Nanomagnetics for Thin-Film Inductor Design

Poster by Dave Kopp. Acknowledgements: Yuqin Sun, Charles Sullivan, Weidong Li,Satish Prabhakaran, et. al; NSF; DoD; Thayer School; Dartmouth College

A one-turn V-groove inductor for high frequency applications is shown in **Figure 1**. Current that flows down the copper wire is linked by the magnetic layer to form the inductor. The substrate may be silicon, which means that it may be placed on the same wafer as traditional components. The insulation can then be SiO_2. The wire may be copper that has been electrodeposited onto a sputtered seed layer. Finding a suitable magnetic material to wrap the wire forms the basis for this work.

V-Groove Design:

1. Bake silicon at high temperatures in the presence of oxygen to passivate the base and provide a nice surface for sputtering
2. Mask oxide except on v-groove and etch with HF
3. Anisotropically etch the exposed Si with KOH to form a 55° angle v-groove.
4. Sputter magnetic material in the v-groove.
5. Sputter a thin layer of copper for as an electroplating seed.
6. Spin photoresist on the wafer surface, and expose the photoresist on the v-groove to remove it, as this this protects the wafer surface from electrodeposition.
7. Electroplate a thick layer of copper (from a CuSO4 bath) to form a wire.
8. Chemically and mechanically polish the surface
9. Sputter more magnetic material on top to complete the magnetic loop.
10. Fabricate contacts and passivate the surface, completing the inductor.

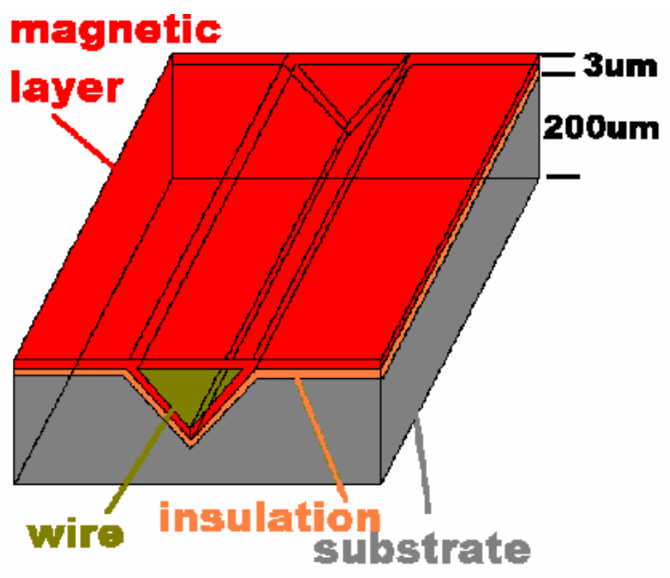


Fig. 1: The inductor design.

Equipment:

Denton sputtering system
4-wire ohmmeter
B-H curve tracer
Alpha-step profilometer
Xray diffraction tester
Scanning electron microscope

