

J. Typek<sup>1</sup>, K. Wardal<sup>1</sup>, G. Zolnierkiewicz<sup>1</sup>, N. Guskos<sup>1</sup>, D. Sibera<sup>2</sup>, U. Narkiewicz<sup>2</sup>, E. Piesowicz<sup>3</sup>

<sup>1</sup>Institute of Physics, West Pomeranian University of Technology, Al. Piastow 48, 70-311 Szczecin, Poland

<sup>2</sup>Institute of Chemical and Environmental Engineering,  
West Pomeranian University of Technology, K. Pulaskiego 10, 70-322 Szczecin, Poland

<sup>3</sup>Institute of Material Engineering, West Pomeranian University of Technology, Al. Piastow 19, 70-310 Szczecin, Poland

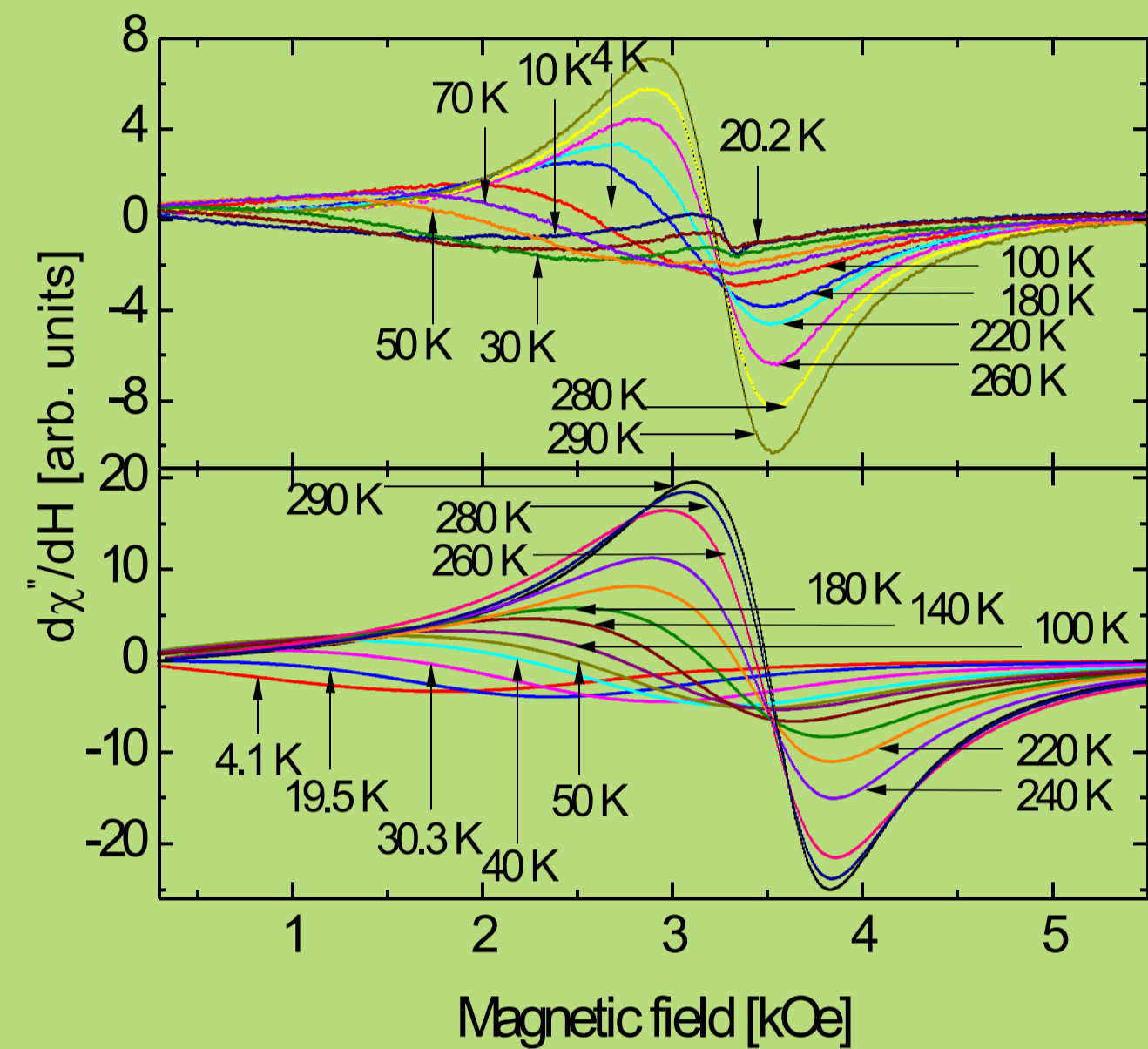


Fig. 1. FMR spectra registered at different temperatures: polymer (top panel), nanopowder (bottom panel) sample.

