High speed electrical spin injection in a quantum well from a ferromagnetic injector

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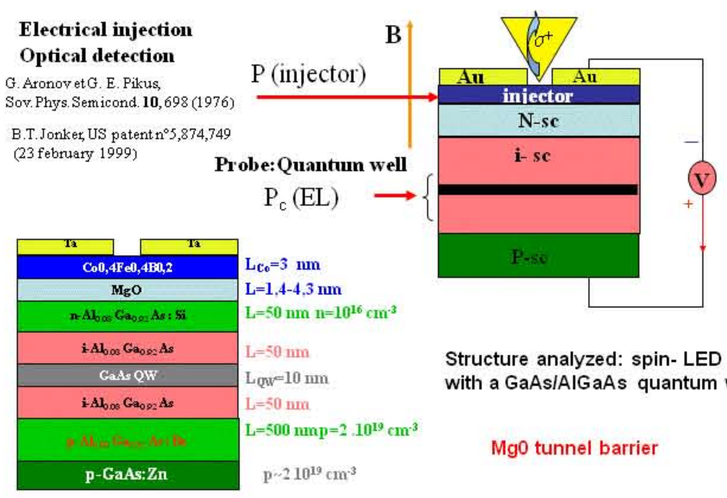
I) Principle of detection and sample

Electrical injection
Optical detection

G. Aronov et G. E. Pikus, Sov. Phys. Semicond. **10**, 698 (1976)

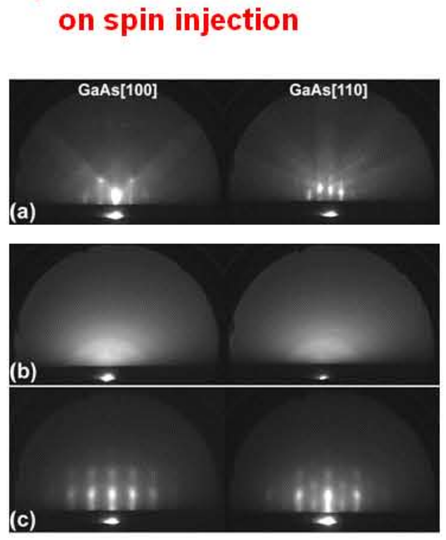
B.T. Jonker, US patent n°5,874,749 (23 february 1999)



Structure analyzed: spin- LED with a GaAs/AlGaAs quantum well

Mg0 tunnel barrier

II) Influence of the structure of the MgO barrier on spin injection



RHEED images obtained from azimuth of (Al)GaAs[100] and (Al)GaAs[110]

