

## Magnetic properties of the ferrimagnetic $\text{FeCr}_{2-x}\text{M}_x\text{S}_4$ ( $\text{M}=\text{In}, \text{Al}$ )

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The polycrystalline samples of ferrimagnetic  $\text{FeCr}_{2-x}\text{M}_x\text{S}_4$  ( $\text{M}=\text{In}, \text{Al}$ ;  $x=0.1, 0.3$ ) have been studied with x-ray diffraction, magnetization, and Mössbauer spectroscopy measurements. The crystal structure was found to be cubic spinel with  $Fd-3m$  space group. The lattice constants ( $a_0$ ) of the samples were linearly increased with Al and In concentration. Mössbauer spectra of  $\text{FeCr}_{2-x}\text{M}_x\text{S}_4$  ( $\text{M}=\text{In}, \text{Al}$ ;  $x=0.1, 0.3$ ) were obtained at various temperatures ranging from 4.2 to 300 K. Magnetic hyperfine field and electric quadrupole interactions for  $\text{FeCr}_{2-x}\text{M}_x\text{S}_4$  ( $\text{M}=\text{In}, \text{Al}$ ;  $x=0.1$ ) at 4.2 K have been fitted, yielding the following results: for  $\text{M}=\text{Al}$ ,  $H_{\text{hf}}=139$  kOe,  $\Delta E_{\text{Q}}=2.54$  mm/s,  $\theta=30^\circ$ ,  $\varphi=0.0^\circ$ ,  $\eta=0.9$ , and  $R=2.7$ ; and for  $\text{M}=\text{In}$ ,  $H_{\text{hf}}=126$  kOe,  $\Delta E_{\text{Q}}=2.64$  mm/s,  $\theta=30^\circ$ ,  $\varphi=0.0^\circ$ ,  $\eta=1.0$ , and  $R=3.1$ . The isomer shift ( $\delta$ ) value of the  $\text{FeCr}_{2-x}\text{M}_x\text{S}_4$  ( $x=0.1$ ) samples for both  $\text{M}=\text{Al}$  and  $\text{In}$  at 300 K was 0.50 mm/s, relative to the Fe metal, which is consistent with the  $\text{Fe}^{2+}$  valence state. The Debye temperatures ( $\Theta_{\text{D}}$ ) of the  $\text{FeCr}_{2-x}\text{Al}_x\text{S}_4$  ( $x=0.1, 0.3$ ) sample were determined to be  $299 \pm 5$  and  $247 \pm 5$  K, respectively, and those of the  $\text{FeCr}_{2-x}\text{In}_x\text{S}_4$  ( $x=0.1, 0.3$ ) samples were determined to be  $257 \pm 5$  and  $239 \pm 5$  K, respectively. © 2010 American Institute of Physics. [doi:10.1063/1.3337662]