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Chiral light–matter interactions in hot vapor-cladded waveguides: supplementary material

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A. Calculation of Rubidium transition susceptibility in the evanescent region

In order to evaluate the effect of magnetic field on our absorption first we need to evaluate the effect broadening mechanisms will have on our line shape. The interaction of light with the Rubidium in our system is modelled in the following way, adopting the formalism which is used to calculate the susceptibility of a quantum emitter that is reflected from a surface with decaying field [1,2]. Essentially, the susceptibility of Rubidium is estimated according to

$$\chi(\nu) \sim \int_{-\infty}^{\infty} dv_z \int_{0}^{\infty} dv_T \frac{W_D(v_z, v_T)}{-2\pi(\nu_0 - \nu) - k_z v_z - i(\gamma - ik_T v_T)} \quad \text{(s1)}$$

where ν_0 is the frequency of a single transition, v_z and v_T are the velocities of the Atom along the propagation and transverse direction, respectively, W_D is the Boltzmann thermal velocity distribution, k_z and k_T are the wave numbers of the mode in the propagation direction and at the transverse direction respectively. They relate to the wavenumber via $k_z^2 + k_T^2 = k^2$. γ is the absorption line natural linewidth. From the susceptibility we can deduce the refractive index of Rubidium according to $n = \sqrt{1+\chi}$. In order to do so, we first need to deduce the mode wave vector. We have used Lumerical mode solver to find the effective index of the mode (n_{eff}) to be 1.56. The wave number of the mode in the propagation direction is $k_x = 2\pi/\lambda \cdot n_{eff}$ and in the transverse direction is ($\sqrt{(2\pi/\lambda)^2 - k_x^2}$). Once we have evaluated the mode wave number we can solve eq 1 for each transition and receive the rubidium imaginary and real parts of the refractive index as can be seen in figure s1a,b respectively. About 10% of the optical mode interacts with the Rb vapor in our device. As a result, the absorption of the optical mode is about 10% of the absorption of the Rb transition. For example, if the Rb cladding has an imaginary index of 2E-4, the mode will have an effective imaginary index of 2E-5. The transmission of our device is described by $T = \exp(-\alpha \cdot L \cdot IF)$ where α is the absorption coefficient deduced from the imaginary index of rubidium, L is the length of the device (3 mm) and IF is the interaction factor of the TM mode we excite with the Rb vapor (~10%). In figure s1.c we plot the simulated transmission.

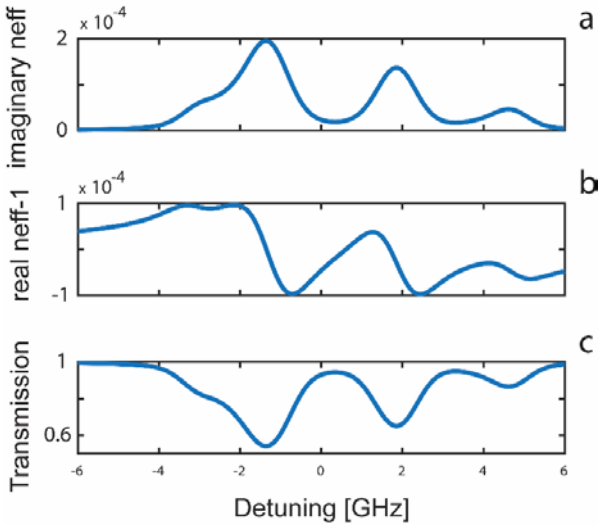

Fig. s1. (a-b) Simulated imaginary and real part of the refractive index of Rb^{85}. (c) simulated transmission of our ACWG.

B. Finding the eigenvalues of the atom Hamiltonian under the influence of magnetic field

The Hamiltonian of the atom with magnetic field B is described by

$$H = H_0 + \left(-\frac{\mu_B}{\hbar}\right)\cdot B\cdot\left(L + g_s S + g_I I\right) \text{ (s2)},$$

