# Upper Critical Field Study of Alloyed $MgB_2$

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## Introduction

In addition to the inherently interesting physical properties of magnesium diboride ($MgB_2$) as a two-gap superconductor having a critical temperature ($T_c$ ~39K) intermediate between low temperature superconductors LTS and high temperature superconductors HTS, this material has been identified as having potentially useful characteristics for novel applications including future MRI magnets. While there is an ongoing effort to optimize the enhancement of the upper critical field $H_{c2}$, and the critical temperature of $MgB_2$ by means of ternary alloying with carbon and other semiconductor or metallic impurities as well as oxygen incorporation, the precise effects of these doping mechanisms remain poorly understood. We have studied the enhancements of $H_{c2}$ and $T_c$ of magnesium diboride with a view to elucidating the mechanisms by which high values of $H_{c2}$ may be achieved and exploring the ultimate limits to which $H_{c2}$ may be increased.

## Experimental

We have measured $H_{c2}$ (up to 45T) of a set of four carbon-doped magnesium diboride films grown by HPCVD from tri-methyl boron (TMB) at varying flow rates from 2.5 to 10 sccm. In addition, we have also measured oxygen-doped and cold-deposited $MgB_2$ films using the 33T and 45T magnets at NHMFL. A rotator probe was used to measure $H_{c2}$ (T) for the set of TMB $MgB_2$ films and the angular dependence of $H_{c2}$ at 4.2 K for the film with the highest TMB flow rate. $H_{c2}$ for the cold-deposited film with subsequent annealing was similarly derived from low-current four-point magnetoresistance.

## Results and Discussion

Smoothly varying but broad transitions with slight hysteresis at the higher temperatures were typically observed in the magnetoresistance for the cold-deposited films. This is in stark contrast to the TMB films which featured sharp transitions as shown in Fig. 1. The carbon-doped films are well textured and $H_{c2}$ increases with increasing TMB flow rate. $H^{\parallel}_{c2}$ (4.2K) exceeds 45 T for the film with the 10 sccm TMB flow rate. There was a 3 month time span between the measurement of $H_{c2}$(T) for these films in 33T and the subsequent angular measurement in 45T. The latter measurement shows an increase in $H_{c2}$(4.2K) from the previous data which we attribute to the effects of aging of the sample. The cold-deposited film is also well-textured and has $H^{\parallel}_{c2}$ (0) estimated at ~ 46T by extrapolation as shown in Fig. 2. In addition, $dH_{c2}/dT$ near $T_c$ for this sample reached a record high value of 2.7 T/K.

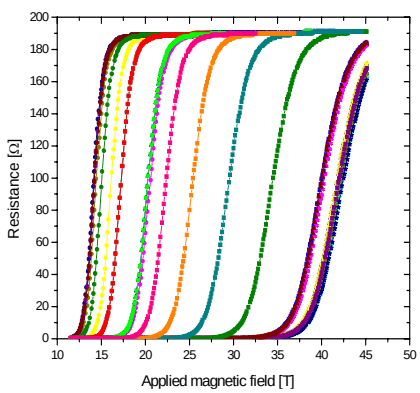


Fig. 1 Magnetoresistance of TMB carbon-doped $MgB_2$.

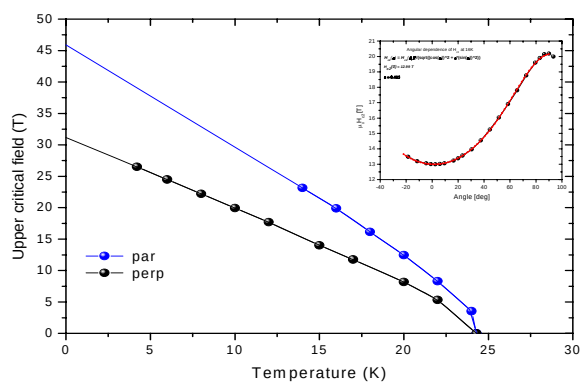


Fig. 2 $H_{c2}$ of a cold-deposited and annealed $MgB_2$ film.

## Conclusions

These results demonstrate two alternate pathways which show promise of achieving very high values of $H_{c2}$ in $MgB_2$ thin films.

## Acknowledgements

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## References

[1] Gurevich, A., Physica C: Superconductivity, Vol 456, Issues 1-2, 160-169 (2007)