UNIVERSITY OF CALIFORNIA,
IRVINE

Spin torque driven magnetization dynamics in nanoscale magnetic tunnel junctions

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Physics

by

Chengcen Sha

Dissertation Committee:
Professor Ilya Krivorotov, Chair
Professor Zuzanna Siwy
Professor Wilson Ho

2018

DEDICATION

To My parents, Zhenglian and Wenyu.

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ACKNOWLEDGMENTS

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ABSTRACT OF THE DISSERTATION

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Doctor of Philosophy in Physics

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Professor Ilya Krivorotov, Chair

Change the abstarct!!!!!!!

Bibliography

Appendix A

Appendix Title

A.1 Detailed System Design of Perpendicular station

We have developed one of the most sensitive Spin-torque ferromagnetic resonance perpendicular magnetic stations. Here we describe the detailed system designs.

First of all, here is all the equipments needed to build the out-of-plane magnetic probe station:

1. GMW Dipole Electromagnet Model 3470
2. Kepco bipolar operational power supply model Model 50-8M
3. Cascade RF probe : SG-120um
4. Cascade RPP210-AI probe positioner (both the probe and the positioner are non-magnetic)
5. Sentech Output 720p Cased Camera

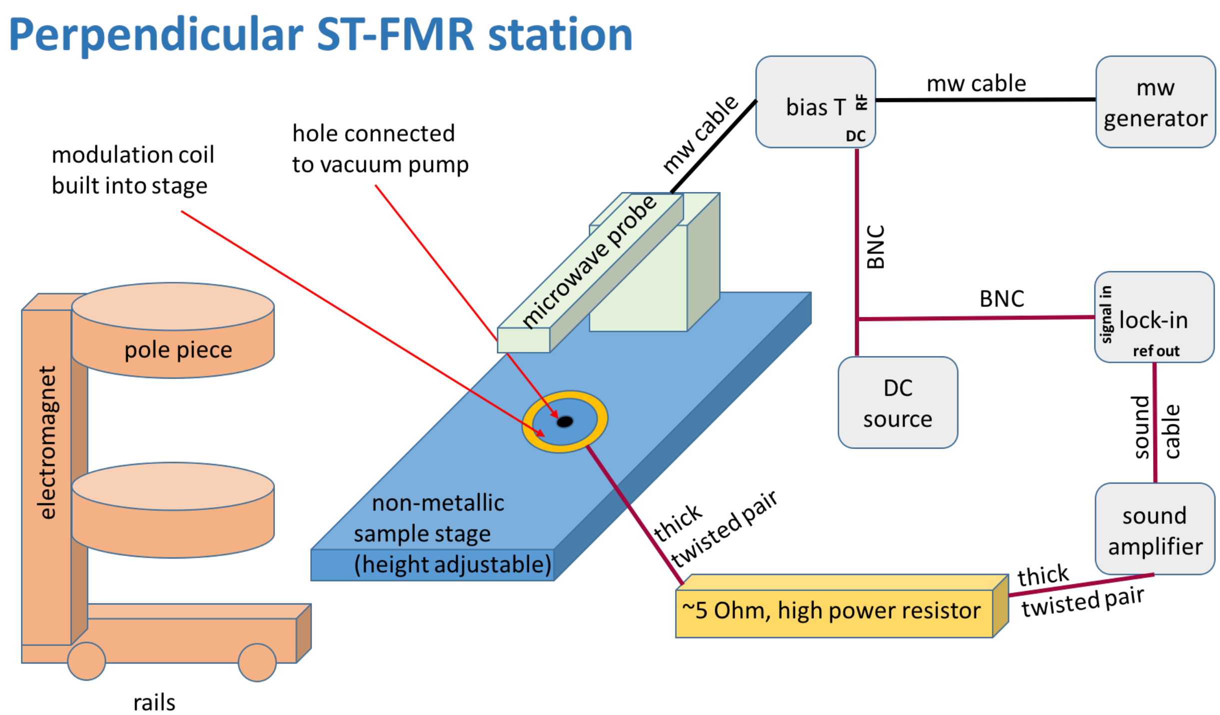


Figure A.1: Perpendicular ST-FMR station Setup

6. Navitar 12X Zoom Lens System

7. AmScope LED-80M 80-LED Microscope Ring Light

Fig.A.1 sketches the design of the out-of-plane station.The magnet is fixed vertically on metal frame and the stage height is adjustable. At first, we can land the probe to make contact of the sample with the magnet moving away(shown in Fig.A.2(a). After making contact of the sample, first remove the camera (the setup could be improved by making a stationary camera). Then we can slide in the magnet so that the sample is located in the center of the magnet. It is important not to touch the probe and microwave cable when sliding the magnet. After moving the magnet we are ready to make ST-FMR measurement as showing in Fig.A.2(b).

Here is the list of equipments needed for making ST-FMR measurements up to 40 GHz.

