TUNING ALLOY DISORDER IN DILUTED MAGNETIC SEMICONDUCTORS IN THE HIGH-MAGNETIC-FIELD LIMIT

S. A. Crooker (NHMFL, LANL) and N. Samarth (Pennsylvania State University)

Introduction

As a measure of disorder and crystal quality in compound semiconductors such as Al$_x$Ga$_{1-x}$As or Zn$_x$Cd$_{1-x}$Te, the linewidth of band-edge photoluminescence (PL) is a powerful and widely employed diagnostic. Even the cleanest of these materials, however, necessarily possess some degree of intrinsic compositional alloy disorder due to the random placement of cation (or anion) species. This alloy disorder presents an inherent and microscopic fluctuation potential that can be directly inferred from the PL linewidth, $\Gamma$. In a PL experiment, photoexcited excitons act as mesoscopic probes of compositional disorder, where each exciton averages microscopic alloy fluctuations over the atoms within its wavefunction. The standard deviation of all exciton energies gives the broadened PL linewidth. $\Gamma$ can therefore be modeled by the statistics of alloy fluctuations over the $N$ cation sites within the exciton’s nominal ‘volume’.

Alloy disorder in II-VI diluted magnetic semiconductors (DMS) has been both measured and calculated. In DMS materials the alloy disorder potential within a given sample can be tuned as the magnetic spins (usually spin-5/2 Mn) align in an applied magnetic field. DMSs therefore provide a flexible material system against which to benchmark models of alloy disorder. Experiments in DMS to date have observed a decrease in $\Gamma$ as local Mn spins align in low fields, and as Mn spin clusters begin to align in high magnetic fields to 60 T, in approximate agreement with models. However, a critical and as-yet-unverified aspect of current models is the expectation that alloy disorder in many DMS materials should increase again as antiferromagnetically-bound clusters of Mn spins achieve full alignment at very high magnetic fields [1]. This field scale is typically quite large, of order 50-100 T.

Experimental

We measure the $\Gamma$ from a single Zn$_{0.70}$Cd$_{0.22}$Mn$_{0.08}$Se quantum well to 89 T using the 100 T Multi-Shot Magnet, which allows non-destructive access to this ultrahigh field regime and -- importantly -- sufficiently long pulse duration to permit collection of high-resolution PL data. Above 70 T, we observe that $\Gamma$ markedly increases, in qualitative agreement with a simple ‘local-bandgap’ model of compositional alloy disorder. These data further validate current models of field-tunable alloy disorder in DMS materials, and support ‘local-bandgap’ approaches to alloy disorder in general. Figure 1(a) shows the raw PL data at peak field for a series of eight hi-field shots. Fig. 1(b) shows the measured linewidth (black trace). After subtraction of a linear component that is due only to the shrinking of the exciton by the applied magnetic field, the corrected data (red) agrees very well with a calculation of the PL linewidth based on a ‘local-bandgap’ model of alloy disorder.

We are indebted to the entire 100 T Magnet design and commissioning team.