

Optical study of Micro-active medium “Metal thin Silver film /p-Si<100>/ Glass” in visible region at room temperature for micro and nano laser systems

Kifah Q. Saleh

Ministry of Higher Education & Scientific Research- Baghdad, Iraq

Abstract- Micro-active medium (MSI) “Metal thin Silver film / p-Si<100>/ Glass” cavity was designed for micro and nano laser systems, based on ~120 nm metal thin Ag film in thickness, p-Si<100> and Glass 0.5 mm in thickness making cavity of material matrix “MSI”. We have shown for the first time strong lasing in visible region “~625nm” from simple material cavity “MSI” after interaction with “Ar+ ion laser, 514.5 nm: 0.7-0.8 watt” at room temperature. Si type was selected after PL study using He-Ne laser “543.5nm” and Ar+ ion laser “514.5” nm. We have obtained excellent results from PL study after thermal treated p-Si<100>. In this work, we discuss the origin of this lasing and explain the relationship between the surface texture of Si and output intensity of lasing action at red emission. We have found there is strong relationship between excitation power and ΔV_{FWHM} of “MSI” matrix emission at room temperature.

Index Terms- Thin film Technology, nano laser systems, Nano particles, PL studies & Micro-Nano cavities design.

I. INTRODUCTION

The use of metallic cavities is a possible way of further miniaturizing lasers, which until now has received little attention [1]. The coupling of radiative emitters to the surface-bound electromagnetic waves supported by metals (surface plasmons) is an important topic in nano-optics [2]. Room temperature lasing of optically pumped semiconductor metallic nano-lasers has also been presented [3]. There are currently two main approaches in designing nanolasers. The first approach utilizes dielectric based structures. Dielectrics have low loss at optical frequencies and can be designed as multilayer stacks to provide strong optical feedback. Light confinement with dielectrics, either by total

Internal Reflection or stop band reflection, entails inherent scalability limitation. The second approach in designing nanolasers uses metal in the cavity. In recent years, nanoscale metallic, plasmonic and metallo-dielectric cavities have shown to confine light in ultra-small volumes and to improve the gain-mode spatial overlap. Moreover, metal cavities offer better thermal management in comparison to dielectric cavities and are more suitable for electrical pumping. However, existing metal-based nanolasers require high threshold pump power because of the significant absorption loss of the metals at optical frequencies [4-14]. Nanolasers are an emerging field of science, with a wide range of applications from on-chip optical communication, ultra high resolution imaging, and single molecule spectroscopy..etc.

In this study, we have demonstrated the simple cavity design of ((Micro-active medium) MSI)) “Metal thin Silver film /Si/ Glass” for microlaser and nanolaser systems and its applications. It is excellent working at room-temperature with CW excitation. The cavity properties are guided light emission with increasing intensity according to incident laser power” Ar+ ion laser, 514.5 nm: 0.7-0.8 watt”. The cavity showed good thermal stability due to metal coating to silicon substrate.

II. EXPERIMENTAL RESULTS

Micro-active medium (MSI) “Metal thin Silver film /Si/ Glass” cavity was designed for micro and nano laser systems from “monocrystalline p-Si<100> wafer was coated with thin Silver film, ~120nm in thickness /glass, 0.5 mm in thickness as shown in Fig.1. The thin (Ag) film is prepared by DC plasma sputter deposition using argon gas.

