Electronic Supplementary Information

Synergistic effect of Ga doping and Mg alloying over the enhancement of Ga doped MgZnO pressure sensor

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Table s1: Composition data of elements in Ga doped MgZnO thin films

Sample	**Ga (at. %)**	**Mg (at. %)**	**Zn (at. %)**	**X_{Mg} = Mg(at%) / Zn+Mg+Ga (at. %)**	**X_{Ga} = Ga(at%) / Zn+Mg+Ga (at. %)**
$Mg_{0.28}Zn_{0.72}O$	-	11.59	29.05	0.285	0
MZO,G30	0.56	12.12	28.95	0.291	0.014
MZO,G40	1.18	12.86	28.43	0.302	0.027
MZO,G50	1.77	12.69	28.21	0.297	0.041
MZO,G60	2.66	11.47	28.31	0.270	0.062
MZO,G70	2.96	11.9	29.53	0.268	0.066
MZO,G80	3.19	10.86	28.04	0.258	0.076

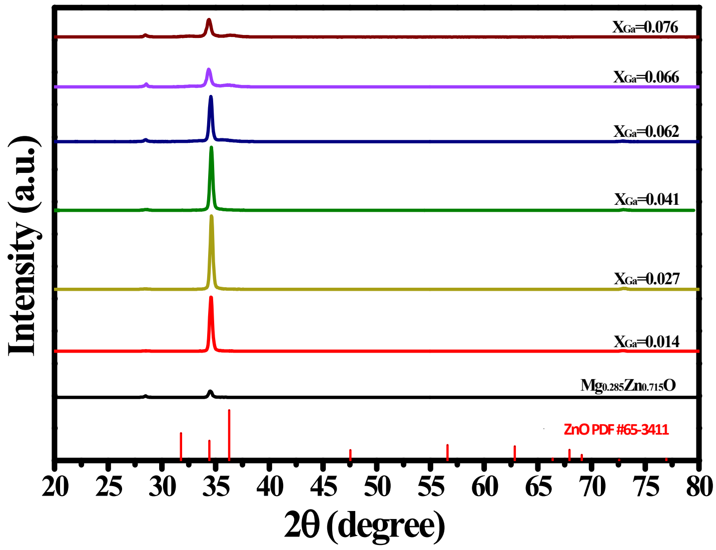
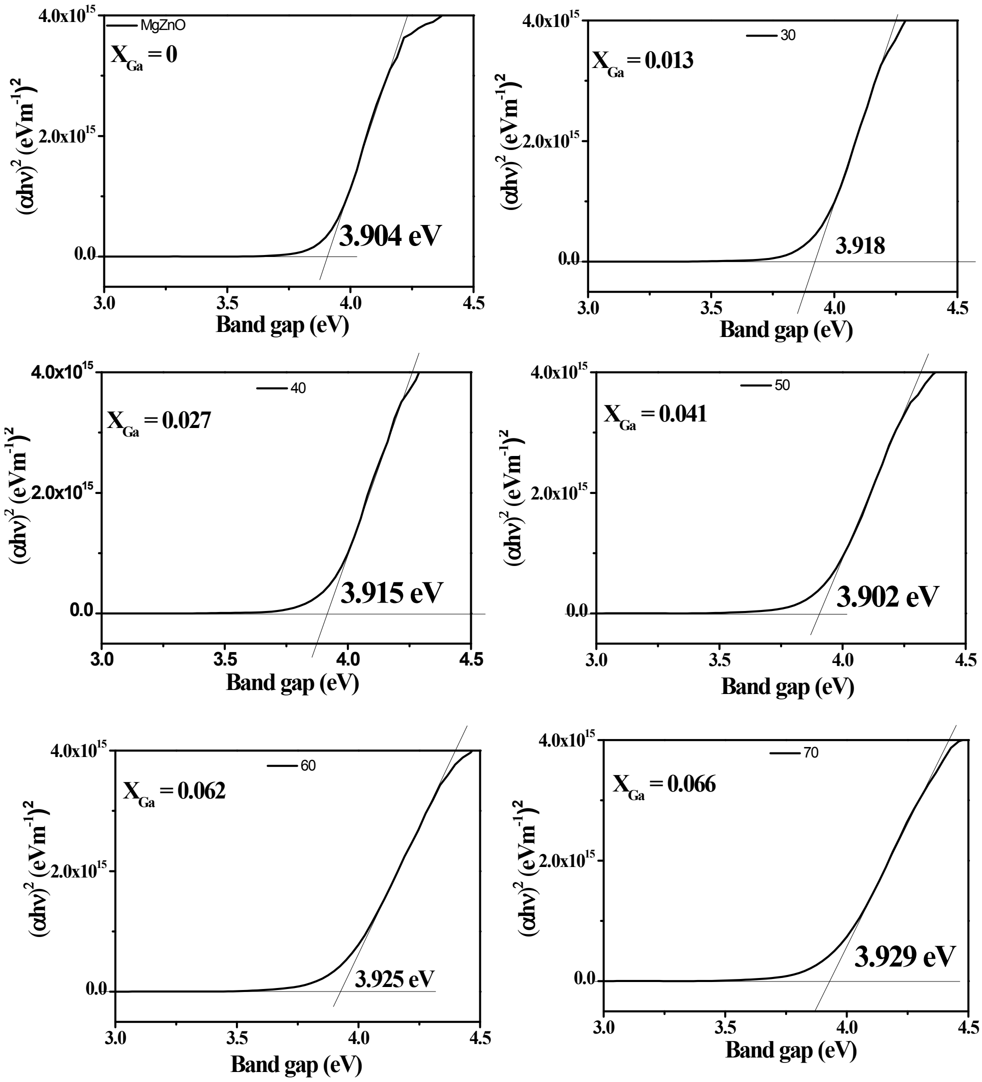


