



US006955858B2

(12) **United States Patent**
ElMasry et al.

(10) **Patent No.:** US 6,955,858 B2
(45) **Date of Patent:** Oct. 18, 2005

(54) **TRANSITION METAL DOPED
FERROMAGNETIC III-V NITRIDE
MATERIAL FILMS AND METHODS OF
FABRICATING THE SAME**

6,255,669 B1 * 7/2001 Birkhahn et al. 257/89
6,876,013 B2 * 4/2005 Okano et al. 257/198

(75) Inventors: **Nadia A. ElMasry**, Raleigh, NC (US);
Salah M. Bedair, Raleigh, NC (US);
Meredith L. Reed, Garner, NC (US);
Hans Stadelmaier, Raleigh, NC (US)

(73) Assignee: **North Carolina State University**,
Raleigh, NC (US)

(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 242 days.

(21) Appl. No.: **10/313,975**

(22) Filed: **Dec. 6, 2002**

(65) **Prior Publication Data**

US 2003/0136986 A1 Jul. 24, 2003

Related U.S. Application Data

(60) Provisional application No. 60/338,226, filed on Dec.
7, 2001.

(51) **Int. Cl.**⁷ **B32B 9/00**; C30B 29/38;
C30B 29/40

(52) **U.S. Cl.** **428/698**; 428/697; 428/704;
423/361; 423/374; 117/952; 117/953; 117/954

(58) **Field of Search** 428/698, 689,
428/697, 704; 423/361, 374; 117/952, 953,
117/954

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,421,576 A * 12/1983 Jolly 117/95
4,609,411 A * 9/1986 Kohashi et al. 117/57
5,294,287 A 3/1994 Chang et al.
5,909,036 A 6/1999 Tanaka et al.
6,007,622 A * 12/1999 Kawase et al. 117/82

OTHER PUBLICATIONS

Bouchaud, Jean-Pierre, "Propriétés Magnétiques et Struc-
turales des Carbonitrides de Manganèse et des Perowskites
Mn₃GaC et Mn₃GaN," *Annales de Chimie*, 3 81-105 (1968).
(abstract) (only Abstract in English).

Dietl et al., "Zener Model Description of Ferromagnetism in
Zinc-Blende Magnetic Semiconductors," *Science*, 287
1019-1022 (Feb. 11, 2000).

Edington, J.W., "Electron Diffraction in the Electron
Microscope," *Monographs in Practical Electron
Microscopy in Materials Science*, 2 51-54 (1975).

Fiederling et al., "Injection and Detection of a Spin-Polar-
ized Current in a Light-Emitting Diode," *Nature*, 402 787-
790 (Dec. 16, 1999).

Hajjar et al., "Magnetoresistance Peaks in the Neighborhood
of Coercivity in Magneto-optical Recording Media,"
Journal of Applied Physics, 72:4 1528-1538 (Aug. 15,
1992).

Kuwabara et al., "Preparation of Wurtzite GaN-Based
Magnetic Alloy Semiconductors by Molecular Beam
Epitaxy," *Physica E*, 10 233-236 (2001).

(Continued)

Primary Examiner—Stephen Stein
(74) *Attorney, Agent, or Firm*—Myers Bigel Sibley &
Sajovec

(57) **ABSTRACT**

Transition metal doped II-V nitride material films exhibit
ferromagnetic properties at or above room temperature. A
III-V nitride material film may be doped with a transition
metal film in-situ during metal-organic chemical vapor
deposition and/or by solid-state diffusion processes. Doping
of the III-V nitride material films may proceed in the
absence of hydrogen and/or in the presence of nitrogen. In
some embodiments, transition metal-doped III-V nitride
material films comprise carbon concentrations of at least
10¹⁷ atoms per cubic centimeter.

35 Claims, 15 Drawing Sheets