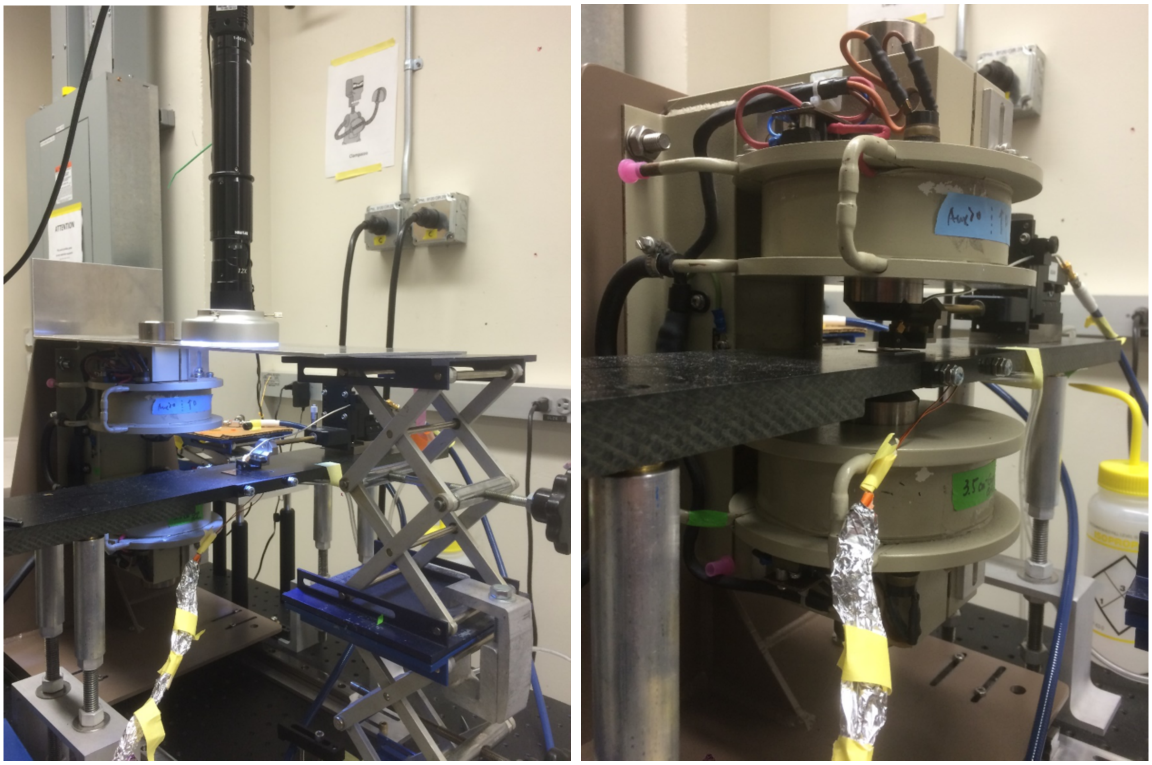


Figure A.2: Operation of Out-of-plane probe station

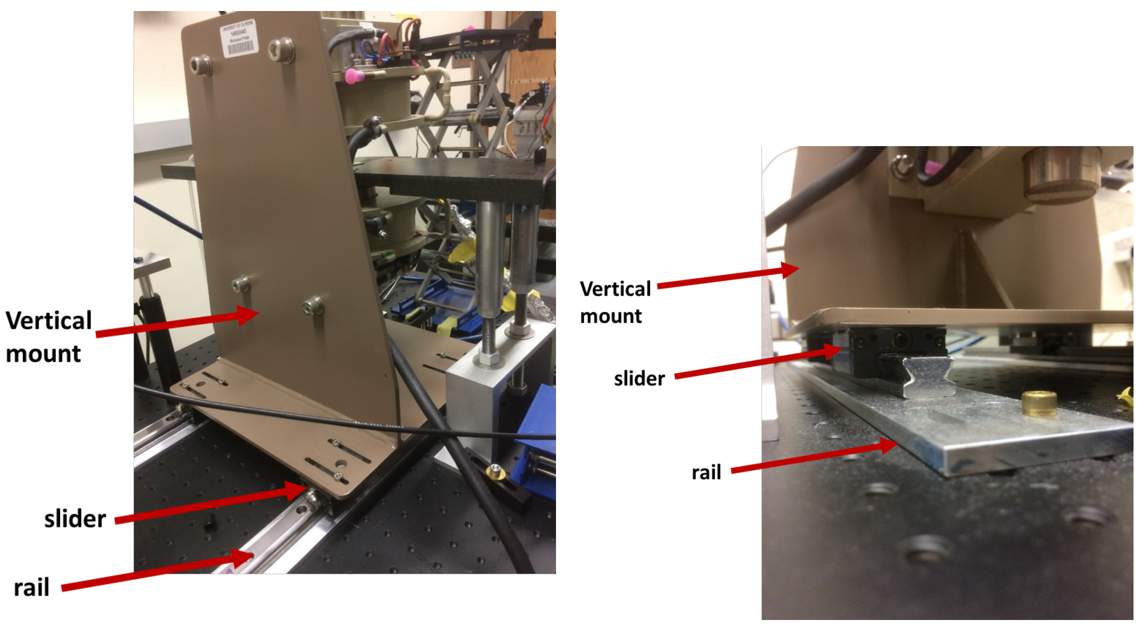


Figure A.3: (a) Side view of the magnet. (b) Bottom view of the magnet

1. Signal recovery 7225 DSP lock-in Amplifier
2. Hittite HMC-T2240 synthesized signal generator, 10 MHz to 40 GHz
3. Clear Microwave Broadband Bias Tee BT50K40 50Khz-40GHz
4. Keithley 2400 Source Meter (DC Source)
5. Microwave cable : Teledyne Accutest R95-0004-072 (72 inch 1GHz- 40GHz)
6. Pomona BNC cables

When connecting the microwave cables, there are two small things worth notice. Firstly, all the connectors should be cleaned regularly. Secondly, the microwave cables should be supported to release all the possible tensions.

The last pieces of equipments needed is the field modulation setup. Here is the list:

1. Behringer EUROPOWER Professional 4,000-Watt Stereo Power Amplifier
2. TE CONNECTIVITY / CGS CJT10004R7JJ Through Hole Wire wound Resistor, 4.7 Ohm
3. High quality cable connecting from lock-in to the input of the sound amplifier : Monster Performer 500 - 10' Speaker Cable
4. BK Precision 2831E Ammeter to control the current through the copper wire

When making the field-modulation coil, it is better to use any low resistance copper wire for magnetic field modulation coil. For out-of-plane field modulations, we use an external coil above the sample as shown in Fig.A.4(a). In-plane field modulation can be achieved by simply placing straight wire above the sample as shown in Fig.A.4(b). In our current design,