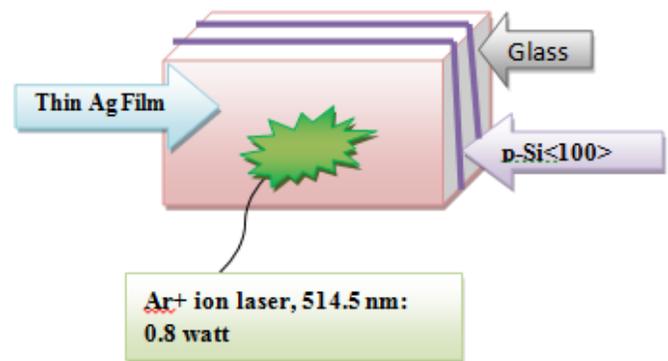


Figure 1 Micro-active medium (MSI) “Metal thin Silver film /Si/ Glass” cavity

To reduce surface scattering of emitted light from Si surface and to increase the matching factor of thin Ag film/ p-type Si surface, it is achieved by thermal treated Si samples. Optically, we have studied those samples using PL system” He-Ne laser “543.5nm” and Ar+ ion laser “514.5” nm”. The plot of Photoluminescence shows good results after the thermal treatment, indicating an increase in light collection efficiency after change the surface texture of Si surface as shown in Fig.1, 2 and 3.

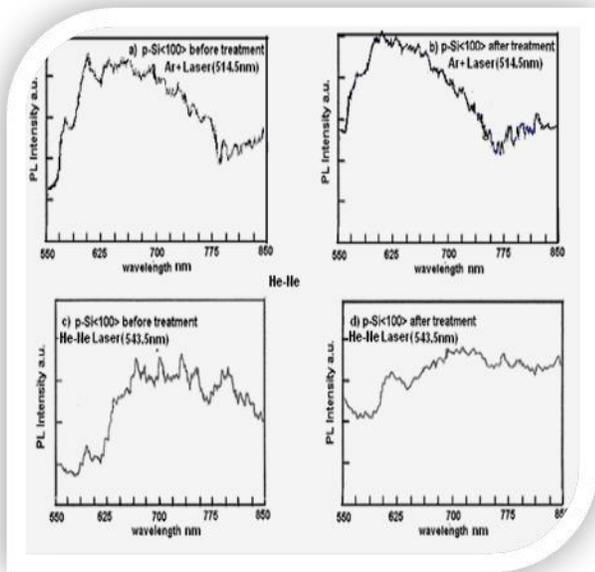


Figure 2 p-type Si gives optimum PL intensity emission before and after treatment at room temperature using green light with different laser systems "Ar+ ion and He-Ne".