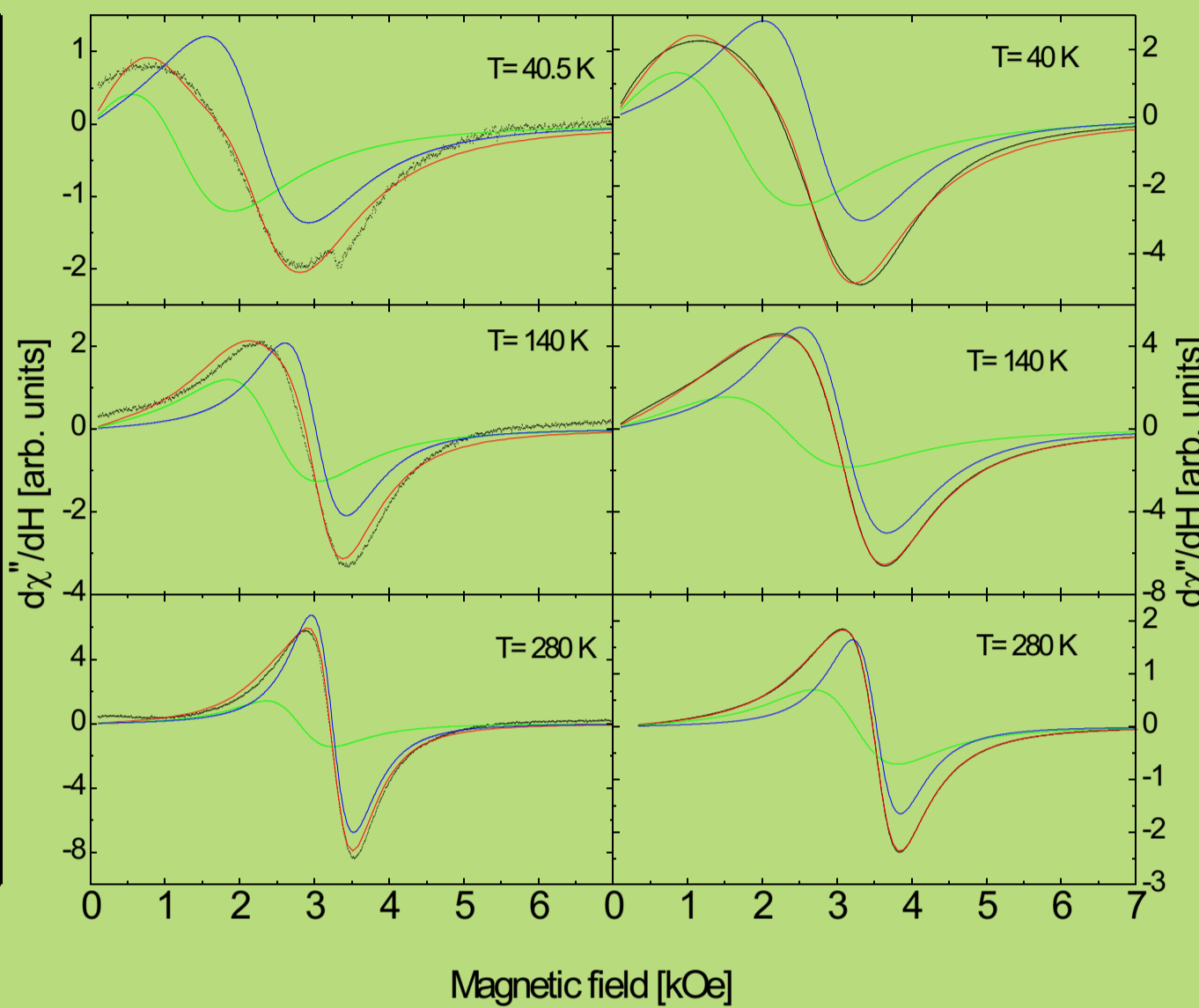


Fig. 2. Fitting of the observed FMR spectra of the nanopowder (left panels) and polymer (right panels) sample with two LL components at three different temperatures.

## Experimental

Nanopowders 0.90 Fe<sub>2</sub>O<sub>3</sub>/0.10 ZnO obtained by the traditional wet chemistry method followed by calcination process in concentrated form and embedded at a concentration of 0.1 wt.% in PEN-b-PTMO polymer were studied by dc magnetization and ferromagnetic resonance (FMR) measurements. Only two phases were detected by XRD and Raman methods: Fe<sub>2</sub>O<sub>3</sub> and ZnFe<sub>2</sub>O<sub>4</sub>. An average size of nanocrystalites was 24 nm for Fe<sub>2</sub>O<sub>3</sub>.

Magnetic resonance measurements were performed on a conventional X-band (=9.4 GHz) Bruker E 500 spectrometer with 100 kHz magnetic field modulation. The temperature measurements of FMR spectra were performed in the temperature range of 4-290 K using Oxford helium-flow cryostat. Magnetic measurements in the temperature range of 293-443 K were performed on Radiopan SE/X 2544-M spectrometer.

DC magnetization measurements were performed on a MPMS-7 SQUID magnetometer in the 2-300 K temperature range and magnetic field up to 70 kOe.

The shapes of the FMR spectra were fitted by using two Landau Lifshitz lines.

