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Elastic constants of tungsten carbide single crystal studied by picosecond ultrasonics

ピコ秒超音波法を用いたタングステンカーバイド単結晶の弾性率計測

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1. Introduction

Cemented carbides cover a wide range of applications in many relevant industries, i.e. as cutting tools for machining of metal components, components of drill bits and road headers in the rock tools and mining area, or wear parts in wire drawing dies and punch tools. Tungsten carbide (WC) is an important cemented carbide, because its hardness and toughness are much higher than those of most materials. To enhance ductility of WC, cobalt is mixed and cemented carbide (WC-Co) is used widely.

To improve these mechanical properties, many researchers studied effects of grain size, synthesis conditions, and addition elements on the properties such as hardness and toughness of WC. However, the elastic constants of single-crystal WC remain unclear; those of polycrystalline specimens have been measured[1)]. Some researchers calculated the elastic constants of WC [2, 3)], but the result highly depends on the calculation conditions.

Therefore, in this study, we determine the elastic constants of WC single crystals by measuring Brillouin oscillation using picosecond ultrasonics. We further measured the isotropic elastic constants of WC-Co specimens by picosecond ultrasonics and resonant ultrasound spectroscopy.

2. Experiment

2.1. Measurement systems

To excite ultrasound, we deposited 10-nm Pt on the surface of the specimens by the RF magnetron sputtering method.

We use picosecond ultrasonics which uses ultrafast laser pulses as pump and probe lights to excite and detect high-frequency coherent phonons. **Figure 1** is a schematic of the optical system we developed.

We use a titanium-sapphire pulse laser whose wavelength is 800 nm and divide the pulse light into the pump and the probe lights by a polarization beam splitter (PBS). Corner reflectors change the arrival time of the pump light to the specimen. The pump light is modulated at 100 kHz by an acousto-optical crystal modulator (AOM). The probe-light wavelength λ is converted into 400 nm by a second harmonic generator (SHG). Both lights incident perpendicularly on the specimen. through an objective lens, and the reflected lights are distinguished by a dichroic mirror (DM), which reflects the 800-nm pump light and transmits the 400-nm probe light. The beam splitter (BS) separates the probe light before incidents on the specimen, and a balance detector collects these two lights. By inputting the intensity difference into a lock-in amplifier, we detect the probe light's reflectivity changes due to the acoustic perturbations.

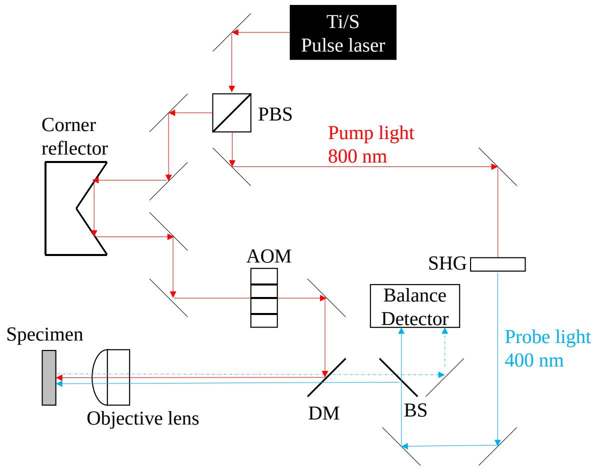

Fig. 1 Schematic of optical systems. Red and Blue lines denote pump and probe lights, respectively.

2.2. Brillouin oscillation

Brillouin oscillation is caused by interference between reflected probe light and diffracted probe light by strain pulses in a transmissive or semi-transmissive material. Strain pulse changes refractive index and dielectric constant in the material. The strapin pulse diffracts the probe light when they satisfy Bragg's

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diffraction condition. The diffracted light interferes with reflected light on the surface, leading to amplitude and phase changes in the reflectivity as the strain pulse propagates. Then, the intensity of diffracted light changes periodically, whose frequency *f* is expressed as follows

$$f = 2nv/\lambda \quad (1)$$

where, *n* and *v* are refractive index and sound velocity of the material, respectively.