Fig. s1: XRD spectra of Ga doped MgZnO films (2θ = 20°-80°)

Band gap in Ga doped MgZnO thin films

The band gap (E_g) in Ga doped MgZnO thin film is estimated by using following equations: $\alpha h\upsilon = c(h\upsilon\text{-}Eg)^{1/2}$, α = absorption coefficient, h = planck's constant, υ (frequency) = c/λ, c= speed of light, E_g = band gap. The absorption coefficient (α) and the percentage of transmittance (%T) in Figure 5(a) are related by the equation: $\alpha = (2.3026/t)\times\log_{10}(100/\%T)$, t = thickness of the CZNA. The band gap is estimated by the extrapolation of the linear portion of the plot between $(\alpha h\upsilon)^2$ with $h\upsilon$ as shown below.



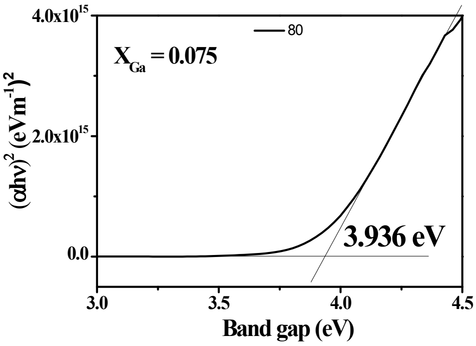


Fig. s2: Bang gap of MgZnO with different Ga doping concentrations

Piezoelectric coefficient in Ga doped MgZnO thin films

Piezoelectric constants were obtained by piezo-response force microscopy (PFM) of a multi-functional scanning probe microscope (Bruker Dimension ICON). The PFM technique is based on the detection of local vibrations of a sample induced by an AC signal applied between the conductive tip of AFM and the bottom electrode of the sample [Ref. s1, Ref. s2]. The local oscillations of the sample surface are transmitted to the tip and detected by using a lock-in amplifier. The resulting movement of the tip is detected by the photodiode and so the minute surface displacement is converted into an oscillating voltage. In our experiments, the voltage is applied in steps (1V, 3V, 5V) through computer control, and the output voltage corresponding to the minute displacement at the AFM tip was recorded using a lock-in amplifier. The piezoelectric constant can be determined from the slope of the minute displacement vs applied voltage plot by the following equation.

Piezoelectric constant (d_{33}) = (slope of the GaMgZnO/slope of ZnO)×12.4 (standard).

Fig. s4 shows the output voltage vs. applied voltage plot along with the slope and the corresponding piezoelectric coefficient for few Ga doped MgZnO samples. Table s2 summarizes the detail PFM analysis data and the piezoelectric coefficient for all the Ga doped MgZnO samples.