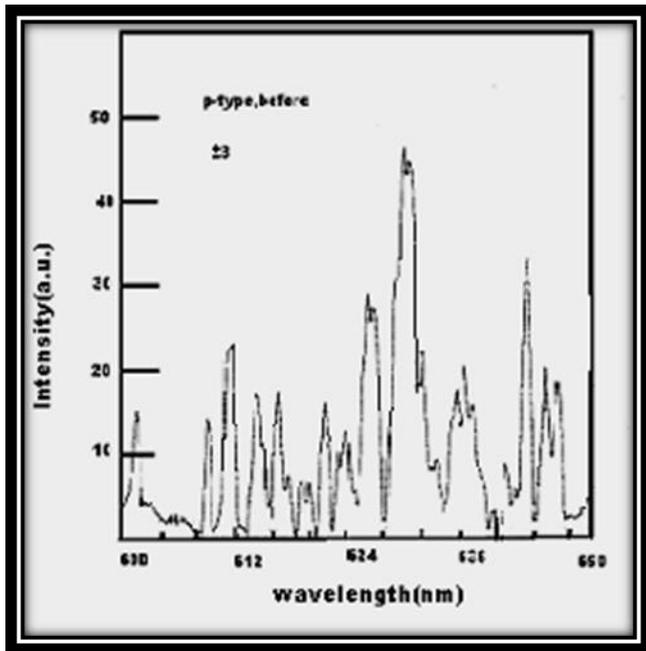


Figure 2 Output emissions from cavity before Si treatment

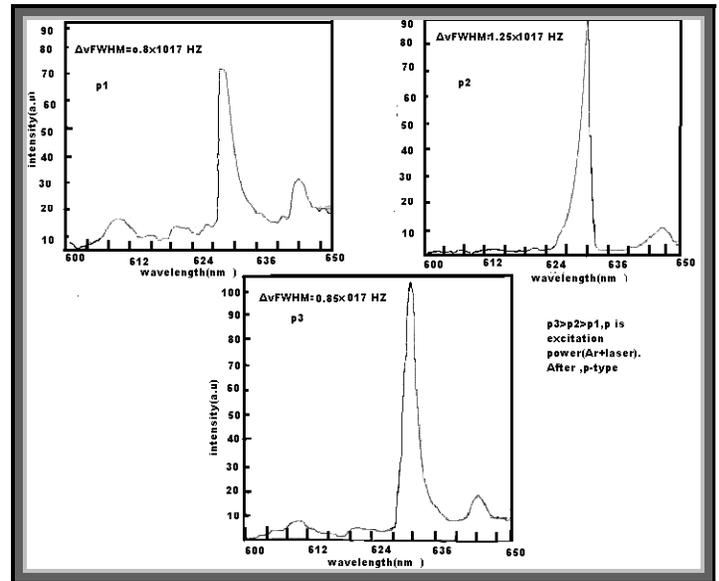


Figure 3 Output emissions from cavity after Si treatment using different excitation power.

The output emission of cavity has recorded using set up experiment with excitation source "Ar+ ion laser, 514.5 nm: 0.7-0.8 watt" working at room temperature. It was made for this setup as shown in Fig.4.

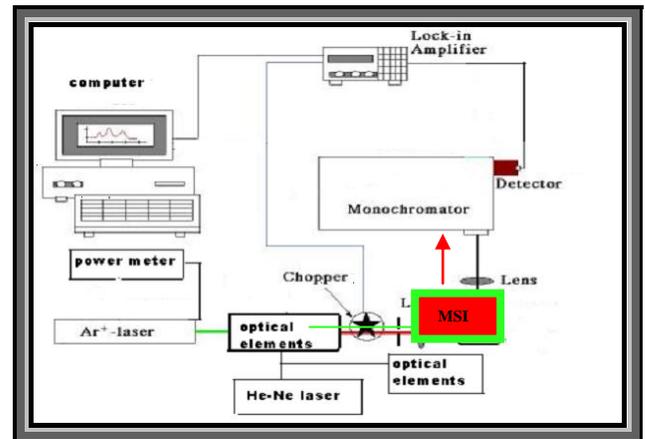


Figure 4 Set up experiment for MSI cavity

III. DISCUSSION & CONCLUSION

Micro laser cavity "Si -silver-Glass" has been designed and characterized optically. Ar+ ion laser "0.7-0.8 watt" showed the optimum excitation power to get red emission with high intensity from that cavity at room temperature. P-type Si showed the optimum type for this design as shown in above figures after thermal treatment. Glass works as good reflector to Red light and good absorber to Green light as shown in Fig.5, it helps the efficiency of optical feedback to enhance output emission of "MSI" cavity in red region.

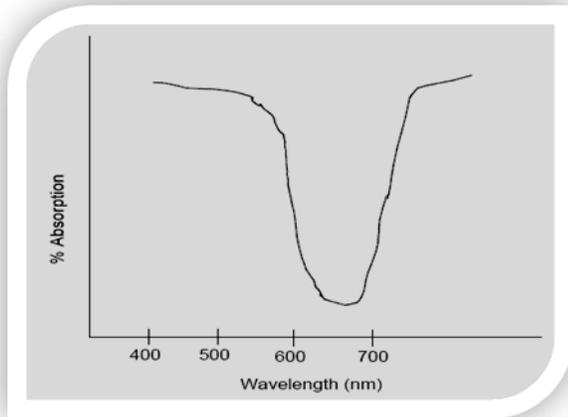


Figure 5 Glass is good absorber to Green light

At the cavity end light is reflected back at Glass surface into the core "M SI", thus forming a Fabry-Perot cavity.

