The Lattice Distortion-Induced Ferromagnetism in the Chemical-Bonded MoSe2/WSe2 at Room Temperature

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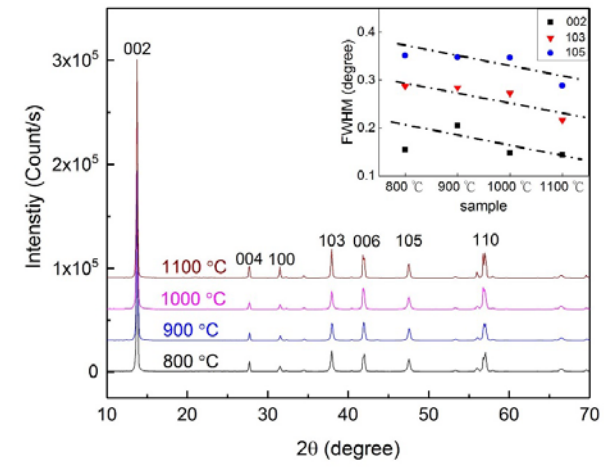
Abstract

- Ferromagnetism to non-ferromagnetism transition is detected in a chemically bonded MoSe2/WSe2 powder with different thermal annealing temperatures.
- All samples exhibit ferromagnetism and Raman redshift, except for the 1100 ˚C thermally annealed sample in which the MoSe2 and WSe2 are thermally dissociated and geometrically separated.
- The element analysis reveals no significant element ratio difference and detectable magnetic elements in all samples.
- These results support that, in contrast to the widely reported structure defect or transition element dopant, the observed ferromagnetism originates from the structure distortion due to the chemical bonding at the interface between MoSe2 and WSe2.

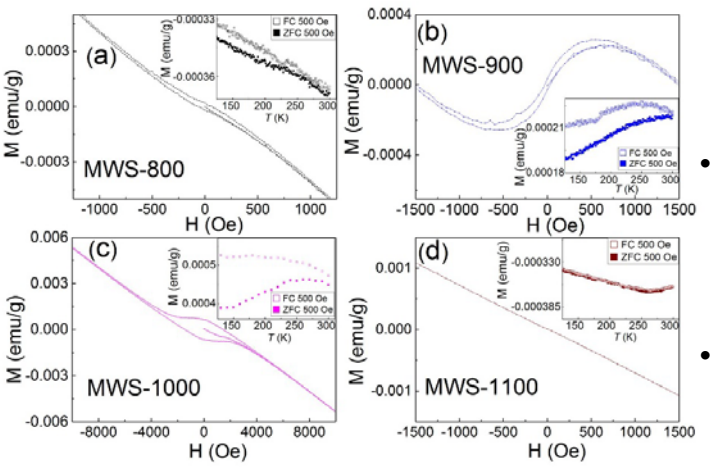
Experiment method

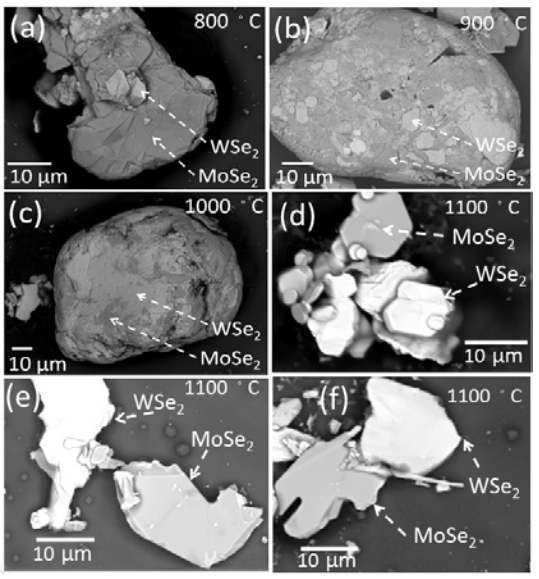
The mixed $WSe_2/MoSe_2$ powder is a commercial product and was purchased from SixCarbon Technology. Co. (ShenZhen, China) The purchased $WSe_2/MoSe_2$ powder was vacuum-sealed in a glass tube with a pressure of 10^{-3} torr, and then further thermally annealed. The $WSe_2/MoSe_2$ powder was heated up to target temperatures by a rate of 2.7˚C/min and maintained at target temperatures for 1 hour. After thermal annealing, it was naturally cooled down to room temperature.

