ISSP Young Scientist Medal

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I am honored to have been awarded the ISSP Young Scientist Medal for our discovery of an acoustic diode based on the principle of magneto-rotation coupling [1-3]. Our discovery could lead to the development of acoustic rectifier devices which allow unidirectional propagation of the surface acoustic wave (SAW). These devices work at microwave frequencies and will have significant application potential in 5G communication technology. This research work would not have been possible without guidance from Prof. Otani, theoretical support from Prof. Maekawa and Yamamoto san, and feedback from other collaborators and colleagues. This accomplishment is a significant milestone in my life. Here, I would like to share my research experience and viewpoint which lead to this discovery.

Before coming to Otani Lab, I had very limited research experience, and I rarely encountered the word “spintronics”. My scientific journey was like a walk in a dark night with sparse light from distant stars energized by my instincts. I started as a master's student at ISSP and eventually graduated from the Ph.D. program. At the beginning of my research journey at Otani lab when I was assigned this research topic I had hardly any idea that this would lead to such an exciting discovery. I express my heartfelt gratitude to Otani sensei and all my lab colleagues who made my research journey joyful and pleasant. I would also like to thank the excellent scientific environment of ISSP which provides an interactive platform for novice researchers like me to grow to full scientific potential and achieve success in life. I am also grateful to all the professors, administrative staff, and students from ISSP and RIKEN for their support during the ups and downs of my research journey.

For a long time, the research focus of Otani lab had been the “spin conversion science” [4] which includes numerous intriguing phenomena where electron, photon, magnon, and phonon are correlated via spin. I have been extremely lucky to have been a part of this broad theme. I was involved in the investigation of the coupling of mechanical oscillation with spin. In my first scientific publication, we demonstrated the inverse Edelstein effect induced by magnon-phonon coupling. We fabricated a Ni/Cu(Ag)/Bi_2O_3. hybrid device and demonstrate spin to charge current conversion via magnon-phonon coupling and an inverse Edelstein effect. This was a significant scientific result where we realized acoustic spin pumping could be an efficient approach to study spin to charge conversion via Rashba spin-orbit interaction at Ag/Bi_2O_3 and Cu/Bi_2O_3 interfaces [5,6].

In 2018, my Ph.D. program started. Encouraged by my first publication I was motivated to investigate phonon-spin coupling further. I was interested to investigate nonreciprocal behavior in the hybridized system which was an unsolved puzzle. We decided to integrate Ta/$Co_{20}Fe_{60}B_{20}$(1.6 nm)/MgO magnetic multilayer system to trigger nonreciprocity via its interfacial Dzyaloshinskii–Moriya interaction (DMI). Although the acoustic wave follows the nonreciprocal rule, once it couples with the spin wave, it may sense the DMI and manifest nonreciprocity. As anticipated our initial experimental attempt showed nonreciprocity at resonant conditions. However, we also observed giant nonreciprocity in the signal intensity which could not be explained with the theoretical understanding at that time. Although intuitively it seemed the lattice rotation accompanied by SAW propagation might have some role in this giant nonreciprocity, it was still a vague hypothesis. Fortunately, our theory collaborators Maekawa sensei and Yamamoto san came to help and developed a theoretical model which provided a perfect explanation of our experimental data. Finally, we came to realize the importance of a long-forgotten coupling mechanism, the "magneto-rotation coupling", which was indispensable to explaining the giant nonreciprocity. The rotational deformation induced by SAW rotates the easy axis of the magnet, introducing the coupling between the magnon and phonon. The hybridized system displays a giant nonreciprocity because the rotation direction is reversed for $+\boldsymbol{k}$ and $-\boldsymbol{k}$ propagating SAW as shown in Fig. 1. After understanding the origin of the nonreciprocity, we designed a hybridized device using Ta/$Co_{20}Fe_{60}B_{20}$(20 nm)/MgO multilayer to enhance the magneto-elastic coupling. Ultimately, our devices showed versatile functionalities such as an acoustic diode, acoustic switch, and acoustic filter in a single device. Even more interestingly by tuning the magnetic field, our device demonstrated unidirectional propagation of SAW acting as an acoustic filter. This unidirectional SAW propagation achieved in our devices at microwave frequencies will have application potential in 5G communication technology.

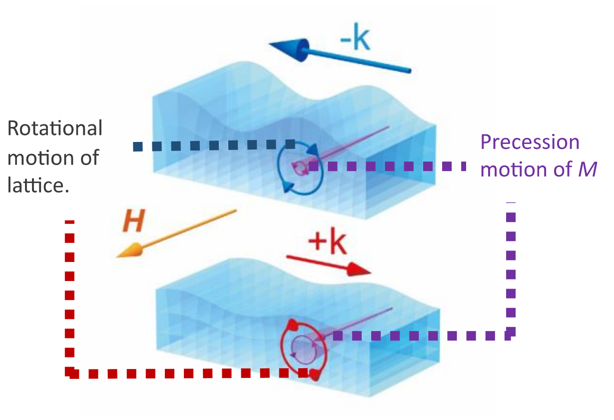

Fig. 1. Depending on the propagation direction, SAWs rotate the lattice in opposite directions (as indicted by the blue and red oriented cycles in the figure). This rotational motion couples with the magnetization via magnetic anisotropies, giving rise to a circularly polarized effective field, which either suppresses or enhances the magnetization precession (purple cone).

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