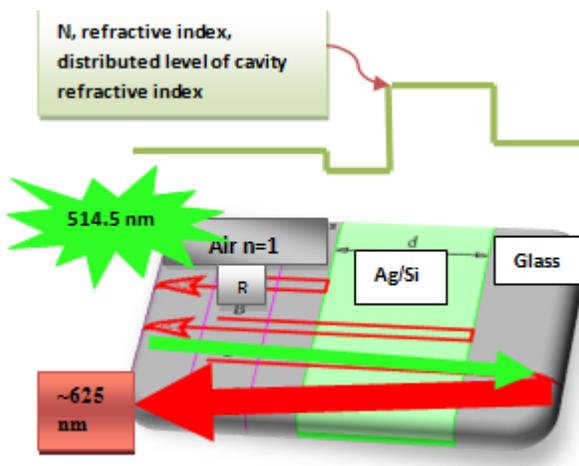


Figure 6 shows the light propagation into MSI cavity and n steps into cavity

Here as shown in Fig.6, the refractive index of Ag and Si working as one optical core because the nano structure of thin Ag film. Both localized surface plasmons found in Ag film and propagating plasmon—polaritons in continuous metallic films would give rise to large luminescence enhancements. Due to the larger penetration of the electric field into the cavity, we would favor the propagating plasmons—polaritons as an explanation for

the increase in the luminescence intensity with increasing the excitation power. On the other hand, surface plasmon excitation on the air/Ag then Ag /Si interfaces by light emitted from the glass is also possible, would give rise large red emission enhancements.

The cavity properties are guided light emission with increasing in intensity according to incident laser power" Ar+ ion laser, 514.5 nm: 0.7-0.8 watt". The cavity showed good thermal stability due to metal coating to silicon substrate.

REFERENCES

- [1] Maier, S. A. Effective mode volume of nanoscale plasmon cavities. *Opt. Quant. Electron.* 38,257–267 (2006).
- [2] H. A. Atwater, "The promise of plasmonics," *Sci. Am.* 296, 38–45 (2007).
- [3] M. P. Nezhad et al., "Room temperature lasing from subwavelength metal-insulator-semiconductor structures," *Proc. CLEO*, paper CMD2, Baltimore, USA, (2009).
- [4] Strauf, S. et al., Self-tuned quantum dot gain in photonic crystal lasers. *Phys. Rev. Lett.* 96 (12)p.127404/1-4 (2006)
- [5] Altug, H., Englund, D. & Vuckovic, J., Ultrafast photonic crystal nanocavity laser. *Nature Physics* 2, 484 - 488 (2006)
- [6] Hill, M. T. et al., Lasing in metallic-coated nano-cavities. *Nat. Photon.*, 1, 10, 589-594 (2007)
- [7] Bergman, D. J. & Stockman, M. I., Surface plasmon amplification by stimulated emission of radiation: quantum generation of coherent surface plasmons in nanosystems. *Phys. Rev. Lett.* 90, 027402 (2003)
- [8] Noginov, M. A. et al., Demonstration of a spaser-based nanolaser. *Nature* 460, 1110–1112 (2009)
- [9] Oulton, R. F. et al., Plasmon lasers at deep subwavelength scale. *Nature* 461, 629-632, (2009)
- [10] Hill, M. T. et al. Lasing in metal-insulator-metal sub-wavelength plasmonic waveguides. *Opt. Express* 17, 11107-11112 (2009)
- [11] Kwon S. H. et al., Subwavelength plasmonic lasing from a semiconductor nanodisk with silver nanopan cavity. *Nano Letters* 10 (9), 3679-3683 (2010)
- [12] Mizrahi, A. et al., Low threshold gain metal coated laser nanoresonators. *Opt. Lett.* vol. 33, no. 11, pp. 1261-1263, (2008)
- [13] Nezhad, M. P. et al., Room-temperature subwavelength metallo-dielectric lasers. *Nat. Photon.* 4, 395 - 399, (2010)
- [14] Yu, K., Lakhani, A. & Wu, M. C., Subwavelength metal-optic semiconductor nanopatch lasers. *Opt. Express* 18, 8790-8799 (2010)

AUTHORS

First Author – Kifah Q. Saleh, Ministry of Higher Education & Scientific Research- Baghdad, Iraq, Mekqs10@yahoo.com, Phone: +964-7711973084