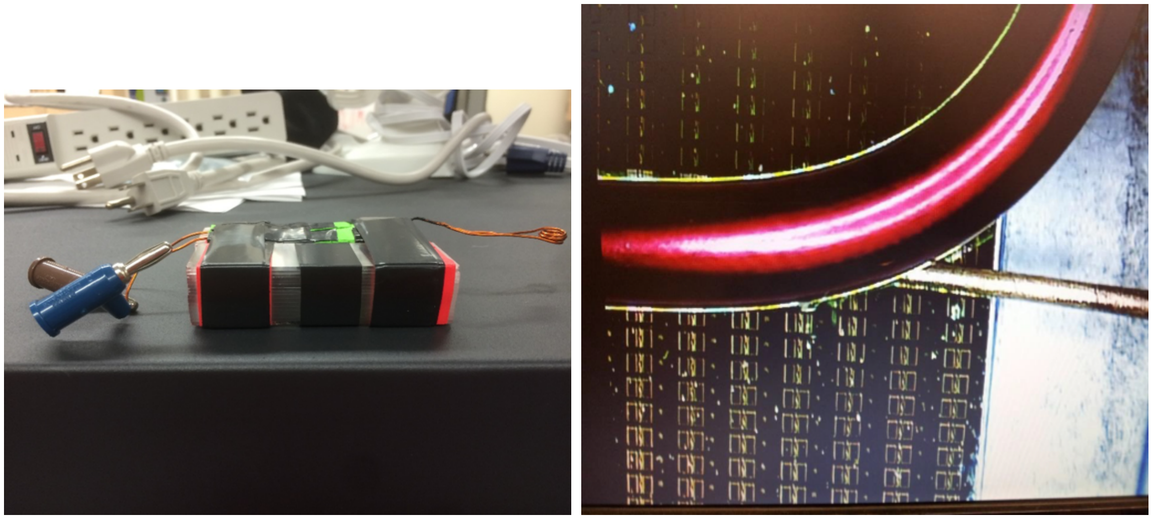
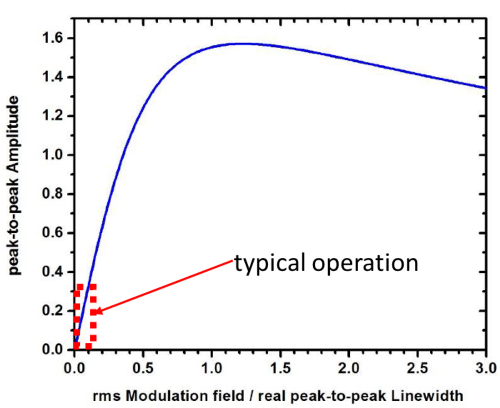


Figure A.4: (a) Coil for out-of-plane modulation (b) Wire for in-plane modulation

we embed the coil into the plastic base right under the sample. It is important to ensure that the wire is not in contact with the sample or any other parts of the microwave setup.

In the experiment, two parameters need to be determined for the field modulation: the amplitude of modulation field and the frequency of the modulation ac field. Typically Increasing the modulation field increases the signal amplitude, but not infinitely as shown in Fig.A.5(a). If you are over-modulating, the signal becomes distorted and the linewidth broadens as shown in Fig.A.5(b). In our current setup, the input ac current is about 3.6 A to achieve the modulation field around a few oersted field, which is enough to have decent signal-to-noise ratio without distorting the spectrum.



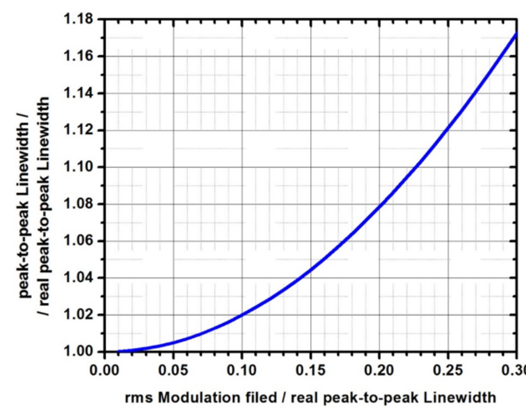


Figure A.5: (a) Peak-to-peak amplitude versus rms modulation field over real peak-to-peak linewidth. (b) peak-to-peak linewidth over real peak-to-peak linewidth versus rms modulation field over real peak-to-peak linewidth.