Time: 8 weeks

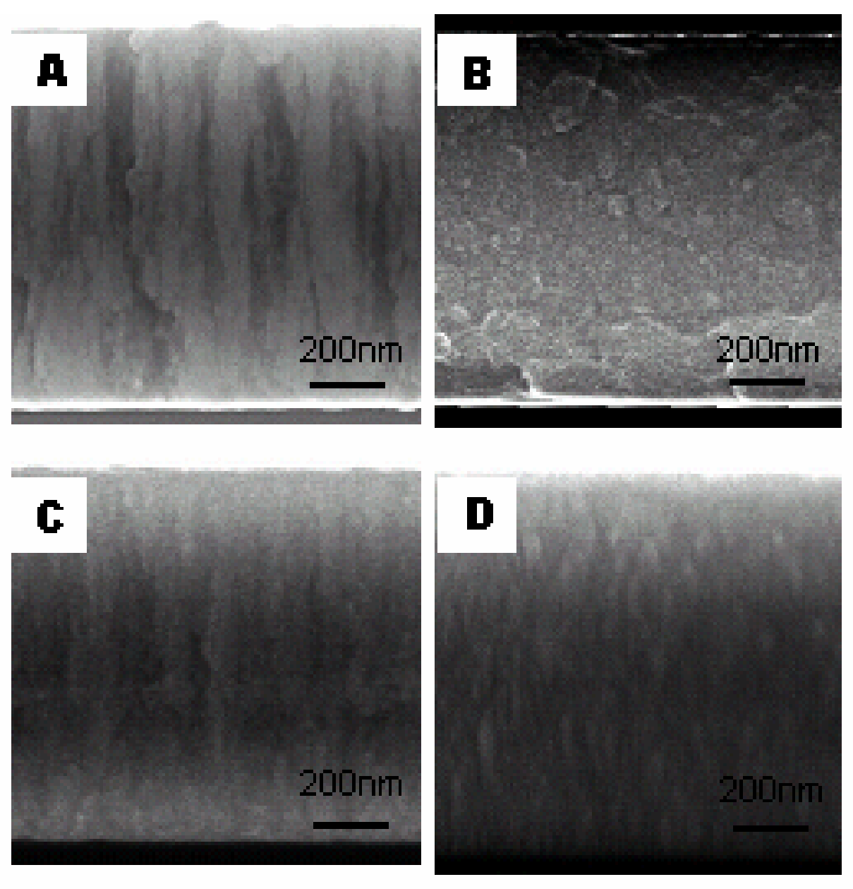


Fig. 2: B has good magnetic properties; the others, with BH loops, show signs of columnar growth.

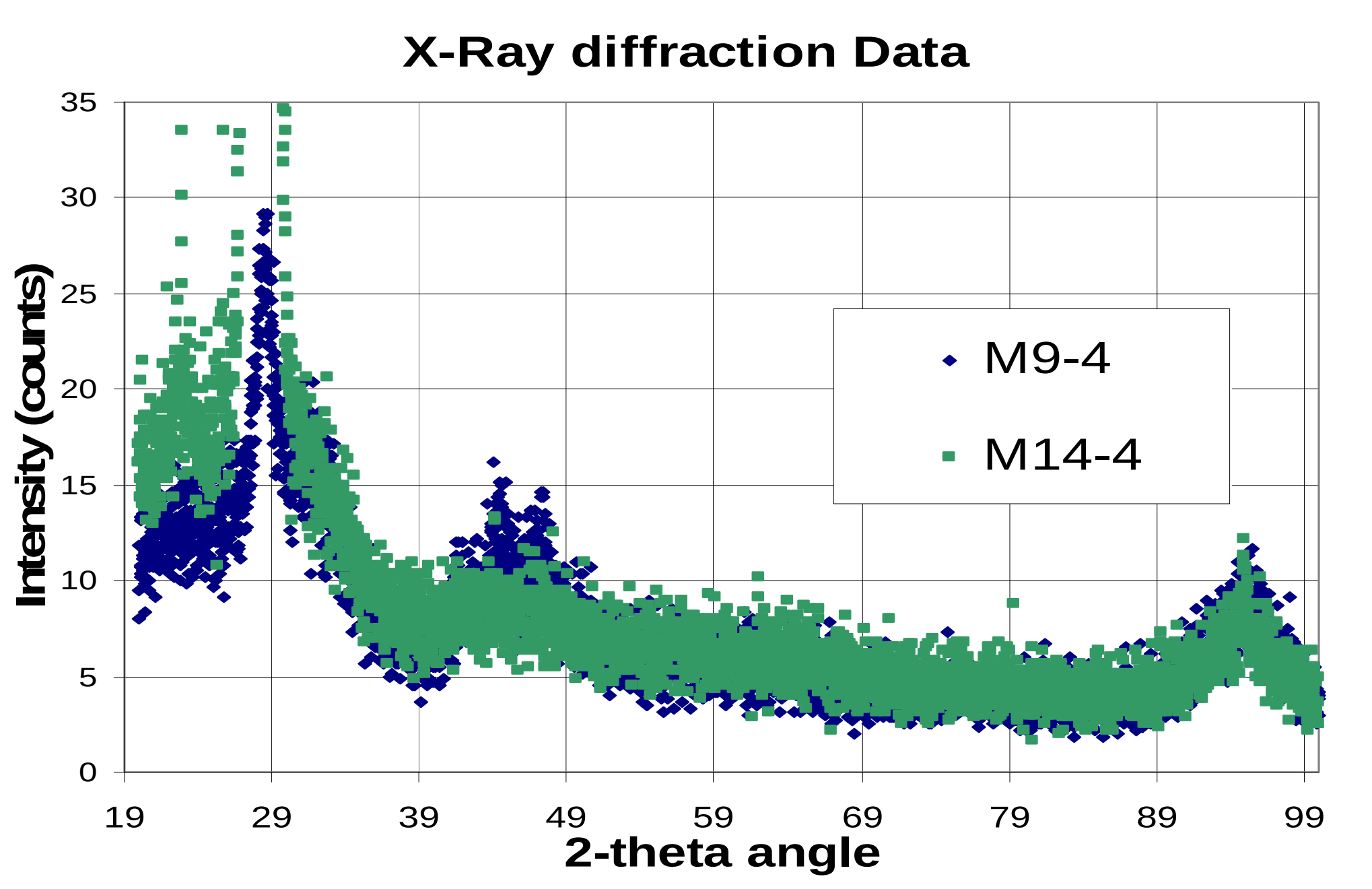


Fig. 3: Samples that show markedly different BH characteristics appear strikingly similar under X-ray diffraction.