Experimental Results



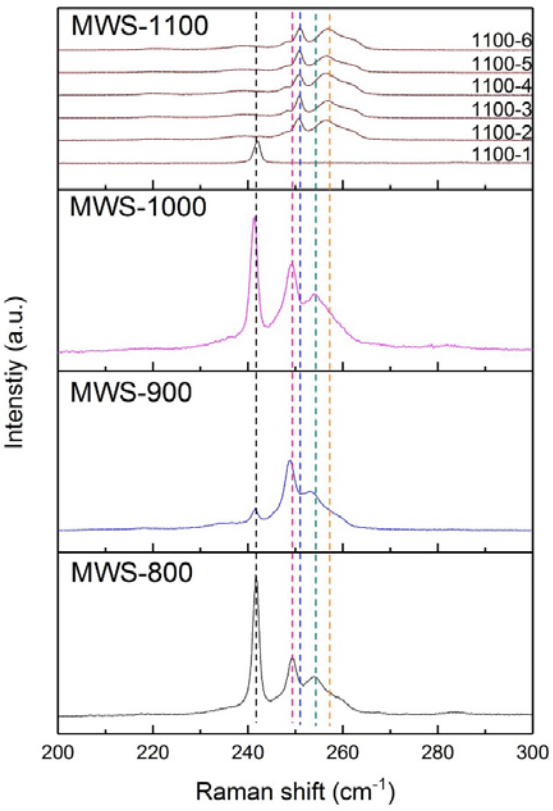
- The XRD spectrum of the MoSe2/WSe2 powder at different thermal annealing temperatures. No peak intensity and obvious peaks shift were observed in all thermal annealing temperatures, and that indicates that the thermal annealing does not change the crystal structure.
- Both MoSe2 and WSe2 are hexagonal structures, and the XRD peak is consistent with the database of hexagonal structures.
- The full-width at half height slightly decreases as the annealing temperature increases. This supports that the thermal annealing further slightly decreases lattice defects and crystallizes MWS powders.





- (a)–(f) show the SEM image of the MoSe2/WSe2 powder with different thermal annealing temperatures in the backscattering emission image mode.
- The EPMA result supports that the W:Se = 1:2 in the light zone and Mo:Se = 1:2 in the dark zone.
- The MoSe2 and WSe2 individually locate after 1100˚ thermal annealed. The others are chemically bonded.

- The magnetic field-dependent magnetization. Figure a–c reveals hysteresis loops. Figure d shows diamagnetism feature and no hysteresis loops.
- The inset shows the magnetization of field cool and zero field cool processes. The field cool and zero field cool curve split in all of the samples except for the MWS-1100.
- Accompany with the SEM images and Raman spectrum, the observed ferromagnetism originates from the chemical bonding between WSe2 and MoSe2.



Material	$MoSe_2$	MWS	WSe_2	MWS	WSe_2
mode	A_{1g}	red shift	A_{1g}	red shift	2LA(M)
unit	cm^{-1}	cm^{-1}	cm^{-1}	cm^{-1}	cm^{-1}
800	241.6	249.4	X	254.3	X
900	241.5	249.0	X	253.8	X
1000	241.5	249.3	X	254.8	X
1100-1	241.9	X	X	X	X
1100-2	X	X	250.7	X	256.6
1100-3	X	X	250.7	X	256.9
1100-4	X	X	250.7	X	256.3
1100-5	X	X	250.7	X	256.6
1100-6	X	X	251.0	X	256.9

- It is 242 cm^{-1} (MoSe2, A_{1g}, black dash line), 251 cm^{-1} (WSe2, A_{1g}, blue dash line) and 257 cm^{-1} (WSe2, 2LA (M), orange dash line) in the Raman spectra. The 249 cm^{-1} (WSe2, A_{1g}, red dash line) and 254 cm^{-1} (WSe2, 2LA (M), green dash line) are the red shift of the oscillation mode WSe2 A_{1g} and WSe2, 2LA (M), respectively.
- The Raman red shift peak is only observed in the MWS-800, MWS-900 and MWS-1000.

Conclusions:

- Ferromagnetism to non-ferromagnetism transition is detected in a chemical-bonded MoSe2/WSe2 powder with different thermal annealing temperatures.
- The MoSe2/WSe2 exhibits the ferromagnetism and Raman red shift, except for the 1100 ˚C thermally annealed sample in which the MoSe2 and WSe2 are thermally dissociated and geometrically separated. The element analysis reveals no significant element ratio difference and detectable magnetic elements in all samples.
- Our experimental studies conclude that in contrast with the widely reported structure defect or transition element dopant, the ferromagnetism originates from the structure distortion due to the chemical bonding at the interface between MoSe2 and WSe2.