Supporting information

A facile synthesis of phase-pure FeCr$_2$Se$_4$ and FeCr$_2$S$_4$

nanocrystals via wet chemistry method

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Conductivity mechanism:

A simplified expression of conductivity can be obtained by converting the previous equation. As shown in Debye’s isotropic continuum model, the resulting expression is:

\[
I = H^2 Q_d^5 / 6\pi^2 K_b T^2 \sum_{s}^{\bar{\mu}} \left( C_s^+ \right) \frac{d}{dx} x^4 \Gamma_\bar{n}(\bar{n} + 1) \tag{1}
\]

In equation (1), where \( x = Q/Q_d \) and \( \Gamma \) and \( \bar{n} \) understood as functions of \( x, T \) and polarization \( s \). The total relaxation is \( \Gamma_{qs}^{-1} = \sum \Gamma_{qs}^{-1}(i) \), with \( \Gamma_{qs}^{-1}(i) \) being the relaxation due to the phonon mechanism. The conductivity can be approximate as:

\[
I = (H^2 / 3 N_0 \Omega K_B T^2) \sum_{qs} \sigma \cos^2(qs) \omega^2(qs) \tau(qs) nqs(nqs + 1) \tag{2}
\]

\[
\sigma = \lambda_L / L^* T \tag{3-1}
\]

\[
\Delta \Omega = \Delta W*V*L_s^{1/2}/W*V = \Delta W*L_s^{1/2}/W \tag{3-2}
\]

In equation (2), provided reasonable forms of the phonon-dispersion relation \( \omega = \omega(qs) \) and relaxation time \( \tau(qs) \) are chosen, it should be straightforward to be proved by the conductivity of a crystal lattice contribution \( (\lambda_L) \). The nature of conductivity is dependent on the NCs’s \( \lambda_L \), where \( L \) is the Lorenz factor, \( \sigma \) stands for the extent of NCs’ crystallization; \( T \) is the temperature value in conductivity measurements (3-1).

The related resistivity \( \Delta \Omega \) which is dependent on the NCs’ size paremeter\( (L_s) \), where \( \Delta W \) is the increase over the crystal resistivity \( W \), \( L_s \) is the average grain size, \( V \) is the volume of NCs (3-2).

References:

Figure S1: The TEM and HR-TEM images of single FeCr$_2$Se$_4$ NCs. Inserted scale bars are 10nm and 2nm, respectively.

Figure S2: The TEM images of growth process: FeCr$_2$Se$_4$ (up) and FeCr$_2$S$_4$ (bottom).
Figure S3: (a) FE-SEM image of OLA-capped NCs. (b) SEM-EDS spectra of FeCr$_2$Se$_4$ NCs.
Figure S4: (a) FE-SEM image of OLA-capped NCs. (b) SEM-EDS spectra of FeCr$_2$S$_4$ NCs.

Figure S5. Representative TEM images of the products collected from the reaction with the same condition with different precursor molar ratio used in the synthesis of nanocrystals.
The TGA data of FeCr$_2$Se$_4$ NCs (black) and FeCr$_2$S$_4$ NCs (red) were obtained (see Figure S6). For the FeCr$_2$Se$_4$ and FeCr$_2$S$_4$ NCs, the onset of decomposition occurred at 260 °C and 254 °C, and the decomposition temperature of FeCr$_2$Se$_4$ and FeCr$_2$S$_4$ NCs were 670 °C and 750 °C with a mass loss of 32.5% and 22.5%, respectively.

Figure S6: Thermal gravimetric analyses of FeCr$_2$Se$_4$ and FeCr$_2$S$_4$ NCs.
Figure S7 Magnetization ($M$) as a function of field ($H$) for FeCr$_2$Se$_4$ and FeCr$_2$S$_4$ NCs at (A, C) 5 K and (B, D) 300 K.
Figure S8: Magnetization (M) as a function of temperature for field-cooled (FC) and zero-field-cooled (ZFC) measurements at 50 Oe for FeCr$_2$Se$_4$ (A) and FeCr$_2$S$_4$ (B) respectively.
Figure S9: Simple fabrication schematic diagram (upper image) and two point Au electrode pad (insert scale bar is 200 micrometer); and SEM images of FeCr$_2$Se$_4$ film (A) and FeCr$_2$S$_4$ film (B), respectively.

Figure S10: I-V curves of drop-casting films built from NCs, the range of voltage was from -1.25eV~1.25eV.