Light and heavy hole exciton polariton Faraday rotation in a single GaAs microcavity

D C T Ferreira, A C S P Pimenta, and F M Matinaga
Depo de Fisica, ICEX, UFMG, Belo Horizonte, MG, Brasil
1 E-mail: matinaga@fisica.ufmg.br

Abstract. Faraday rotation (FR) can also be observed in a resonantly excited system without an external magnetic field. In a microcavity, polaritons spin population imbalance generates an effective magnetic field across the cavity mode, which results in an amplified FR on the emitted photon. Also, when the cavity is tuned to light hole (LH) exciton energy, an additional field momentum will be added to the effective magnetic field parallel to cavity mode, resulting in an additional FR.

1. Introduction
Polaritons on a microcavity have a dynamical scattering process between states on the lower or upper polariton branch. It can generate an unbalanced spin plus/minus population, i.e. a spin splitting doublet, which results in a system with an effective magnetic field normal to the quantum well even without an external field.[1,2] Such field enhances the Faraday rotation for the emitted light, since it travels back and forth hundreds times in a Fabry Perot cavity. By tuning the cavity resonance for higher energy, light hole polaritons (LHP) can be generated in the same way as the heavy hole polaritons (HHP).[3] In this case, the effective magnetic field has an additional field due to the LH exciton magnetic momentum z-component ($p_z$). Such field would be an additional reason to use polaritons in a quasi resonant excitation as an all optical switching device.[4]

In this work we tune the cavity resonance from heavy hole to light hole exciton energy, measuring the Faraday rotation (FR) on the polariton emission as a function of the pump excitation, just by scanning the sample position. We discuss this effect in terms of the effective magnetic field in the cavity, without external field, i.e. the optically induced FR.

2. Experimental Results
An usual photoluminescence (PL) setup was used to measure the FR on the polaritons emission (fig.1a). The microcavity is formed by two DBR mirror with 26.5/24 Al$_{0.2}$Ga$_{0.8}$As/AlAs pairs and a GaAs - SQW gain medium in the center of lambda cavity as described on the literature.[5] Reflectance measurement shows a cavity mode splitting at 798 nm (fig.1b) for the HH exciton ($\Delta=3.4$meV) and a broadening due to the LH (792 nm) coupling (fig.1c). That exciton – cavity mode interaction is weaker than for HH exciton due to smaller LHP oscillator strength. However, it is not a simple change on the reflectance deepness due to LH absorption, showing a smaller coupling of the LH exciton with the cavity field.

We analyzed the linear polarization (LP) angle ($\theta$) direction behavior of the polariton emission intensity for a resonant Ti:Sapphire continuous wave laser excitation as a function of the emission angle (we use $\lambda/2$ plate to rotate the emission polarization angle), as illustrated by the
red dashed line (fig.2a). The LP Polarization angle rotation, i.e. the FR effect was observed by measuring the $\theta$ (fig. 2b) for each pump power.

![Figure 1](image1.png)

Figure 1: a) A single GaAs microcavity photo-luminescence characterization system. b) White light reflectance spectrum as a function of cavity resonance along of the sample positions ($P_i$). c) Cavity resonance deep FWHM for LHP.

Firstly, we took that data for a non-resonant excitation (fig.2c). For all these FR data, we took the emission LP degree $\rho$ as:

$$\rho = \frac{I_{\text{max}} - I_{\text{min}}}{I_{\text{max}} + I_{\text{min}}}$$

Where $I_{\text{max, min}}$ are the maximum/minimum PL integrated intensity. Here we see a huge change on $\theta$ ($\approx 80^\circ$), fixing around 130$^\circ$ for higher pump power. This behavior, a pinning of the LP light emission in a fixed direction is somewhat previewed for high purity microcavity,[6] and the huge change determine the $\theta$ behavior around off resonant exciton laser pump threshold.