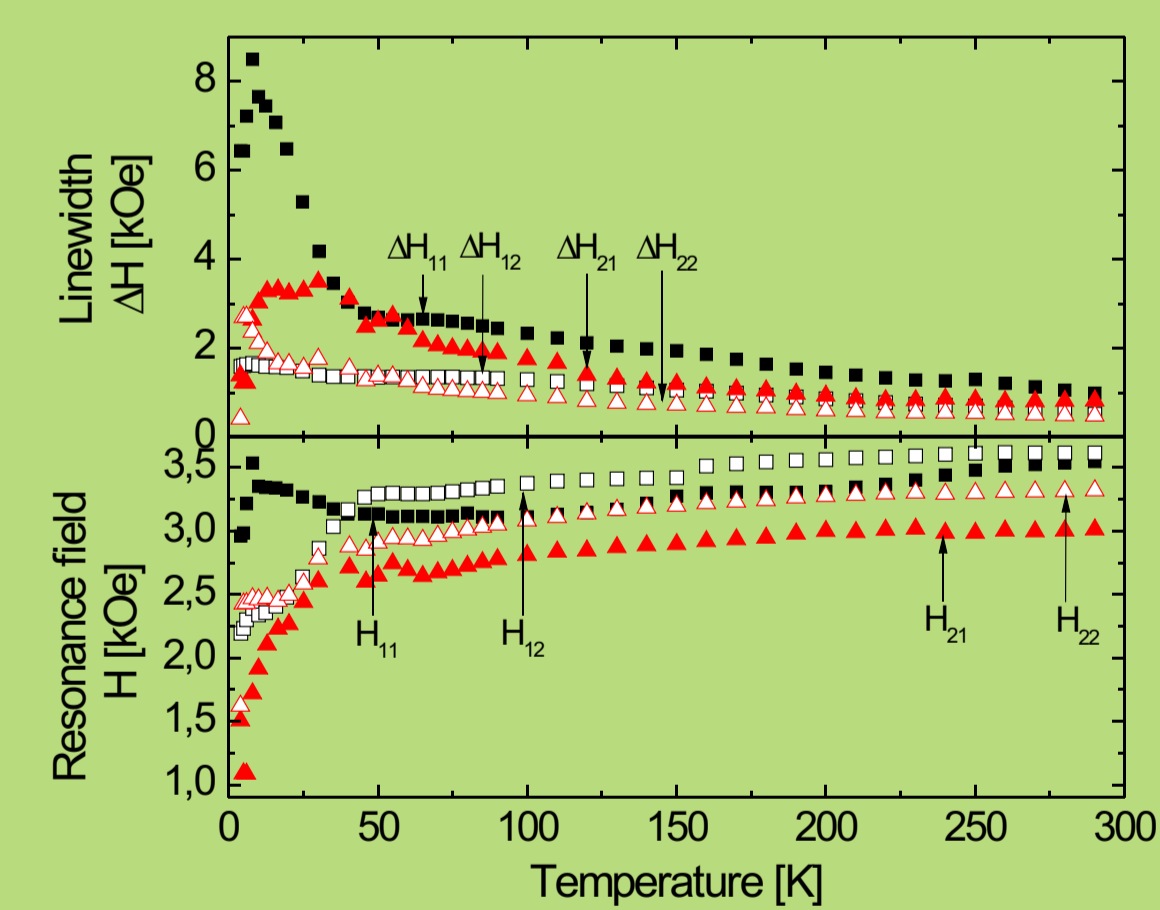


Fig. 3. Temperature dependence of linewidths (top panel) and resonance fields (bottom panel) of two components in nanopowder (full and empty black squares) and polymer (full and empty red triangles) samples.

