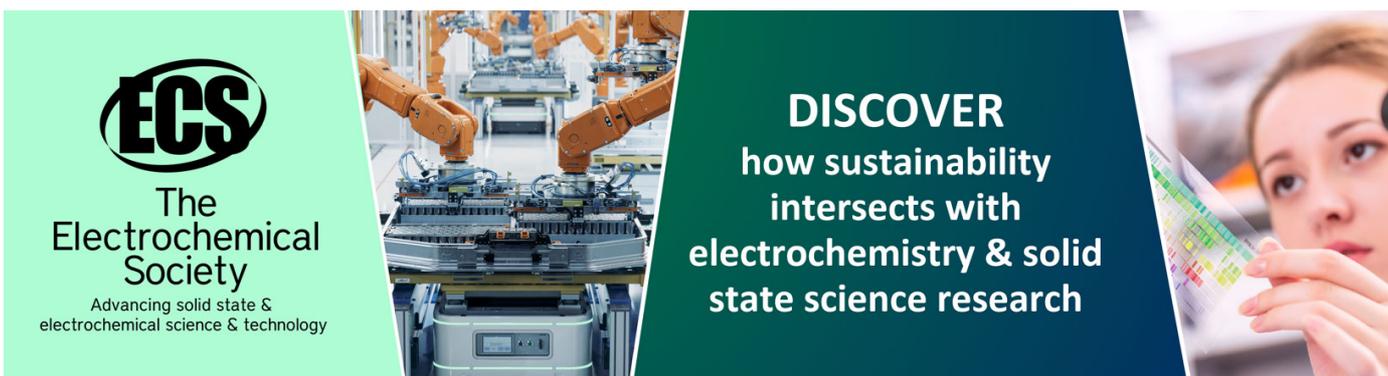
Development of Scribing Technique by using Multiple-laser Beams for Multi-filamentary Coated Conductors

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Development of Scribing Technique by using Multiple-laser Beams for Multi-filamentary Coated Conductors

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Abstract. The REBa₂Cu₃O_{7-d} (REBCO) coated conductors (CCs) with the multi-filamentary structure is very useful for controlling the AC-loss and the shielding current. We have developed laser scribing technique to fabricate multi-filamentary structure by irradiating a rectangular beam using excimer laser source (KrF, $\lambda \sim 248\text{nm}$). Since the reflectance of stabilized silver and copper at the wavelength of Nd: YAG or fiber laser ($\sim 1\ \mu\text{m}$) is 98% or more, destructive thermal processing must be required for processing in the wavelength range, which was the reason why we chose the excimer laser as light source. Actually, we successfully fabricated scribing structure with high precision. On the other hand, the improvement of the processing speed has been an important issue to be solved. Although the multi-laser beam system is effective for this purpose, the uniform intensity distribution in the width direction has to be realized. There is no strong Gaussian component in the excimer laser compared with a solid laser. The uniformity is useful for a single beam, however, it is not enough for the multi-beam system. In order to solve this issue, we have modified the beam intensity distribution by using homogenizer. Concretely, the beam intensity in the minor axis direction was flattened by a homogenizer using a plurality of horizontally elongated cylindrical lenses. This modification made the uniform range of laser intensity wider and it was confirmed that multi-laser beams can be applicable as a high-speed scribing technique.

1. Introduction

Reduction of the AC loss and control of the influence of shielding magnetic field are indispensable for applying CCs to superconducting magnet. For that purpose, we have been developing the thinning process of coated conductors by the laser scribing method which digs stabilizing and superconducting layers into a slot shape[1]. We have developed a long scribing equipment using excimer laser (KrF), which has an excellent controllability of slot width almost without deterioration of performance[2]. Additionally, the process can suppress degradation of peel strength. And the applicability to the long tapes was already confirmed. Many other research institutes have been also trying scribing machining [3,4], but only we have made it possible to perform scribing processing for a long CC of 100 m class[5]. The next technical problem on this excimer laser scribing method is to improve the processing speed.