The major issue which the team faced was that the V-groove design required that a magnetic layer be sputtered on a sloping surface. Previous experience had shown that cobalt developed columnar growth when it was sputtered on a slant. Experience also shows that columnar growth brings with it poor magnetization characteristics. Some of the input flux is lost in the columns and is apparently directed perpendicular to the desired flux path. This results in reduced efficiency in the finished inductor.

To correct this issue, a layer of Co-Zr-O was deposited. The raw materials were as follows:

- One Co(85%)Zr(15%) target connected to a DC power supply;
- One Zr(100%) target connected to an RF power supply;
- Gas 1, which contained pure argon;
- Gas 2, which contained 90% argon and 10% oxygen;
- Silicon and glass substrates mounted under the targets on a 55° slanted surface that rotated to allow even material distribution.

The target wattages and gas flow rates could be precisely controlled.
The best single layer that we manufactured occurred at the condition

- 100W DC applied to Co-Zr alloy target
- 50W RF applied to Zr target
- Gas 1 set to 4 sccm
- Gas 2 set to 5 sccm

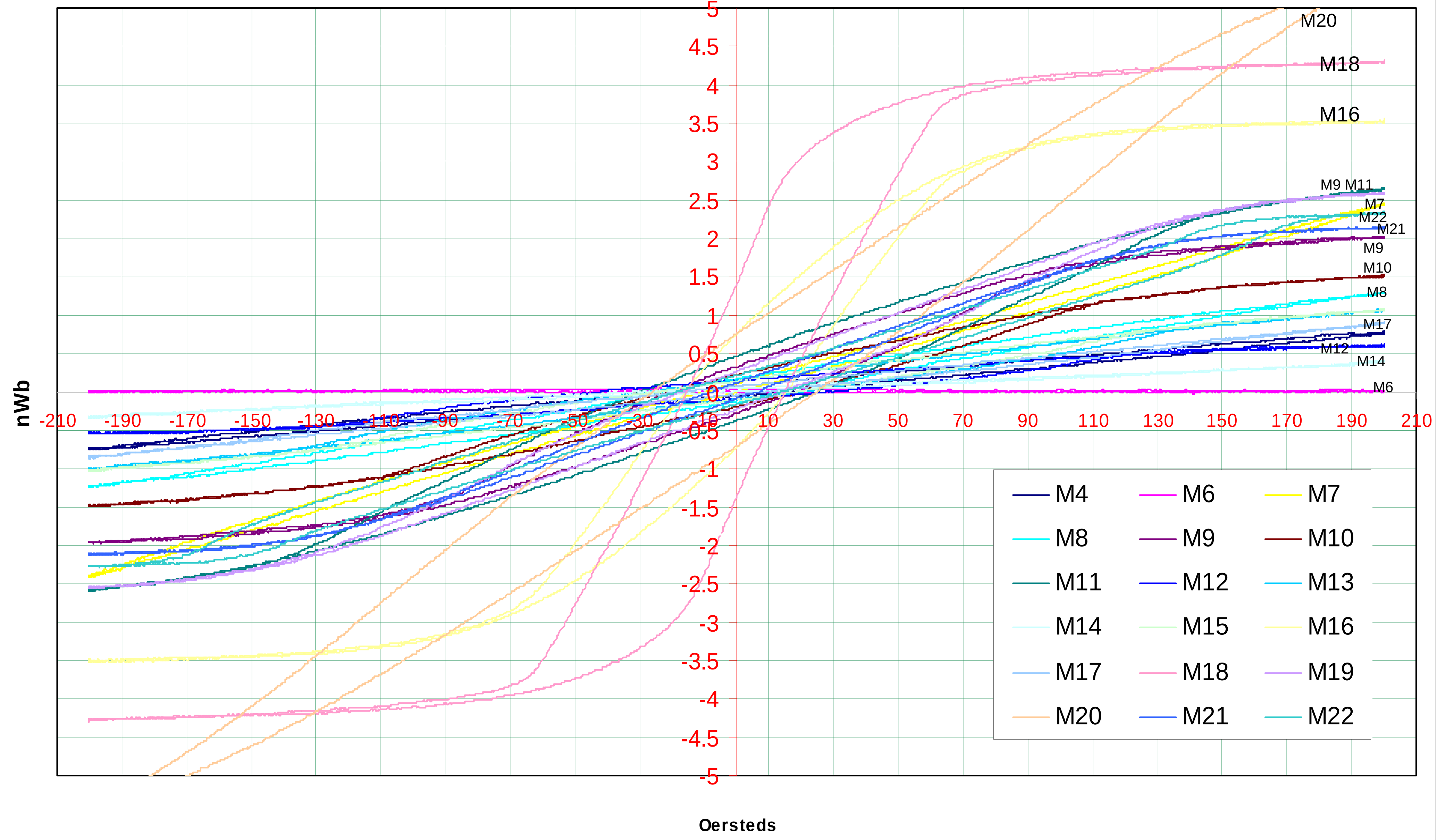
However, the striping behaviour was still noticeable.