(a) LED after As desorption

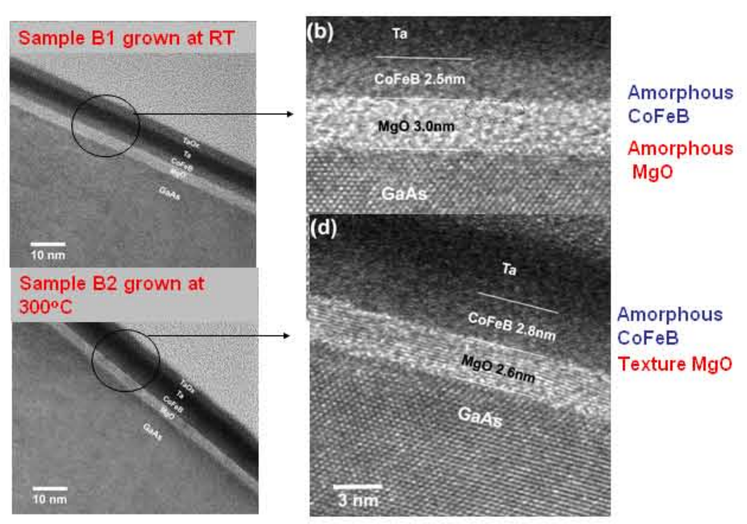
(b) Sample B1 with 3nm MgO grown at RT

➡ amorphous MgO

(c) Sample B2 with 3nm MgO grown at 300°C

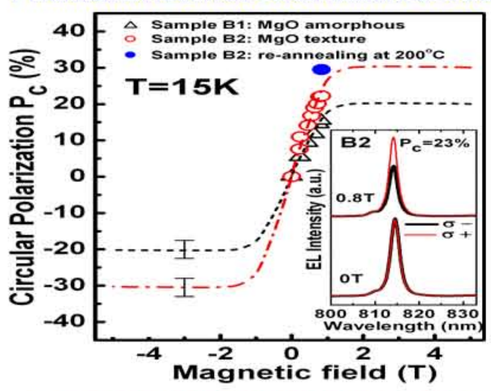
➡ MgO crystal

HRTEM



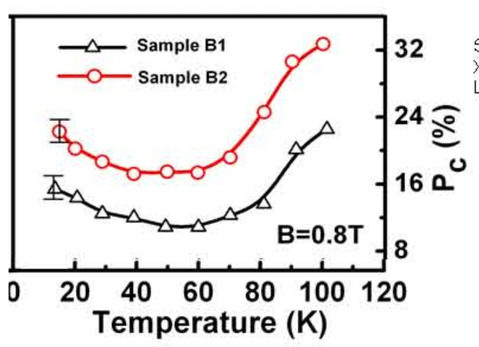
II) Influence of the structure of the MgO barrier on spin injection

Polarization resolved electroluminescence (EL)



➡ Spin injection efficiency is higher for texture MgO

III) Influence of the temperature on spin injection



See also: X. Jiang et al., Phy. Rev. Lett. 94, 056601 (2005)

Origin ?
- Temperature dependant spin injection process from CoFeB through MgO ?
- Role of spin relaxation within the QW during carrier lifetime: temperature dependant process?
- Other...

Time and polarization resolved photoluminescence measurements (TRPL)

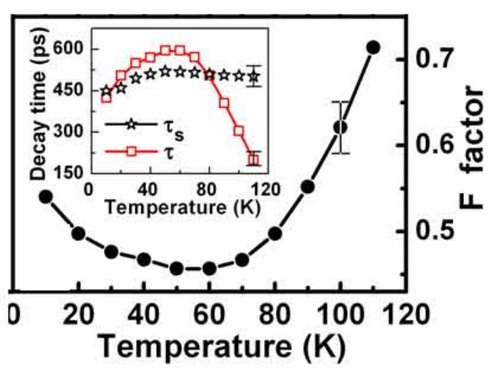
$P_C = F * P_s$

P_s : spin polarization of electrons injected in the QW

$$F(T) = \frac{1}{1+\tau(T)/\tau_S(T)}$$

τ electron lifetime and τ_S spin relaxation time

Measurement of $\tau(T)$ et τ_s (T) et F(T) by TRPL

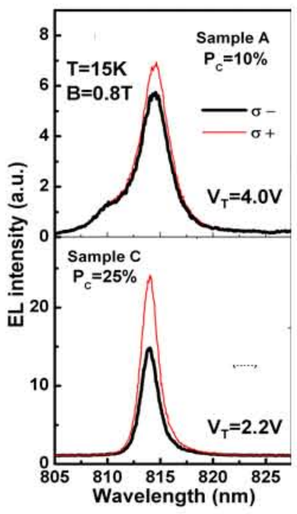


➡ The temperature dependence of P_C is controlled by the electron spin relaxation during its lifetime within the QW

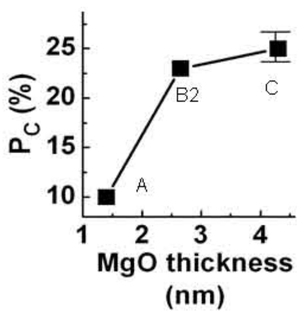
G. Salis et al. APL 87, 262503 (2005)