In our previously developed equipment, it was the biggest factor limiting the processing speed that only one beam could be irradiated at a time. Although the coherent excimer laser used as a laser source is a gas laser, it does not have a stronger Gaussian component than a solid laser, but the laser



beam shaped into a rectangle by the optical mask is not uniform, then only one beam could be used in the one scribing path.

Therefore, we attempted to make the beam intensity uniform in wider area on the mask surface by introducing a beam homogenizer in the direction corresponding to the width direction of the CCs. Then, the dual beam irradiation was taken place in the obtained uniform beam, and the effectiveness of this modification was evaluated.

2. Experimental

As shown on the left of fig. 1, the intensity distribution of the laser beam is not uniform, and in general, it has a Gaussian distribution with high intensity at the center of the beam. In order to produce a plurality of rectangular beams from one beam, it is necessary to create a top-hat type distribution having uniform intensity on the mask surface as shown in the right side of fig. 1. After designing and modification of the equipment, we carried out real scribing process of REBCO and evaluated it.



Figure 1 Schematic view of beam profiles before modification(left) and expected shape by the modification(right).

2.1. New design of optics of laser scribing equipment

For dual beam formation, it is necessary to equalize the laser beam intensity in the width direction (minor axis direction) of the CCs. Since the CCs are transported at a constant speed under the irradiation of rectangular shape pulsed beams, there is no need on uniformity in the longitudinal direction of the CCs. A conceptual diagram of the optical system for the modification is shown in fig.2.

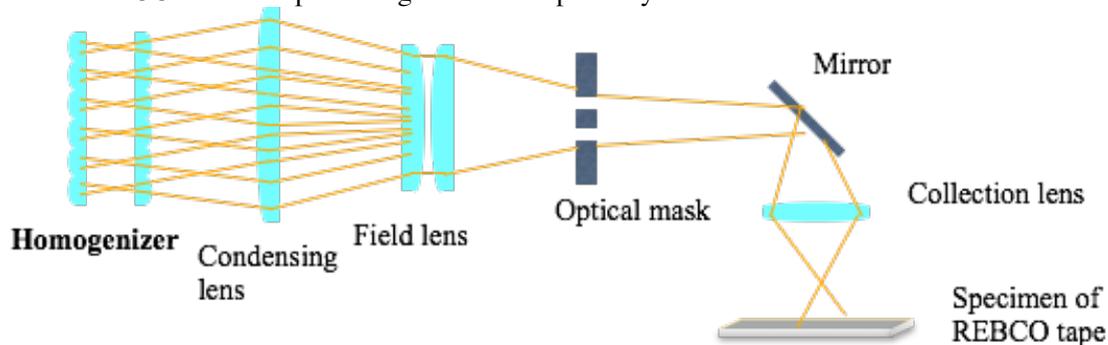


Figure 2 A concept of optical design for widely uniform laser beam

As a method of homogenizing the beam in the minor axis direction, a system (homogenizer) in which two sets of several cylindrical lenses were combined in the minor axis direction was adopted. Also, a condensing lens was provided to make the size of the field lens surface constant before the mask. A new field lens was also provided to irradiate the beam that passed through the mask. The uniform range on the tape surface was designed to be 0.6 mm or more in the width direction.