The next step was to introduce a layer of pure Zr to interrupt the striping. The result was a magnetic multilayer substance consisting of stacked Co-Zr and Zr layers, with varying thicknesses. Experimental optimization of this multilayer nanostructure was a slow process and consumed the bulk of the work. Some of the data that resulted from this analysis is shown at right. The multilayer structure M21 shows the best curve to date.

This nanomaterials work will assist in the development of high-frequency, high-power density, thin film inductors that can be manufactured on silicon.

Slope Hard-axis B-H curve

This chart shows the B-H curves of some of the samples under study. A good curve has as little area inside the loop as possible for a given thickness. The blue curve M21 is the most promising in the set.



M	Base pressure (torr)	No of layers	ZrO2 layer gas1 SCCM	ZrO2 layer gas2 SCCM	ZrO2 Sputter pressure (mTorr)	ZrO2 RF wattage	ZrO2 seconds per layer	Co-Zr-O layer gas1 SCCM	Co-Zr-O layer gas2 SCCM	Co-Zr-O Sputter pressure (mTorr)	Co-Zr-O RF wattage	Co-Zr-O DC wattage	Co-Zr-O sec/layer	#1 mV	#1 mA	#1 thickness (nm)	#1 resistivity (uohm-cm)	#3 mV	#3 mA	#3 thickness (nm)	#3 resistivity
7	5*10^-7	20	0	15	1.4	200	75	4	6	0.6	100	50	120	2.02	0.576	2350	4436	7.37	0.538	1.55	8228
8	low	10	0	15	1.4	198	75	4	5	0.6	50.4	105	120	27.3	9.15	1050	1420	55.4	7.95	665	2109
9	<4*10^-7	10	15	0	1.4	198	75	4	5	0.6	50.4	105	120	27.3	9.153	1130	1530	55.4	7.95	710	2240
10	low	10	15	0	1.4	198	75	4.1	4.0	0.3	50.4	102	120	?	?	1120		?	?	715	
12		15	0	15		199	75	4	5		50	100	60	10.6	9.5	1120	557	27.29	8.61	760	1092
13		15		15	?	200	45	4	5	?	50	100	60	8.55	9.48	770	314	23.72	9.33	520	599
14		15	0	15	0	198	45	4	5		50	104	30	14.42	9.35	700	490	66.7	8.58	450	1590
15	4*10^-7	15	0	15.2	1.1	198.9	45	4.1	5.1	0.38	50.4	104	70	2.94	9.3	940	134.6	15.04	8.38	575	468
16	2.8*10^-7	15	0	15	1.37	197	75	4.1	5.1	0.4	50	104	150	17	9.44	1850	1508	15.04	8.38	1120	911
17	low	1						4	5		49.5	101	1800	10.23	30.55						
18	low	15	0	15		199	75	4	5		198	103	200	2.63	9.37			8.09	8.976		
19	2.4*10^-7	15	0	15	1.41	199	25	4	5	0.49	49	98	75	6.8	5.4						???
20	3.6*10^-7	32	0	15		198	25	4	6		50	103	75	9.25	10.14			15.49	9.68		
21	3.8*10^-7	15	0	15		199	10	4	5		50	95	75	5.89	10.41			16.73	10.35		

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