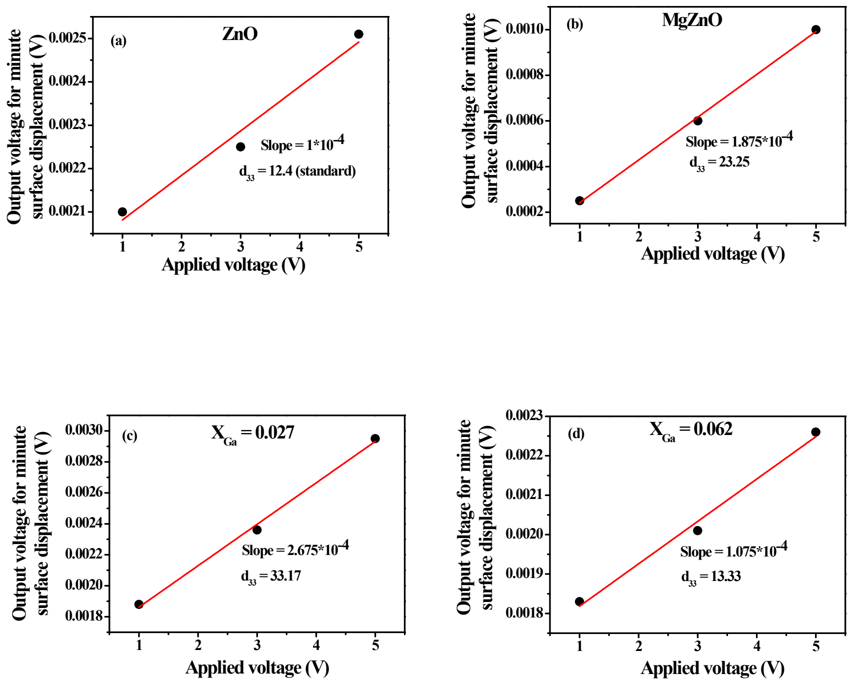


Fig. s3: Piezoelectric coefficient (d_{33}) from PFM data

Table s2: PFM data analysis for piezoelectric coefficient (d_{33})

R.f power of Ga_2O_3 target	X_{Ga}	Slope	Piezoelectric coefficient (d_{33})
0	0	1.875×10^{-4}	23.25
30	0.01345	1.45×10^{-4}	17.98
40	0.02778	2.675×10^{-4}	33.17
50	0.04148	2.35×10^{-4}	29.14
60	0.06268	1.075×10^{-4}	13.33
70	0.06668	3×10^{-5}	3.72
80	0.07579	2.25×10^{-5}	2.79

Ref. s1: M.-H. Zhao, Z.-L. Wang, S. X. Mao, Piezoelectric Characterization of Individual Zinc Oxide Nanobelt Probed by Piezoresponse Force Microscope, Nano letter, 4(4), (2004) 587-590

Ref s2: J. A. Christman, R. R. Woolcott, Jr., A. I. Kingon, R. J. Nemanicha, Piezoelectric measurements with atomic force microscopy, Appl. Phys. Lett. 73, 26, (1998) 3851-3853

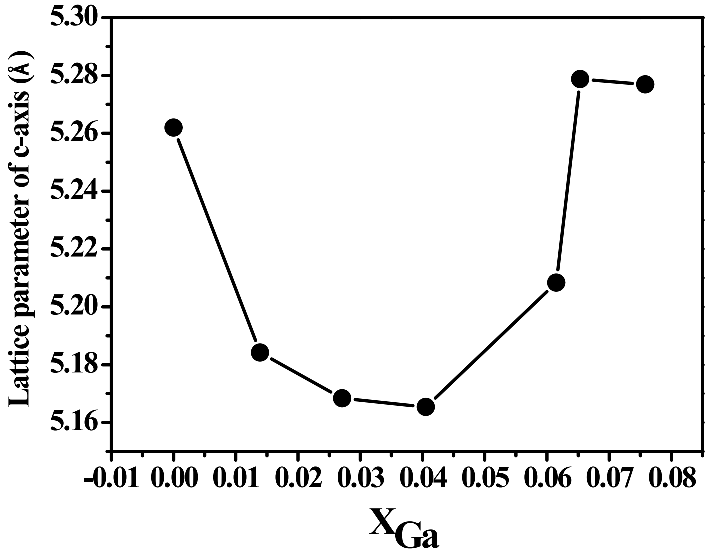


Fig. s4: Variation of c axis lattice parameter with Ga doping concentration.

Table s3: Stress values for different weight NEED TO DISCUSS

Weight (kg)	Force (N)	Stress (Pa)	Stress (MPa)	Force and stress calculation (Film area = 3cm^2)
0	0	0	0	**For 0.2 kg,** $Force = 0.2\,kg \times 9.8\frac{m}{s^2} = 1.96\,N$ $Stress = \frac{1.96\,N}{3 \times 10^{-4}\,m^2} = 6533.33\frac{N}{m^2} = 6533.33\,pa$
0.2	1.96	6533	0.00653	
0.5	4.9	16333	0.01633	

Table s4: Stress sensitivity of Ga:MgZnO thin film with Ga doping concentration

Ga doping concentration	Unstressed current (A) at 5V	Stressed current (A) at 5V, (0.2 kgf, 0.00653 MPa)	Sensitivity of change in current $\frac{\Delta I}{I} = \frac{I((\varepsilon) - I(0)}{I(0)}$	Stress sensitivity (MPa^{-1}) $\frac{\Delta I/I}{stress}$
0	6.98461×10^{-4}	8.28462×10^{-4}	0.18613	28.50
0.027	8.57008×10^{-4}	0.00103	0.20482	31.36
0.041	0.00252	0.00294	0.16692	25.56