2.2. Observation of beam uniformity and processing for CCs

The beam intensity distribution on the surface of CCs was observed by a beam profiler (LaserCamHR, COHERENT). We used EuBCO CCs for processing, the thickness of Ag was $8 \mu\text{m}$ on the top of EuBCO layer and the thickness of EuBCO layer was $0.8 \mu\text{m}$. The stainless steel optical mask (thickness: 0.2 mm) was designed to form two rectangular beams of $20 \mu\text{m}$ wide and 1 mm long on the surface of the CCs. Since the magnification of the condensing lens is 15 times, the rectangle opened of the mask was $300 \mu\text{m}$ wide and 15 mm long. The distance between the two rectangles was designed to be $450 \mu\text{m}$ on the tape surface. Using this mask, a scribing process was carried out to

divide the 10 mm width tape into 21 filaments. Because the dual beams scribe two slots at one-path, the irradiation position was shifted by $940\ \mu\text{m}$ steps, and the tape was divided into 21 by 10 times of processing. The processed length was 60 cm. The depths of the slots formed in the EuBCO CCs were observed with a scanning laser microscope (VK8700, KEYENCE).

3. Results and discussion

Figure 3 shows the observed results of the laser intensity distribution on the CCs surface. Figure 3 (a) shows the beam-intensity distribution before the modification, showing that the center of the beam was strong and a Gaussian type. In the case of (b) which is the beam intensity distribution after modification, it was found that a uniform beam profile of $600\ \mu\text{m}$ in the width direction was obtained which is the same width in the design. In the case of (c) in which the mask ($100\ \mu\text{m}$ width) was inserted for producing a dual beam, it succeeded in obtaining dual beams with similar intensity.

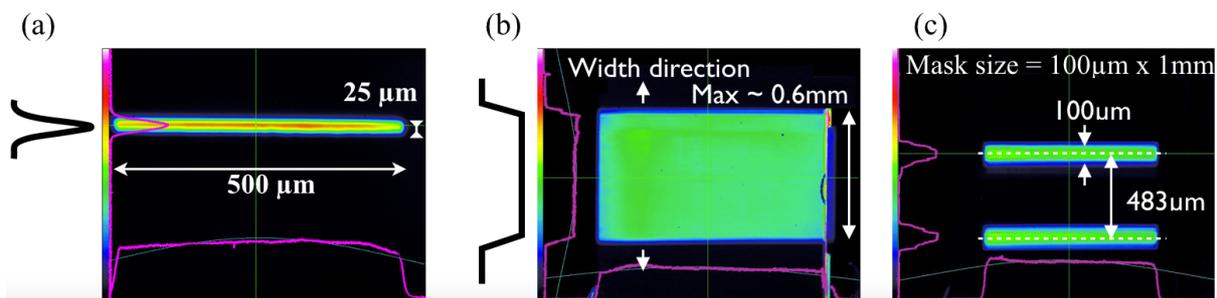


Figure 3 Beam profiles of laser beams on the position of specimens. (a) 2D-profile of laser beam intensity before modification, (b) 2D-profile without mask after modification, (c) 2D-profile of dual beams after modification.

Figure 4 shows the observation results of the two slots scribed by the dual beams by a scanning laser microscope. From this depth distribution, line profiles could be calculated and data on the depth and width of the slots could be obtained. It was confirmed that the average of the widths of the 19 filaments excluding the two at both edges was $450\ \mu\text{m}$ and which corresponded to the filament width as designed. Also, the groove width was $20\ \mu\text{m}$ on average, and it was also found that slots were formed as intended.

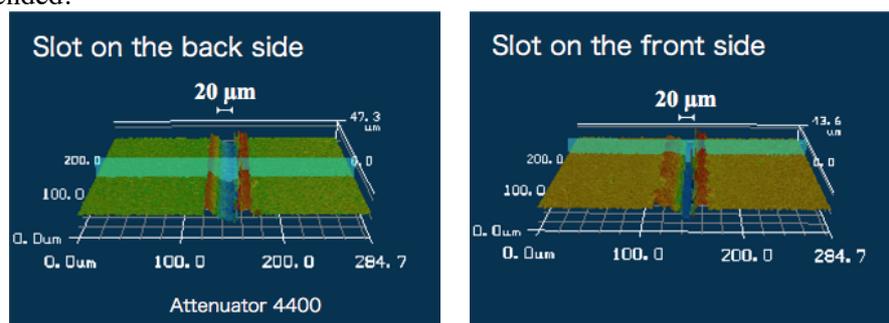


Figure 4 Observation result by scanning laser microscope for dual slots at back side (left) and front side (right).

