Low-Frequency Noise of Magnons

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The majority of devices for information processing and sensing applications are based on the charge transfer in different media, e.g. semiconductors, metals, vacuum, etc. Recently, significant attention received a completely different approach owing to the development of magnonics - subfield of spintronics, which deals with the manipulation of the spin currents carried by the magnetization waves – magnons – in electrical insulators [1]. Spin current in insulators avoids Ohmic losses and, therefore, Joule heating. A number of new devices based on magnon propagation have already been proposed and demonstrated for data processing, sensing and imaging applications [1 - 4]. The operation frequency of magnonic devices expands from the low GHz to THz frequency ranges. The key material for these devices is Yttrium Iron Garnet (YIG). It is also used for filters and resonators, operating at frequencies up to 26 GHz.

Despite the strong interest to magnonic devices, their low-frequency noise characteristics remained largely unexplored. In this paper, we report the low-frequency noise of magnons in a YIG waveguide, focusing specifically on the phase noise. The YIG-film of 9.6 µm thickness and 1.5 mm × 15 mm in dimensions was grown on the Gadolinium Gallium Garnet (GGG, Gd3Ga5O12) substrate by the liquid phase epitaxy. The Ti/Au antennas for spin wave (SW) excitation and detection were fabricated on the surface of YIG-film waveguide (see inset in Figure 1). The devices were placed in magnetic field created by the permanent neodymium magnets. Depending on the orientation of the magnetic field, the spin waveguide structure supports either the magneto-static surface spin waves (MSSWs) or backward volume magneto-static spin waves (BVMSWs). Propagating in the waveguide, magnon current acquires variations in the amplitude and phase due to the fluctuations of the physical properties of the YIG thin film.

We found that the low-frequency amplitude noise of magnons increases sharply at the on-set of nonlinear dissipation processes. In this regime, the noise is dominated by the random telegraph signal (RTS) noise with the large number of magnons participating in each RTS step [5]. Although RTS noise was not found in the phase fluctuations, the noise spectra of the phase noise within the frequency range 10 Hz < f < 1 kHz also had the form of the Lorentzians with the characteristic frequency within 10 Hz – 100 Hz (see Figure 1). With the excitation power of ~2 dBm on one of the antennas, the phase noise at the frequency of 10 Hz was measured to be around -68 dB/Hz.

We attributed the phase noise to the magnetization wave phase velocity fluctuations. The velocity fluctuations can be estimated as $S_{\Phi}/V^2$=Sw/Ψi, where $\Psi_i$ is the phase difference accrued by the spin wave between the antennas, which can be measured by the vector network analyzer. We found $\Psi_i$=93 rad, which gives $S_{\Phi}/V^2 \approx 2 \times 10^{-11}$ Hz$^{-1}$ at the frequency of the analysis $\approx 10$ Hz. This value of the velocity fluctuations can be used to estimate the phase fluctuations in the waveguides of an arbitrary length.

In conclusion, the low-frequency noise of MSSWs was measured in YIG waveguides at the frequencies $f<1$ kHz. The noise spectra had the Lorentzian shape with the characteristic frequencies below 100 Hz. At these frequencies, the noise of magnons sets the limit for data processing, sensing and imaging applications. It can also contribute significantly to the phase noise of RF devices based on YIG crystals.