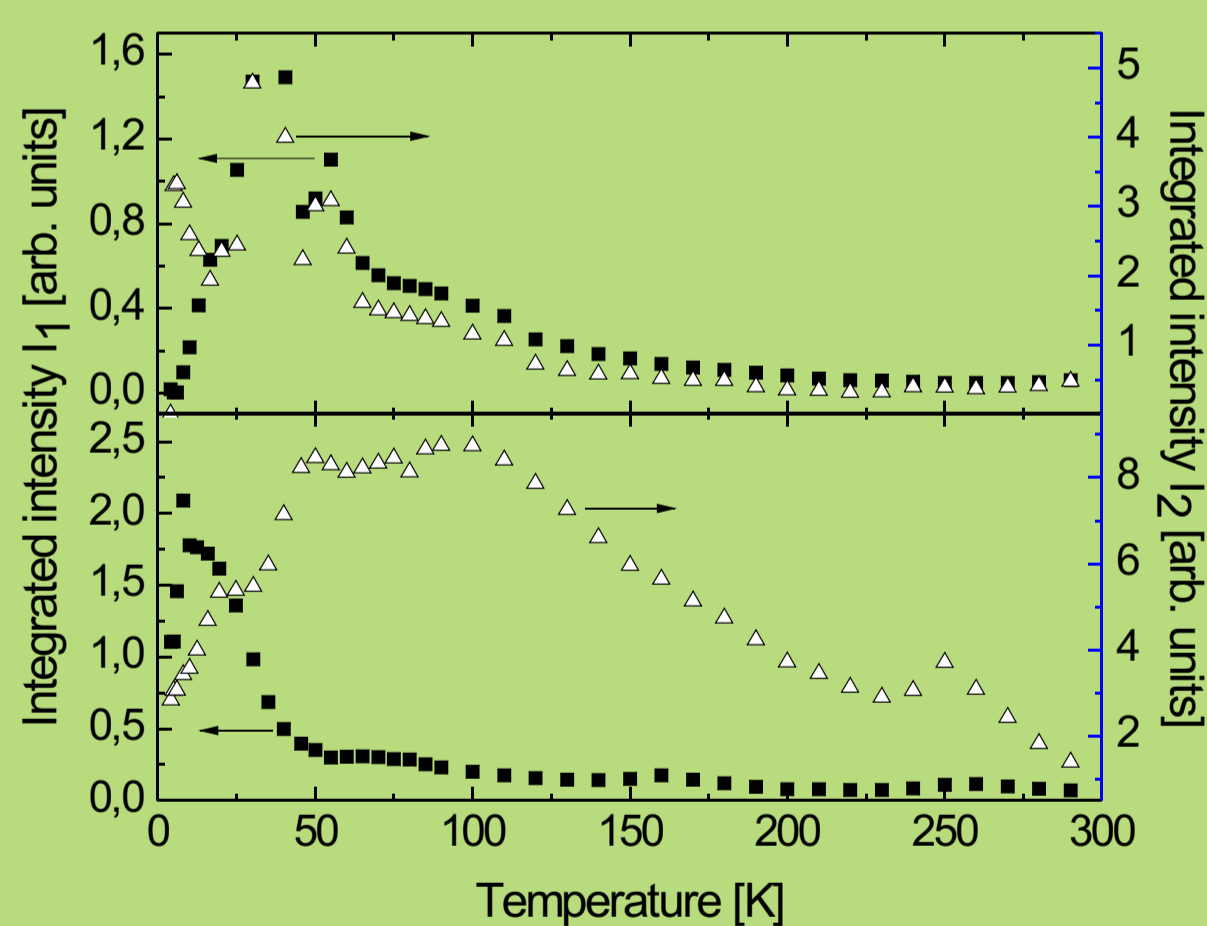


Fig. 4. Temperature dependence of integrated intensity of the two components in polymer (top panel) and nanopowder (bottom panel) samples. Different left- and right-hand vertical scales are used.