➡ The spin injection process from CoFeB into n-AlGaAs does not depend on temperature up to 120K, for both amorphous and crystaline MgO

IV) Influence of the Mgo tunnel barrier thickness on spin injection

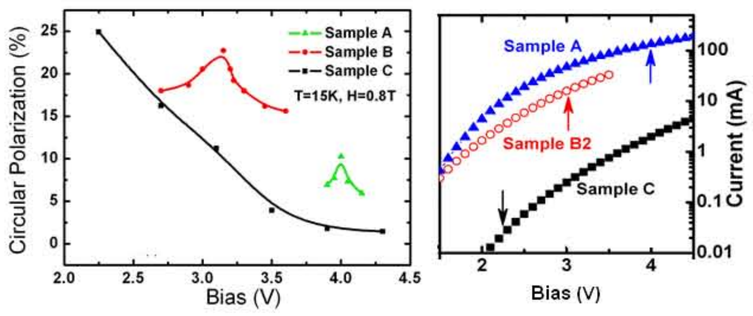


Sample	Thickness (nm)
A	1.4
B2	2.6
C	4.3



➡ The EL circular polarization increases with MgO thickness

Detailed parameters for samples A and C when Pc is maximum (with voltage)

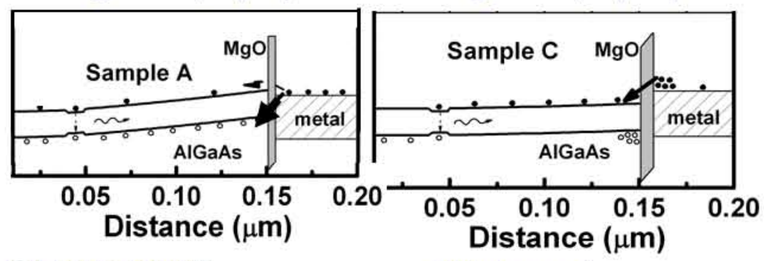


Sample	MgO thickness t (nm)	Polarization P_{max}(%)	Bias V_T (V)	Current I (mA)	EL Intensity (arb unit)
A	1.4	10	4.0	134	7
C	4.3	25	2.2	0.03	24

➡ The current is stronger for the sample with a thin MgO barrier

➡ The EL intensity is stronger for the sample with a thick MgO barrier

Thin MgO barrier (sample A) — **Thick MgO barrier (sample C)**



- Large hole current
- Electron-hole recombinaison at the interface
- Band bending in the sc region

- Bipolar current
- Electron-hole recombinaisons within the QW
- Flat band in the sc région

W. Van Roy et al. Mat.Sci. Eng. B 126, 155 (2006)

Increase of EL circular polarization with the tunnel barrier thickness:

➡ Band bending in the p-i-n junction depends on thickness

For a thin MgO tunnel barrier
- ➡ Large hole current
  - ➡ BAP mechanism
- ➡ Electric field in the QW
  - ➡ Quantum stark effect → τ ↗ F ↘

➡ Spin filtering due to MgO? Spin dependent tunnel effect

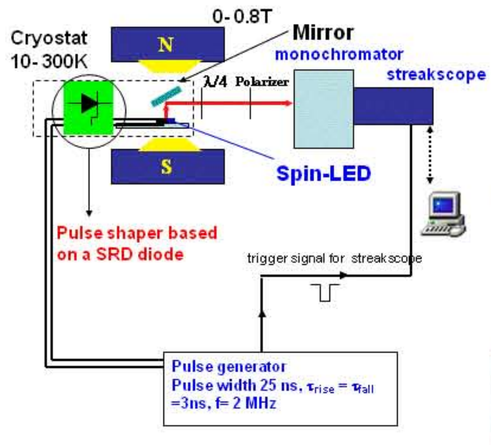
W.H. Butler, X.-G.Zhang, T.C.Schulthess, and J. M. MacLaren, Phys. Rev. B 63, 054416 (2001).