3. Results and discussion

Figure 2 shows the X-ray diffraction (XRD) spectrum of our WC-Co specimen. We observe many intense diffraction peaks of WC and a few weak peaks of Co, indicating that the specimen is manly composed of isotropic WC, and impurities are negligible. We calculated the lattice constants using a least squares method, and obtain *a* = 2.907 Å and *c* = 2.838 Å. These values agree with measurement values with 0.41 and 0.39 % respectively[4, 5].

We show observed reflectivity changes and extracted Brillouin oscillations in **Figures 3 (a) and (b)**, respectively. We measured the Brillouin-oscillation frequency on different points of the specimen, which varied depending on the position; the maximum frequency difference among them is 18%. From equation (1), the sound velocity is proportional to the Brillouin-oscillation frequency, so that the frequency difference is identical to the sound-velocity dispersion. We estimated sound velocity of longitudinal wave propagating in each crystallographic plane direction using the elastic constants determined by the density functional theory, and found that the difference between the sound velocities propagating to *a*- and *c*-axes is 13%, which is comparable to the measured difference in the Brillouin-oscillation frequency. We will measure and calculate the refractive index, and measure the sound velocity of WC crystals composed in resin, discussing the elastic constants of WC in a cemented carbide alloy.

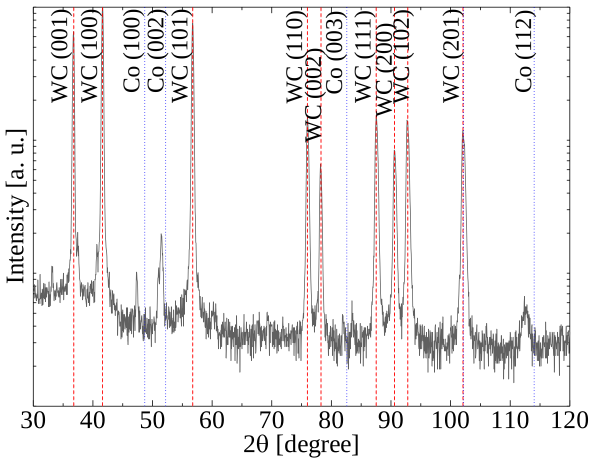

Fig. 2 XRD spectrum of WC-Co. Red and blue lines are calculated peak of WC and Co, respectively.

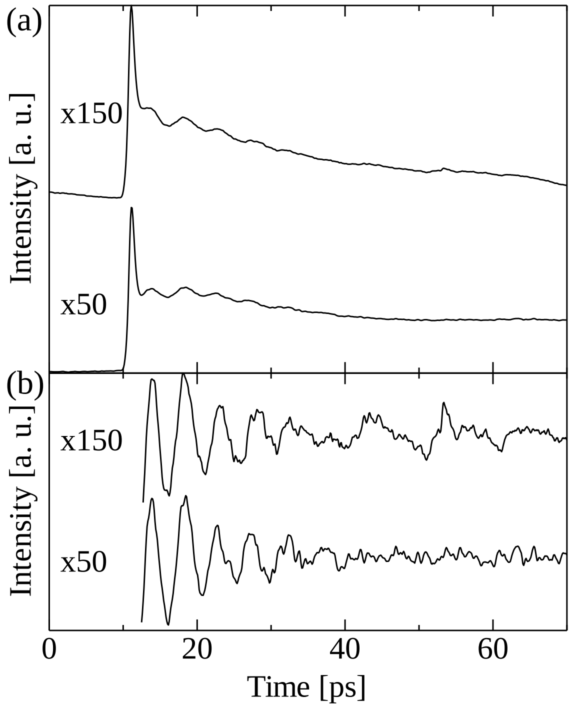

Fig. 3 (a) Reflectivity changes of WC-Co by 50- and 150-magnification objective lens and (b) extracted Brillouin oscillation.

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