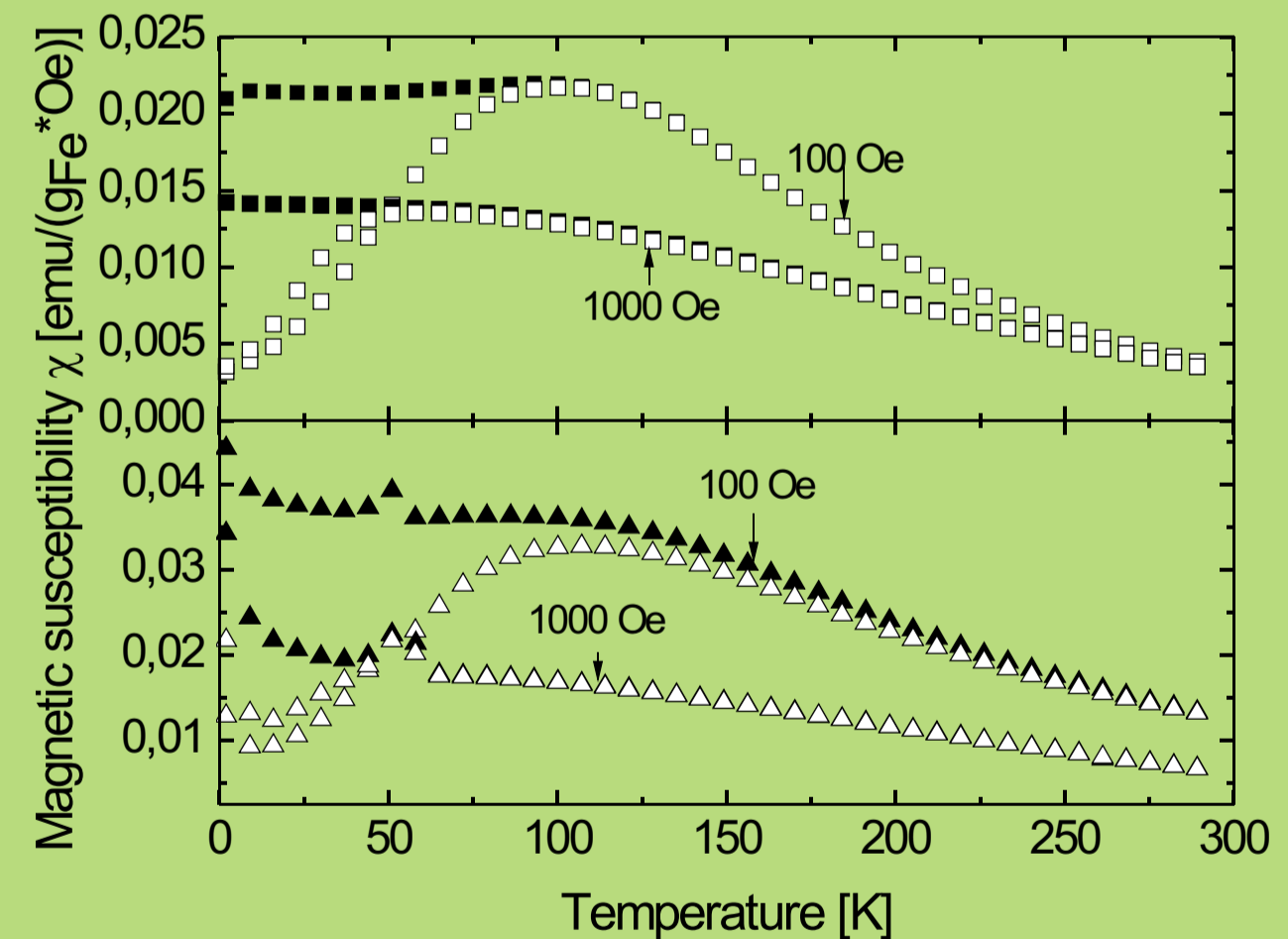


Fig. 5. Temperature dependence of dc susceptibility in ZFC (empty symbols) and FC (full symbols) modes obtained for nanopowder (top panel) and polymer (bottom panel) sample.

## Conclusions

FMR spectra of nanopowder and polymer sample taken at different temperatures in the 4 - 300 K range are presented in Fig. 1. All registered spectra could be very well fitted with the sum of two Landau-Lifshitz (LL) lines (Fig. 2). The LL lineshape function is given by the following equation

$$\chi''(B) = \frac{1}{\pi} \frac{B_r^2 [(B_r^2 + \Delta_B^2) B^2 + B_r^4] \Delta_B}{[B_r^2 (B - B_r)^2 + B^2 \Delta_B^2] [B_r^2 (B + B_r)^2 + B^2 \Delta_B^2]}$$

where  $B_r$  is the resonance field and  $\Delta_B$  is the linewidth. Usage of two LL components can be explained by the presence of two different nanoparticles: ZnFe<sub>2</sub>O<sub>4</sub> and  $\gamma$ -Fe<sub>2</sub>O<sub>3</sub>, as evidenced by XRD. From the synthesis reaction it follows that there should be 3.62 times more  $\gamma$ -Fe<sub>2</sub>O<sub>3</sub> than ZnFe<sub>2</sub>O<sub>4</sub>. In Figure 3 temperature dependence of linewidths and resonance fields of the two components determined from the fittings is presented, in nanopowder and polymer sample. The resonance fields and linewidths of components are generally smaller in polymer sample than in nanopowder what can be explained by lower magnetic anisotropy of nanoparticles. In Figure 4 temperature dependence of the integrated intensity of the two components in polymer and nanopowder samples is shown. The ratio of integrated intensity of each component reflects its relative concentration and is consistent with calculated amount of  $\gamma$ -Fe<sub>2</sub>O<sub>3</sub> and ZnFe<sub>2</sub>O<sub>4</sub> phases. In polymer samples both components reach a maximum intensity at ~40 K, but in nanopowder there is a considerable temperature difference between both maxima. It may indicate the presence of larger aggregates in that sample. Figure 5 shows temperature dependence of dc susceptibility in ZFC and FC modes obtained for nanopowder and polymer sample. In the high temperature range (depending on the applied magnetic field) the superparamagnetic phase is detected. ZFC mode susceptibility displays typical for nanoparticles behavior with blocking temperature (~50 K in H=1 kOe) which is the same for both types of samples. Low temperature behavior of ZF susceptibility in polymer sample indicate on the presence of an additional paramagnetic component.