![Figure 2](image2.png)

Figure 2: a) Polarization polar view: Polariton emission intensity as a function of the LP angle emission for a fixed 200 mW pump power. b) LP $\theta$ measurement for 793 nm, together with the LP degree ($\rho$) for a LP pump. c) $\theta$ measurement for off resonant excitation at 798 nm.
The LP angle emission changes (FR) for the polariton emission as a function of pump power show in this case a FR of 13°, this also represents a polarization change in relation to the pump excitation LP angle. Fig.2c shows a saturation angle change above pump threshold for the nonresonant excitation, indicating a fixed LP angle for the microcavity laser emission. This polarization data were measured above pump threshold for this nonresonant excitation intensity relation.

3. FR Results & Discussion

The FR in a microcavity is proportional to the effective magnetic field \( B_i \) parallel to the cavity mode, so we can have for a HHP emission, a field due to the population imbalance with spin up and down (eq.1) and for LHP, there is an additional z magnetic field momentum (eq.2,3).

\[
g\mu_B B_{in} = 2(V_1 - V_2)(N_1 - N_2) \quad \text{(eq.1)}
\]

\[
\Phi_{3\frac{1}{2}\frac{1}{2}} = -\frac{1}{\sqrt{6}} \left[(p_x + ip_y) \downarrow -2p_z \uparrow\right] \quad \text{(eq.2)}
\]

\[
\Phi_{3\frac{1}{2}\frac{1}{2}} = -\frac{1}{\sqrt{6}} \left[(p_x + ip_y) \downarrow -2p_z \uparrow\right] \quad \text{(eq.3)}
\]

Where \( g \) – exciton factor, \( \mu_B \) - Bohr magnetic momentum, \( V_i \) – the triplet and singlet energy dispersion and \( N_i \) - spin up and down population. \( \Phi_{m,n} \) represents the light hole momentum, with each spatial components \( p_i \), indicating the spin up (\( \uparrow \)) and down (\( \downarrow \)) field components. The eq. 2,3 show an effective magnetic field parallel to the cavity mode(\( z \)), which also depends on the excitation pump resonant light polarization, CP or LP. [7]

Considering the \( B_i \), we measured the FR for LHP emission using LP and circular polarization (CP) excitation light as shown on fig. 3, together with the emission LP degree \( \rho \) The cavity tuning was done by moving the pump spot along the sample position.

Figure 3: FR measurements for polaritons together with the emission LP degree \( \rho \). a) FR for LP light excitation. b) FR for CP light excitation.
Since the FR for LHP results from two magnetic fields, it explain the higher FR (FR=30°) close to LH exciton resonance (793nm), compared to the HHP (FR=6°) for a LP pump excitation. On the other side, for the CP light excitation, we see a larger value for the HHP (FR=16°) in comparison to the LHP (FR=8°). For the LHP emission, we note a polariton spin (σ+) population difference higher for the LP pump excitation, compared to the CP excitation. On the other side, for CP excitation, the scattering dynamic favor the LP light emission (fig.4). For the HHP emission, we saw a smaller FR for LP pump excitation and higher value for CP.

Figure 4: LP or a CP (σ+) excitation, generating polaritons states, with balanced or not populations.

Those results reflect the σ+ spin population imbalance produced by a CW pump (LP,CP) due to not only the dynamic behavior, but also to the spin exchange field, which is discussed somewhere. Any way, we see a strong contribution on the cavity effective field when we excite the LHP, if we compare the much higher HHP emission (higher oscillator strength compared to the LH exciton) intensity for the same excitation intensity with a single quantum well.

4. Conclusion
The measured FR was 30 degree to LH LP excitation and 16 degree for HH CP excitation. Such huge FR results illustrate the enhancement of the cavity effective magnetic field due to z magnetic field component of the LHP emission parallel to cavity mode.

5. Acknowledgments
This work was supported by Fapemig and CNPq.

6. References
[1] Kavokin A et al 2003 Phys. Rev. B 67 195321
[2] Giri R et al 2012 Phys. Rev. B 85 195313
[3] Comiti V S et al 2014 Sol. Stat. Comm. 193 37
[4] Amo A 2010 Nature Phot. 4 361
[5] Cotta E A et al 2007 Phys. Rev. B 76 073308
[6] Klopotowski L et al 2006 Sol. Stat. Comm. 139 511
[7] Singh et al 1993 Physic ofSemiconductors and their Heterostructure (New York Mc Graw-Hill)
[8] Renucci P et al 2005 Phys. Rev. B 72 075317