Table s5: Stress sensitivity of Ga:MgZnO thin film with load

Different loadings	Current (A) at different load	SBH (meV) at different load	Sensitivity of change in current $\frac{\Delta I}{I} = \frac{I((\varepsilon) - I(0)}{I(0)}$	Stress sensitivity (MPa^{-1}) $\frac{\Delta I/I}{stress}$
0	0.00243	0	0	0
0.2	0.00294	-4.9	0.21	32.14
0.5	0.00361	-10.5	0.48	29.75

Limit of detection and detection range

We have taken a series of I~V curves at zero load to find out the minimum detection limit and the stability of the device output.

No. of Run	Voltage (V)	Current (A)	Variation of sensitivity at zero load	% change
1	5	4.43E-04	0.00E+00	0.0%
2	5	4.53E-04	-2.25E-02	-2.2%
3	5	4.40E-04	7.79E-03	0.8%
4	5	4.43E-04	1.24E-03	0.1%
5	5	4.41E-04	5.26E-03	0.5%
6	5	4.43E-04	-4.61E-04	0.0%
7	5	4.43E-04	1.66E-04	0.0%
8	5	4.47E-04	-7.39E-03	-0.7%
9	5	4.38E-04	1.11E-02	1.1%
10	5	4.42E-04	2.50E-03	0.2%

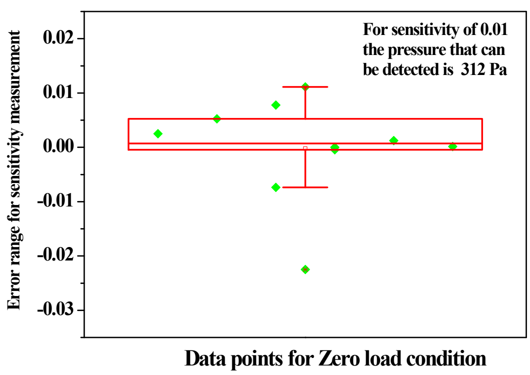


Figure s5: Detection limit and detection range

- Here, we can see the error bar created at zero load for a series of I~V measurements.
- The maximum change in current (sensitivity) we can obtain is around 0.01.
- We know the sensitivity value of 0.21 corresponding to a compressive stress of 6533 Pa.
- The corresponding pressure for 0.01 is [6533*0.01/0.21] = 311.0952 Pa.
- **Thus, this calculation defines the pressure less than 312 Pa will not be detected.**

Stablility test

- The stability/ repeatability study has been done by taking i-t curve (Current vs time) at a constant bias of 5V.
- The repeated load is provided by applying force against the sample several time.

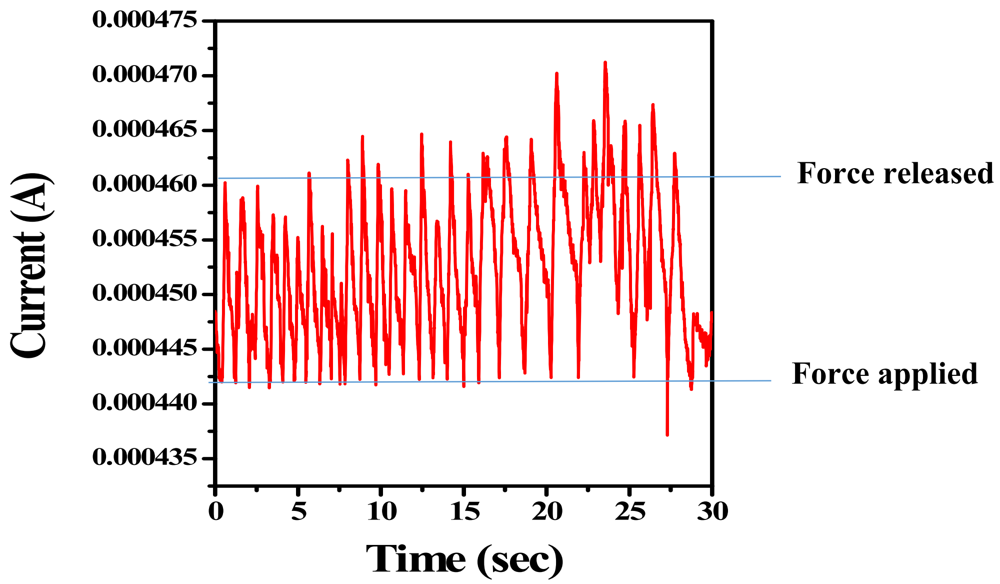


Figure s6: Stability of Ga:MgZnO pressure sensor