where S is the spin angular momentum and L is the orbital angular momentum, I is the nuclear spin, g is the Lande g factors, B is the applied magnetic field, μ_B is the Bohr magneton and H_0 is the unperturbed Hamiltonian. In order to understand the behavior of the atoms with the presence of magnetic field we need to solve the eigenvalues of the Hamiltonian. By solving the eigenvalues of the Hamiltonian, we found the energy shift of each Zeeman sub-level. The direction of the magnetic field defines the quantization axis. Therefore, we can us the unperturbed atomic states vector $\left|F, m_F\right\rangle$, under this representation the expectation value of the diagonal elements in the Hamiltonian is $\left\langle F, m_F \left| H \right| F, m_F \right\rangle = E_0(F) - \mu_B g_F m_F B_Z$, where E_0 is the energy sublevels of the $\left|F, m_F\right\rangle$ and g_F is the associated Lande factor. The expectation value of the off-diagonal matrix elements may be non-zero only between $\Delta F = \pm 1$ and $\Delta m_F = 0$ sub levels. These values are evaluated by the following expression:

$$\left\langle F-1, m_F \left| H \right| F, m_F \right\rangle = \left\langle F, m_F \left| H \right| F-1, m_F \right\rangle =$$

$$\frac{-\frac{\mu_B}{2}\left(g_J - g_I\right)B_z\left(\left[\left(J+I+1\right)^2 - F^2\right]\cdot\left[F^2 - \left(J-I\right)^2\right]\right)^{0.5}\left(F\right)^{-0.5}}{\left(F^2 - m_F^2\right)^{-0.5}\left(F\left(2F+1\right)\left(2F-1\right)\right)^{0.5}}$$

Now we consider applying laser light. The laser light's influence on the atom is taken into account by interaction term coupling electric dipole and the oscillating laser electric dipole $-d\cdot E$. Therefore, the $\left|g\right\rangle -> \left|e\right\rangle$ transition dipole moment for an atom interacting with longitudinal magnetic field is proportional to

$$\left|\left\langle e\left|D_q\right|g\right\rangle\right| \propto \sum_{F_e, F_g} c_{F_e' F_e}\, a\left(F_e, mF_e; F_g, mF_g; q\right) c_{F_g' F_g}$$

with

$$a\left(F_e, mF_e; F_g, mF_g; q\right) =$$

$$\frac{\left(-1\right)^{1+I+J_e+F_e+F_g-mF_e}}{\left(2J_e+1\right)^{-0.5}\left(2F_e+1\right)^{-0.5}\left(2F_g+1\right)^{-0.5}}\cdot\begin{pmatrix} F_e & 1 & F_g \\ -m_{F_e} & q & m_{Fg}\end{pmatrix}\cdot\begin{Bmatrix} F_e & 1 & F_g \\ J_q & I & J_e\end{Bmatrix}$$

where the parentheses and the curly brackets denote the 3-j and 6-j coefficients, respectively. q is the polarization of the light (e.g., for right handed circular polarization light (σ_+) q=1).

C. Simulating the ACWG response taking into account the transitions shifts and broadening effects.

In figure s2 we present the simulation results adding the rubidium 85 (green) and 87 (blue) transitions. These simulations are calculated for temperature of 70C.

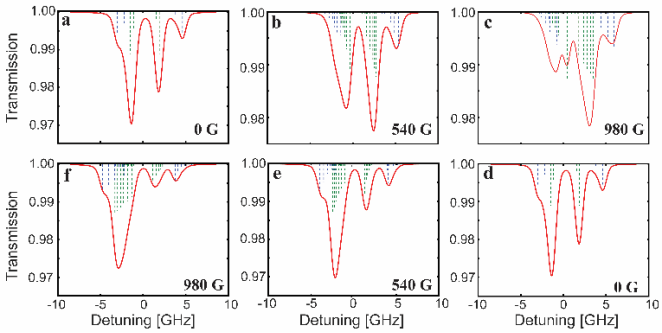

Fig. s2. Simulated transmission spectra of the ACWG with different magnetic fields (Red dotted lines), a-c right handed, d-f left handed polarization. The additional green lines represent the Rb85 transitions and the additional blue lines represent the Rb87 transitions.

References

1. M. Ducloy, "Nonlinear selective reflection from an atomic vapor at arbitary incidence abgle," Phys. Rev. A **38**, 5197–5205 (1988).
2. L. Stern, B. Desiatov, I. Goykhman, and U. Levy, "Nanoscale light-matter interactions in atomic cladding waveguides.," Nat. Commun. **4**, 1548 (2013).