Fig. 5 shows the energy density dependence of the depth of slots scribed by dual beams. The energy density is controlled by attenuating the beam intensity before reaching the mask surface by the attenuator. Therefore, the horizontal axis of fig. 4 shows the count number of the stepping motor that rotates the attenuator, the energy density increases as the count number increases, and the 5500 count corresponds to about $100\ \text{mJ} / \text{mm}^2$. The depth distributions of the dual beams in the front and back sides were almost the same, and it was shown that dual scribing processes can be simultaneously performed as designed.

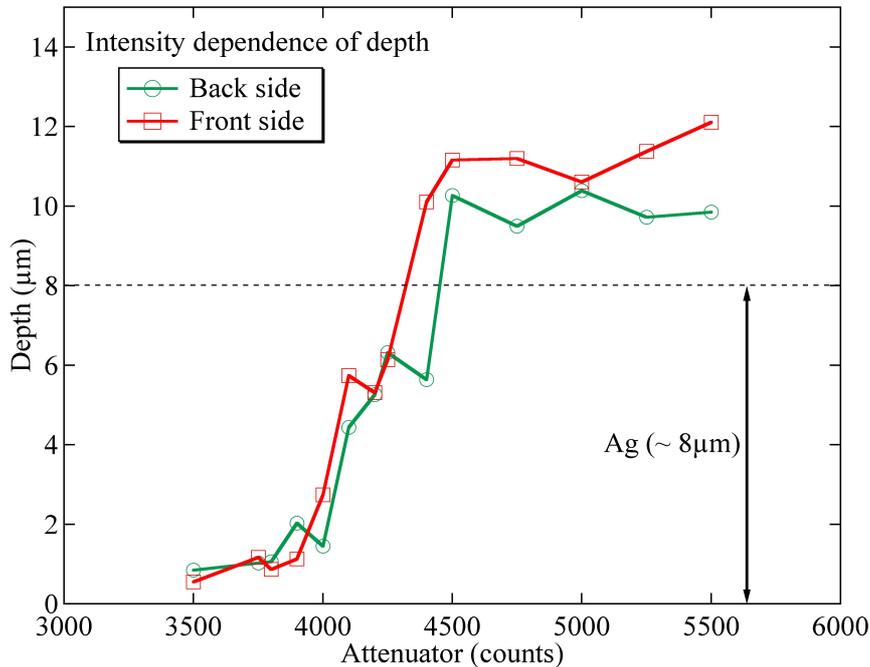


Figure 5 The energy density profiles of the slope depth in simultaneous laser scribing processing.

It was confirmed that the scribing time was shortened to about half the time than before. The sheet resistance between the filaments was as low as $0.63 \Omega / \text{sq}$. It is assumed that the poor electrical isolation was arisen from the re-adhering debris which increased by spouting from the two slots. Therefore, it is necessary to establish an optimum assist gas spraying for blowing debris. The I_c of each of the 21 filaments was measured and summed up to be 173.7 A. As I_c before processing was 195 A, the reduction rate of I_c was about 11%. The width of the slot was $20 \mu\text{m}$, and since there were 20 slots, the area reduction rate was 8%. Therefore, the reduction rate of I_c due to scribing was about 3%. This value is equivalent to the rate of reduction when the slots were scribed one by one irradiation, and deterioration did not increase by scribing with the dual beam.

4. Summary

In order to make the scribing speed higher, we have improved the uniformity of beam intensity distribution for dual beam irradiation at one-path processing. By introducing a homogenizer in the optics of equipment, the beam intensity in the minor axis direction was flattened, and we have succeeded in dual beam scribing. In the future, we will develop techniques to further increase the number of beams.

Acknowledgement

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