Mode 0	10.98	11.92	11.57	11.98	10.94	11.71	10.94	11.84	11.38	11.8	12.09
Mode 1	12.85	14.6	13.98	14.64	13.21	14.28	13.05	13.6	14.29	14.66	14.01
Mode 2	13.75	15	15.4	15.33	13.2	15.48	13.66	14.57	14.86	15.24	14.18
Gap 0-1	1.87	2.68	2.41	2.66	2.27	2.57	2.11	1.76	2.91	2.86	1.92
Gap 0-2	2.77	3.08	3.83	3.35	2.26	3.77	2.72	2.73	3.48	3.44	2.09
Gap (1+2)/2 - 0	2.32	2.88	3.12	3.005	2.265	3.17	2.415	2.245	3.195	3.15	2.005

Table A.1: C06 70nm summary

Mode 0	9.83	10.5	11.05	10.54	11.89	11.39	11.2	10.39	10.61	10.39	11.07
Mode 1	11.76	12.68	13.24	12.61	13.78	13.6	13.19	12.85	13.47	12.6	13.02
Mode 2	12.71	13.04	13.86	13.04	14.88	14.29	13.5	14.06	13.79	12.99	13.99
Gap 0-1	1.93	2.18	2.19	2.07	1.89	2.21	1.99	2.46	2.86	2.21	1.95
Gap 0-2	2.88	2.54	2.81	2.5	2.99	2.9	2.3	3.67	3.18	2.6	2.92
Gap (1+2)/2 - 0	2.405	2.36	2.5	2.285	2.44	2.555	2.145	3.065	3.02	2.405	2.435

Table A.2: C07 80nm Summary

Mode 0	9.94	10.19	9.28	10.54	9.14	9.14	9.6	9.77	9.13	10.51
Mode 1	11.65	12.41	10.93	12.29	11.2	11.2	12.07	11.8	10.69	11.96
Mode 2	12.15	12.66	12.07	12.29	12.05	12.05	12.36	12.9	11.26	12.65
Gap 0-1	1.71	2.22	1.65	1.75	2.06	2.06	2.47	2.03	1.56	1.45
Gap 0-2	2.21	2.47	2.79	1.75	2.91	2.91	2.76	3.13	2.13	2.14
Gap 0-(1,2)	1.96	2.345	2.22	1.75	2.485	2.485	2.615	2.58	1.845	1.795

Table A.3: C08 90nm summary

Mode 0	7.88	9.62	9.09	8.97	9.07	8.84	9.24	8.35	8.75	8.77	7.96
Mode 1	9.55	11.4	10.43	10.36	10.4	10.25	10.47	10.23	10.35	10.57	9.89
Mode 2	9.96	11.59	10.52	11.2	10.7	10.52	11.8	10.59	11.31	10.61	10.49
Gap 0-1	1.67	1.78	1.34	1.39	1.33	1.41	1.23	1.88	1.6	1.8	1.93
Gap 0-2	2.08	1.97	1.43	2.23	1.63	1.68	2.56	2.24	2.56	1.84	2.53
Gap 0-(1,2)	1.875	1.875	1.385	1.81	1.48	1.545	1.895	2.06	2.08	1.82	2.23

Table A.4: C09 120 nm

Mode 0	8.02	7.61	7.81	8.13	7.86	7.94	7.85	7.46	7.18	8.33	8.73	7.98	7.65
Mode 1	9.71	8.8	9.36	9.13	9.27	9.37	9.16	8.79	8.13	9.3	9.73	9.14	8.77
Mode 2	9.9	8.96	9.83	9.81	9.52	9.37	9.44	9.42	8.71	9.91	10.22	9.6	9.21
Gap 0-1	1.69	1.19	1.55	1	1.41	1.43	1.31	1.33	0.95	0.97	1	1.16	1.12
Gap 0-2	1.88	1.35	2.02	1.68	1.66	1.43	1.59	1.96	1.53	1.58	1.49	1.62	1.56
Gap 0-(1,2)	1.785	1.27	1.785	1.34	1.535	1.43	1.45	1.645	1.24	1.275	1.245	1.39	1.34

Table A.5: C10 150 nm summary