Pb: here CoFeB is amorphous

➡ Role of defects at the interface?

V) High speed electrical spin injection

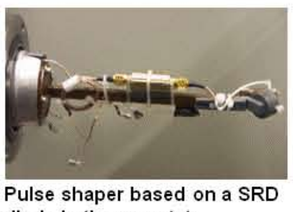
Time and polarization Electroluminescence set-up (TREL)



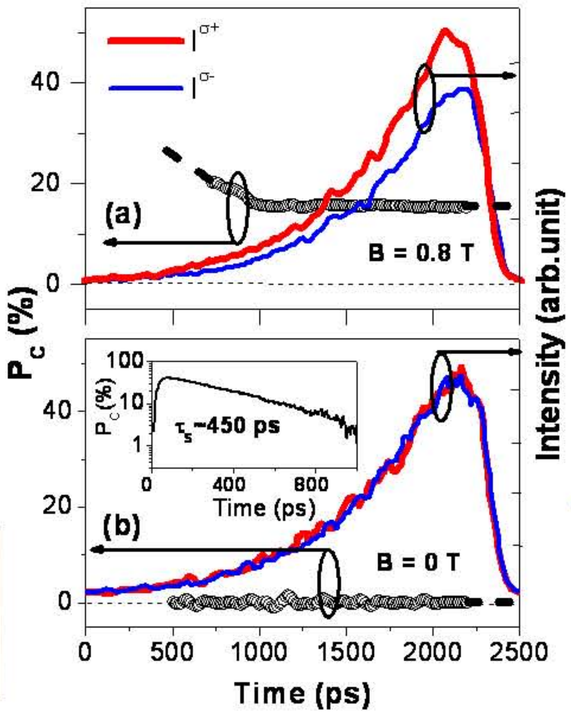
Spin-LED with 300 μm mesa diameter

4 ns width voltage pulse rise time and fall time ≈250ps

(characterized by a fast sampling oscilloscope Tektronic 3S1 head)



Pulse shaper based on a SRD diode in the cryostat



- Under pulsed electrical excitation, TREL on a nanosecond time-scale exhibits a plateau of Circular Polarization degree as high as 15 % under a 0.8 T magnetic field
- The initial decay of P_C^{EL} could be due to electron spin relaxation process in the quantum well
- The temporal build-up of the electronic spin polarization degree in the QW is much faster than the rise time of EL intensity

VI) Conclusions

➡ Very efficient spin Injection due to CoFeB/MgO injector (CoFeB saturation field= 1,3T < Co saturation field= 2,2T)

- The efficiency is larger for crystaline MgO
- The temperature does not play any role on the spin injection process (but T has a strong influence on electron spin relaxation during its lifetime within the QW)
- The electroluminescence circular polarization increases with MgO thickness

Y. Lu, V.G. Truong, P. Renucci *et al.* Appl. Phys. Lett 93, 152102 (2008)

Other works related to spin injection through MgO

X. Jiang et al., Phys. Rev. Lett. 94, 056601 (2005)
A. Sinsarp et al., JJAP 46 L4-L6, (2007)
T. Manago et al., JAP 102, 083914 (2007)
B.T. Jonker et al., Nature Physics vol 3 p542 (2007)
S. Hövel et al., Appl. Phys. Lett. 93, 021117 (2008)

➡ We have demonstrated high speed pulsed electrical spin injection from CoFeB/MgO spin injector into a AlGaAs/GaAs semiconductor LED

- EL circular polarization plateau as high as 15 % during the short nanosecond windows of light emission at 15 K under a 0.8T magnetic field
- The temporal build-up of the electronic spin polarization degree in the QW is much faster than the rise time of EL intensity

V.G. Truong, P.H. Binh, P. Renucci *et al.* Appl. Phys. Lett 94, 141109 (2009)